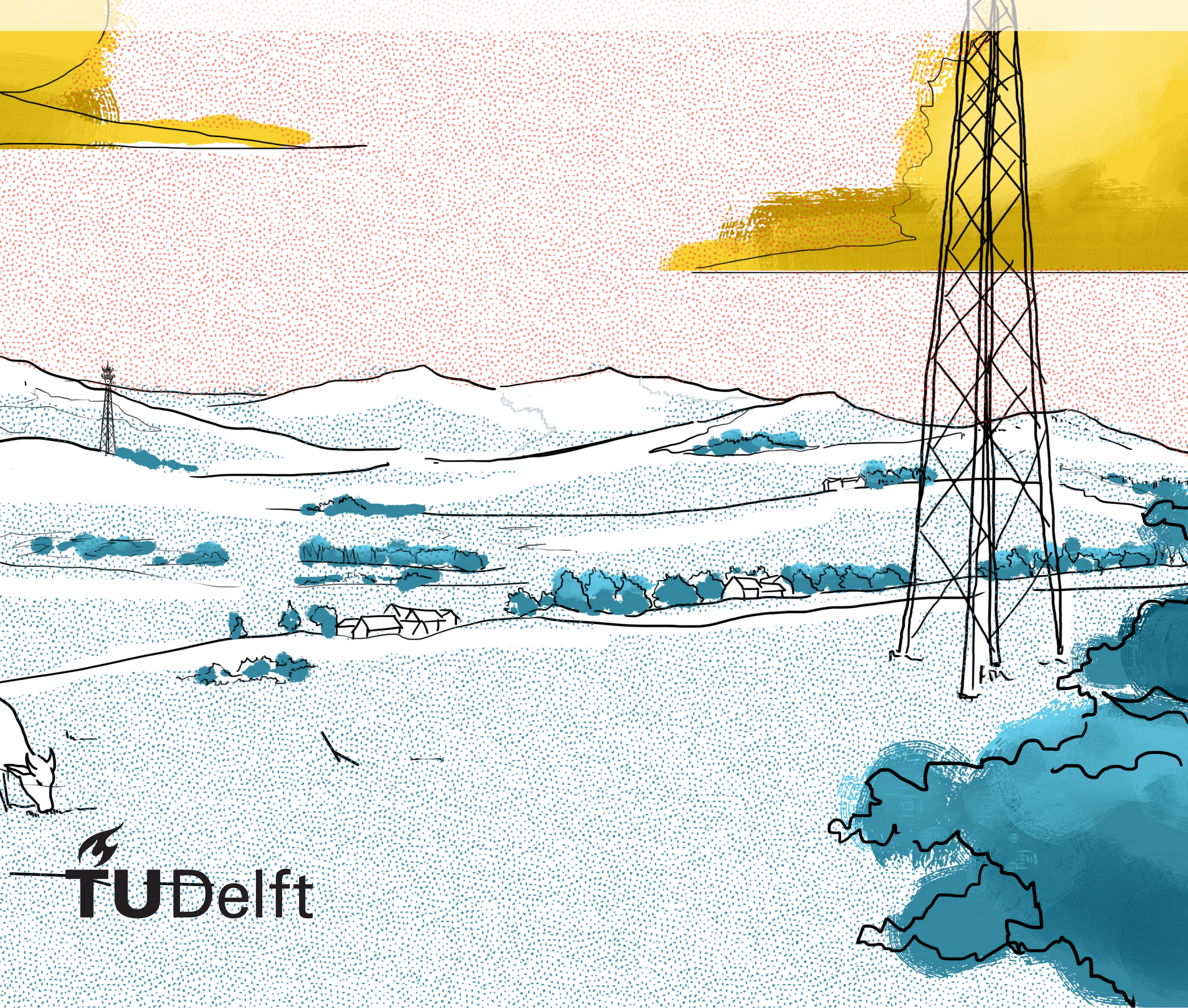
Solving the Mobile Coverage Gap in Rural Areas

Indonesian Case Studies

Master Thesis

Vannesya Harahap



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Indonesian Case Studies

by

Vannesya Harahap

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Summary

Growth in telecommunication penetration has been widely acknowledged as positively associated with human and economic development. Meanwhile, mobile telecommunication services play a more crucial role in developing countries than in developed countries compared to the fixed telephony networks. As a result, an equal distribution of mobile telecommunications networks becomes very important for developing countries, including Indonesia.

Developing countries are mainly composed of rural areas compared to urban areas, and, in particular, rural areas have been more heavily exposed to the mobile coverage problem. As of now, thousands of villages in Indonesia are still not covered by mobile telecommunication services. Without proper counter-measures put into place to reduce or diminish the problem, the digital divide between the people living in urban areas and those living in rural areas will be exacerbated in the future. Therefore, it would be worth looking further at how mobile network coverage in rural areas in a developing country, Indonesia, is currently established and how to improve it.

The lack of mobile telecommunication coverage in rural areas in developing countries is a complex socio-technical issue in which technology, society, business and institutional components are involved. There are multiple and diverging actors' interests involved in managing this system and interdependencies between actors. Seeing the mobile coverage problem as a complex socio-technical issue in designing or finding the solution is essential. Furthermore, the national governments have an important role and instruments in improving the mobile network coverage expansion. A solution for the mobile coverage problem can be adequate and impactful if it accommodates the actors' perceptions and is implementable by the policymakers.

Based on those situations and complexity, this research aims to support the national government of Indonesia to make an informed selection of the solutions to improve mobile coverage in Indonesian rural areas. They lead to our main research question: How can the Indonesian Ministry of Communication and Informatics advance the mobile coverage in Indonesian rural areas?

We use a qualitative exploratory case study as the approach of this research. The qualitative exploratory approach explores the possible solution in the literature to solve the problem through a systematic and exhaustive literature study in which 149 papers were reviewed. In addition, a literature study combined with empirical data analysis is also conducted to find the cause of the mobile coverage problem in Indonesia. The results were subsequently analysed through an embedded case study in which three rural villages in Indonesia (Unipa village, Tampang Muda village and Terusan village) are used to identify the suitable solutions from the literature and act as the representatives of Indonesian rural areas. As part of the case study, some interviews with relevant actors of the Indonesian mobile communication sector are conducted to gather the actors' perceptions towards the possible solutions provided by the literature.

We present five main deliverables as the results of this research as listed below:

1. The causal diagram the mobile coverage problem in rural areas general (globally) (Figure 1)

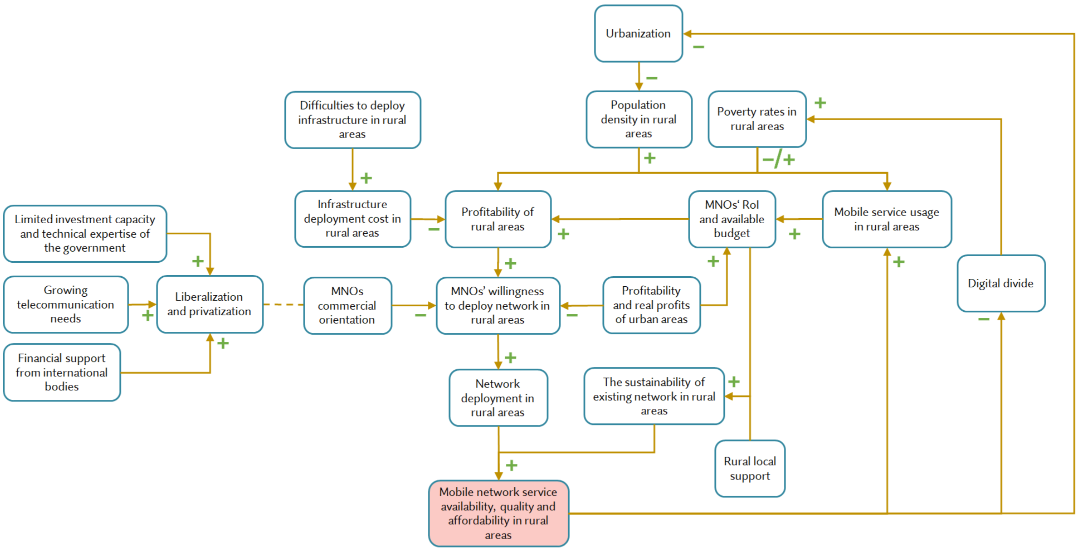

Figure 1: Causal diagram the mobile coverage problem in rural areas general

2. The key factors of the mobile coverage problem in Indonesian rural areas
   Through a literature study and empirical data analysis, we identify seven key factors causing the mobile coverage problem in Indonesian rural areas: 1) Low population density; 2) Lack of electricity grid; 3) Low road accessibility; 4) Difficult topography; 5) Lack of local support; 6) Low MNOs' financial capacity, and 7) Ineffective coverage compliance policy.

3. A list of possible solutions for the mobile coverage problem in rural areas and their characteristic
   We map onto a table 21 different possible solutions for the problem and the solution's characteristics, i.e., the key factor(s) it addresses, its requirements and its challenges. The solutions were all coming from the literature we studied. We classify them into three types: technology, organisation and regulatory. Technological solutions address the problem using specific network architectures, technology and equipment. Organisational solutions address the problem by introducing a new actor or involving certain actors. Meanwhile, regulatory solutions are mainly about governmental interventions in the form of new/modified regulations and/or policies.

4. The Decision Support Scheme
   The Decision Support Scheme is an approach that the Indonesian Ministry of Communication and Informatics (Kominfo) can use to identify the possible solution for solving the mobile coverage problem in Indonesian rural areas, illustrated in Figure 2. Starting with juxtaposing the possible causes of the problem, the available and applicable solutions, and the target village's condition, Kominfo can identify the solution options consisting of technology, organisation and regulatory solutions. Afterwards, Kominfo evaluates them with stakeholders' perspectives.

5. The proposed solution for solving the mobile coverage problem in Unipa village, Tampang Muda village and Terusan village as in Table 1

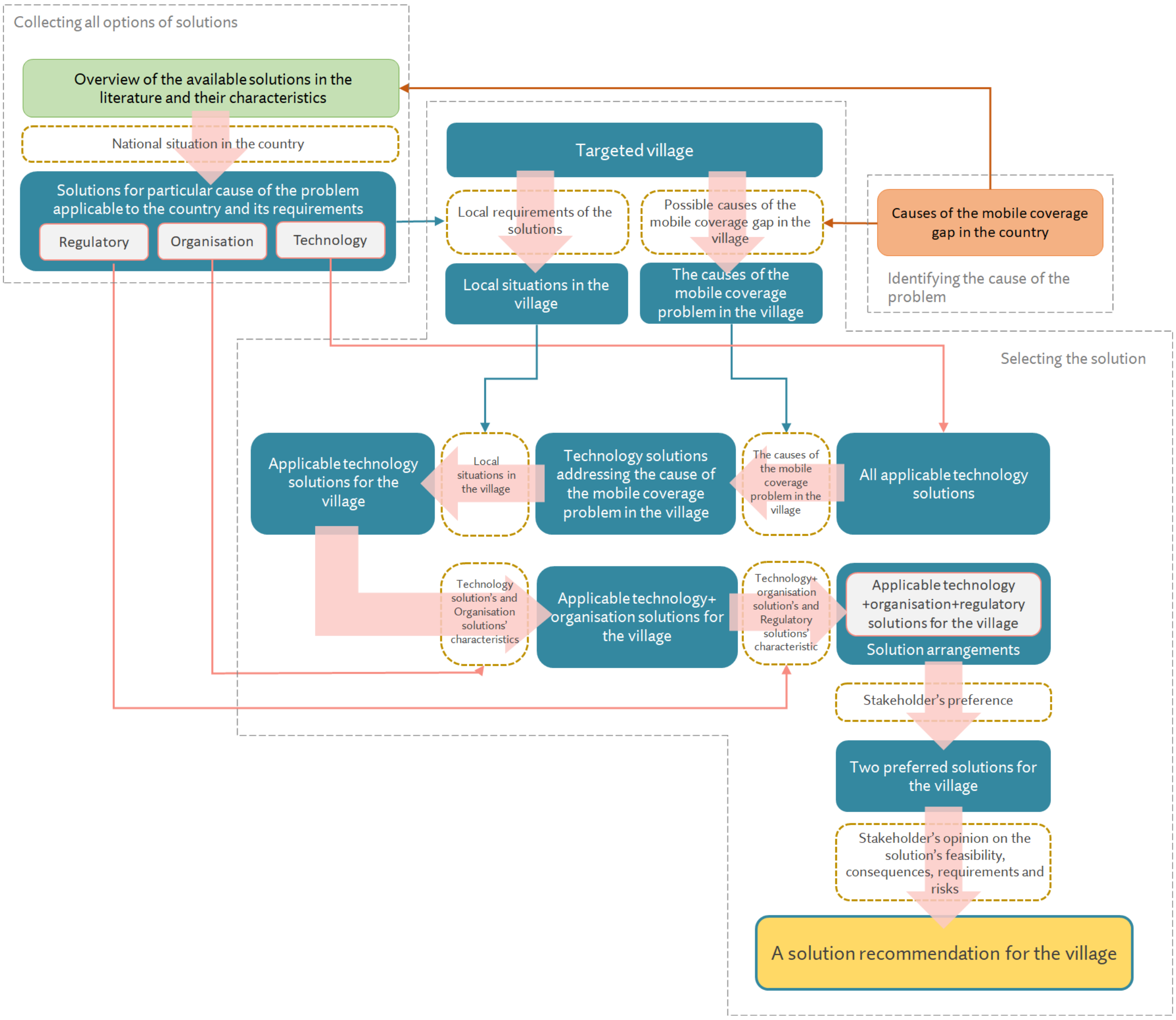

Figure 2: The Decision Support Scheme

Table 1: The proposed solutions for the exemplary villages

Village	**Solution**		
	Technology	Organisation	Regulatory
Unipa	TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
Tampang Muda	VillageCell (OpenBTS access & satellite backhaul) + solar power source + battery prediction model	SRO (BAKTI) + central and local authority	USF
Terusan	TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF

We argue that some of the deliverables can be used in relevant future research in another country. The list of possible solutions for the mobile coverage problem in rural areas, their characteristics, the causal diagram, and the Decision Support Scheme can be used as a starting point by any country that wants to study the mobile coverage problem in their areas. Meanwhile, the key factors and the proposed solution for the exemplary village can be helpful for the relevant study, specifically in Indonesia in the future.

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Contents

Abbreviations

Abbreviation	Definition
2G	2nd Generation
3G	3rd Generation
4G	4th Generation
ACPU	Average Cost per User
AN	Access Network
AP	Access Point
ARPU	Average revenue per User
BAKTI	The Indonesian Telecommunication Accessibility Agency
Bappenas	The Indonesian National Development Planning Agency
BH	Backhaul
BIG	The Indonesian Geospatial Information Body
BPN	The Indonesian State Land Agency
CAPEX	Capital Expenditure
CCN	Community cellular network
Ditdal	The Directorate of Post and Information Technology Control
Dukcapil	Directorate General of Population and Civil Registration of the Indonesian Ministry of Home Affairs
eNodeB	Evolved (4G) NodeB
EIRP	Equivalent Isotropic Radiated Power, effective radiated power
EPA	Engineering and Policy Analysis
GDP	Gross Domestic Product
GEO	Geosynchronous Equatorial Orbit
GR	The Government Regulation
HLR	Home Location Register
ICT	Information and Communication Technology
ISP	Internet Service Provider
ITU	International Telecommunication Union
Kominfo	The Indonesian Ministry of Communication and Informatics
LOS	Line of Sight
LSA	Licensed Shared Access
MCDA	Multi-Criteria Decision Analysis
MEC	Multi Edge Computing
MNO	Mobile Network Operator
MOS	Mean Opinion Score
MPLS	Multi-Protocol Label Switching
MSC	Mobile Switching Center
MTTR	Mean Time to Repair
MTBF	Mean Time Between Failures

Abbreviation	Definition
OPEX	Operational expenditure
Permendagri	The Regulation of Internal Affair Minister
PermenESDM	The Minister of Energy and Mineral Resources Regulation
Permenkominfo	The Regulation of Communication and Informatics Minister
PLN	The Indonesian National Electricity Company
PV	photovoltaic
Q2	Quarter-2 or 2nd quarter
QoS	Quality of Service
RES	Renewable Energy Source
RoI	Return on Investment
RNC	Radio Network Controller, controller for 3G
SAS	Spectrum Access System
SDR	Software Defined Radio
SIM	Subscriber Identity Module
SRO	Small Rural Operator
SRQ	Sub research question
TCO	Total Cost of Ownership
UAV	Unmanned Aerial Vehicles
US	The United States (of America)
USF	Universal Service Funds
VSAT	Very Small Aperture Terminal
WiLD	WiFi IEEE 802.11 modified for Long Distance
WiMAX	Worldwide Interoperability for Microwave Access
WTP	Willingness to pay

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Chapter 1

Introduction & Research Definition

Growth in telecommunication penetration has been widely acknowledged as positively associated with human and economic development. Ten per cent increase in mobile penetration can increase GDP per capita by 0.81% (Bhavnani et al., 2008). Many studies also have revealed a positive connection between telecommunication service and human development index (Ejemeyovwi et al., 2019; Qureshi and Afzali, 2017). This makes equal distribution of mobile telecommunications networks very important for a country, including Indonesia. Whereas, thousands villages in Indonesia are still not covered by mobile telecommunication service (Ditdal PPI, 2021a). This chapter introduces the research by describing the role of mobile telecommunication (Section 1.1), its current situation in Indonesia (Section 1.2) and the key concepts of the research subject (Section 1.3). Further, it explains the research gaps (Section 1.4), by which the research will be defined. The research definition includes the research questions (Section 1.5) and the research methodology (Section 1.6). Lastly, the research flow diagram is provided in Section 1.7 to illustrate the interconnection between different chapters in this study.

1.1 The importance of mobile telecommunication for rural areas

Mobile telecommunication services are playing a more crucial role in developing countries than in developed countries. The mobile telecommunication service allows the developing countries (in which the fixed telephony networks are under-developed) to cover the uncovered area and leapfrog the fixed network. With its less expensive rolling-out cost and the fixed-line penetration decline, mobile telecommunication becomes the primary means of communication in the developing countries (Arakpogun et al., 2017; Kefela, 2011; Loo and Ngan, 2012). As the primary means of communication in developing countries, its role in developing countries' development is more significant than in the developed ones.

Developing countries are mostly composed of rural areas compared to urban areas, and, in particular, rural areas have been more heavily exposed to the digital divide (Pimenidis et al., 2009), while the urban areas tend to be served by most advanced technology (like the forthcoming 5G) (Andrews et al., 2014). Without proper counter-measures put into place to reduce or diminish the divide, the digital divide between the people living in urban areas and those living in rural areas is going to be exacerbated in the future.

The digital divide is described as inequality or lack in access, distribution, and use of ICT technologies, including mobile services, between two or more populations (Wilson, 2006). The vast majority of people in developing countries live as rural populations (Anríquez and Stloukal, 2008; Bhuiyan, 2004). Moreover, most of the unserved or underserved areas are rural areas (Chiha et al., 2020). An empirical study in 2002 in Africa suggested that mobile services were mainly concentrated in urban areas and the farther one travels from urban areas the less likely it is that optimum network coverage will be available (Arakpogun et al., 2017; Gebreab, 2002). In Peru, based on data in 2016, out of 62,826 unserved populated centres, 62,616 are rural areas (Prieto Egido et al., 2020). Similar to that, in Indonesia, based on data in Q2 2020 from the Indonesian Ministry of Communication and Informatics (Ditdal PPI, 2021a), out of 3100 villages without mobile coverage, 3079 villages are composed of less than 20% of settlement areas [1].

It has been widely heralded that mobile telecommunication is a crucial component for promoting economic and human development (Conceição, 2019; Saunders et al., 1994). Networks and telecommunications are perceived as important pillars in today's digital-based economy (Ruffini et al., 2019). The access to and use of mobile telecommunication offers individuals a communication platform that expands the citizen agency level in developing local and international social, economic, and political endeavours and offers individuals opportunities regardless of geographic location (Cruz and Touchard, 2018). Access to mobile networks enables people to access information and services that can improve their health (Kamsu-Foguem and Foguem, 2014), education (Erdogdu and Erdogdu, 2015), and economy (Cruz and Touchard, 2018). According to the World Bank, a 10% increase in mobile penetration increases GDP per capita by 0.81% in developing countries (Bhavnani et al., 2008). Empirical research using data from 179 countries in 2017 suggests that increased penetration of mobile phones enables people to lead healthier lives (Qureshi and Afzali, 2017). Governments have a great interest in expanding mobile network services in rural areas as a way to improve the national economy, ensure human rights and basic needs and improve institutional presence (Prieto Egido et al., 2020).

From several empirical studies, rural communities' need for mobile communication services was shown to be realistic. They need to communicate with someone in the city for commerce, for talking with relatives or friends who emigrated from the community (Prieto Egido et al., 2020) and for talking with someone within the community (Heimerl et al., 2013). Agüero and de Silva (2011) found that telecommunication service is a necessity for users at the Bottom of the Pyramid, instead of a luxury good, as the portion of telecommunication service expenditure to their total income ranged from 25% to 57%, and this percentage is getting decrease as the income increase. Having high poverty rates (Cruz and Touchard, 2018; Galperin and Bar, 2007; Jha and Saha, 2016; Prieto Egido et al., 2020), rural populations in developing countries can be considered users at the Bottom of the Pyramid. Furthermore, from the study's result, it can also be concluded that the necessity of telecommunication services for the rural population is higher than for the urban population.

Therefore, considering the importance of ICT for living these days, the necessity of telecommunication service for rural population compared to the urban population, the significance of mobile telecommunication service for developing countries compared to developed countries and how heavy rural areas exposed to lack of ICT access have been, it would be worth to look further at how mobile network coverage in rural areas in developing countries is currently established.

Despite the cruciality, developing countries experience challenges in covering all of their population with mobile telecommunication services. In 2017, there were still 1.2 billion people who were excluded from participating in the digital economy and e-government services due to being covered by no mobile telecommunication network – the vast majority of them lived in the rural areas in developing countries (Cruz and Touchard, 2018).

The lack of mobile telecommunication coverage in rural areas in developing countries is a complex socio-technical issue. It denotes that the issue is dependent on the interactions between the technical, the social and the institutional components of the system (Geels, 2004). It involves society, institutional government, technology and business. In short, it is a consequence of an economic challenge: expensive infrastructure deployment cost in remote areas combined with much lower revenue opportunities profoundly affects the business of mobile network operators (MNOs) to deploy infrastructure (Cruz and Touchard, 2018). How-

[1] Without mobile coverage, here means no 2G, 3G and 4G coverage on the village's land area at all

ever, because of the importance of telecommunication service, society relies on its quality and provision (Geels, 2004) and, consequently, institutions should monitor the system compliance to ensure that public values are maintained (Ubacht, 2020). There are multiple and diverging actors' interests involved in managing this system and interdependencies between actors.

1.2 Mobile network coverage in Indonesia

Indonesia is an archipelago country. It consists of five large islands and 17,503 smaller islands, around 6000 of which are inhabited (Embassy of the Republic of Indonesia, n.d.). The large islands are Sumatera, Java, Kalimantan, Sulawesi and Papua. As of 2020, its total population is 270.2 million (Badan Pusat Statistik, 2021). It is situated on the equator line, which makes its climate tropical. Indonesia has many mountains—the highest of over four kilometres above sea level—, tropical rainforests, jungles, big and small rivers, and lakes. Indonesia's total land area is around 1.8 million square kilometres, two-thirds of its total area (Embassy of the Republic of Indonesia, n.d.). According to the Regulation of Internal Affair Minister (Permendagri) No. 72 of 2019, in total, Indonesia has 34 provinces (adm1), 514 municipalities (adm2) and 83,411 villages-subdistricts (adm4).

Kominfo, specifically Directorate of Post and Information Technology Control (Ditdal), provided mobile network coverage examination data showing Indonesia's latest mobile coverage status, called CovData (Ditdal PPI, 2021a). CovData consists of the information about the 2G, 3G and 4G coverage level (in square meter) in each village and subdistrict in Indonesia captured on the 2nd quarter of 2020. The data are derived using geospatial analysis software ArcGIS by overlaying three maps:

1. combined mobile service coverage prediction map submitted by all MNOs,
2. the adm4 administrative border map created by Indonesian Geospatial Information Body (BIG), and
3. the map of settlement area created by BIG and Indonesian State Land Agency (BPN).

An example of those three maps combined is shown in Figure 1.1. Map 1 represents the mobile network coverage status per Q2 2020. Map 1 was created by merging the coverage maps from MNOs into one. The map was created by MNO using a network planning tool that predicts the coverage of a base transceiver station by taking into account its configuration (its longitude and latitude position, the frequency it uses, its altitude, etc.) and the surrounding environment (the terrain, the obstacles around the site, etc.). Map 3 represented the settlement map and was updated at the end of 2020. Map 3 was created using satellite imaging technology complemented with manual rendering. Map 2 was delineated in 2019 and consisted of 33 provinces, 514 municipalities and 83,285 villages-subdistricts. Map 2 has fewer villages-subdistricts than Permendagri No. 72 of 2019 because new villages from the village division were introduced in Permendagri. To Kominfo, BIG acknowledged this gap and explained that updating the map is not easy as Permendagri's list did not come with the map and villages-subdistrict border is set by the regional authority. Despite this issue, the map was considered to remain representative for Kominfo's coverage analysis. Hence it will also be used in this research.

Table 1.1: Mobile telecommunication service coverage in Indonesia as of mid-2020

Technology type	Covered land area	Covered settlement area
2G	65.29%	97.89%
3G	42.91%	94.28%
4G	45.40%	95.60%

There are two kinds of the coverage mentioned in the CovData: land area coverage and settlement area coverage. Land area coverage (%) is calculated by comparing the mobile network coverage over a region (sq km)

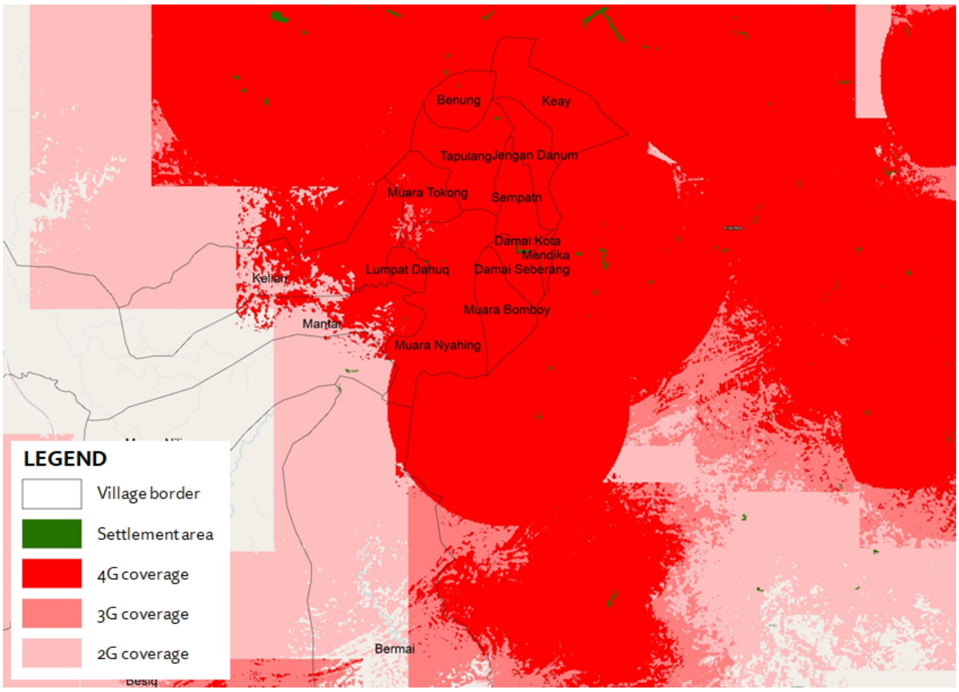

Figure 1.1: A sample of CovData source map

to its total land area (sq km). Meanwhile, settlement area coverage (%) is calculated by comparing the mobile network coverage over the settlement area in a region (sq km) to the total settlement area in that region (sq km). According to Kominfo, based on BIG and BPN in 2020, Indonesia's total land area and settlement area is 1,877,464.952 sq km and 45,822.97056 sq km, respectively. By mid-2020, 2G, 3G and 4G services have covered 65.29%, 42,91% and 45.4% of total land area. While the settlement area has been covered, 97.89%, 94.28% and 95.6%, respectively. This national coverage level is summarised in Table 1.1.

Though the settlement area coverage looks quite good, Indonesia still has thousands of villages uncovered. According to CovData, in the 2nd quarter of 2020, out of 83,285 villages and sub-districts in Indonesia, there are still 3100 villages totally uncovered and 3980 villages covered only by 2G network. Almost all of them have less than 30% settlement area and are located outside Java and Bali island, the two most dense and commercial islands in Indonesia. With the target to have 9.5% of its GDP in 2025 from the digital economy (Yasyi, 2020), solving mobile telecommunication coverage gaps in rural areas becomes even crucial for Indonesia.

A literature review is conducted to understand the research problem, develop perspectives, and know the state-of-the-art solutions in this field, hence a better definition of the research. A phased approach was followed to select relevant articles about the mobile network coverage gap problem in rural areas. First, we searched using two terms of *mobile telecom coverage rural* and *digital divide* in the reference database Scopus to select the literature. Second, we reviewed these articles by excluding some irrelevant subject areas. Third, using the most relevant articles derived from the previous phase, we snowball-searched other relevant articles, which led to a list of 25 articles to be reviewed in the next subsections. The list of articles can be found in Appendix A.

From the selected articles, two main background knowledge regarding the mobile network coverage are identified: the key concepts and the knowledge gaps. Each of them will be described in the following sections. Section 1.3 informs the definition of the mobile network coverage, while 1.4 conveys the identified research gaps regarding the mobile coverage gap problem in the existing literature and then help to scope the research.

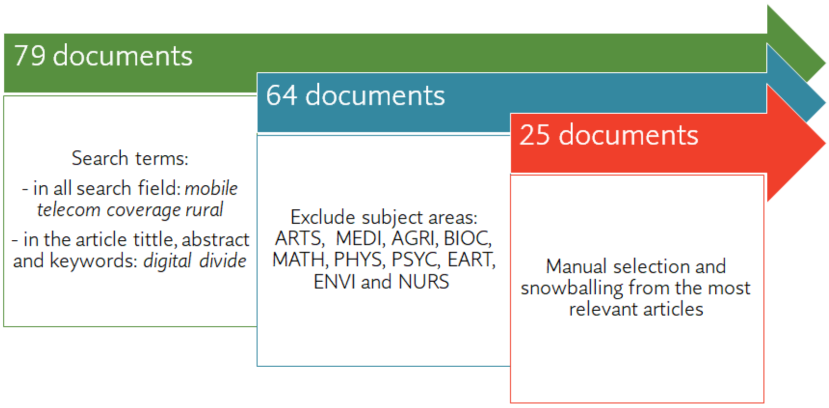

Figure 1.2: Literature research steps

1.3 Key concepts

There is no explicit definition of what mobile network coverage is from the literature reviewed. However, there is a definition in a commercial website that describes network coverage as "the geographical area covered by the network of a service provider. Within this area, the phone will be able to complete a call using the carrier's network or a partner network" (GSMArena, n.d.). Nonetheless, there are many implicit definitions of telecommunication network coverage related to mobile coverage gaps in the literature. Arakpogun et al. (2017, p. 619) used the universal service presence in the form of "access to fixed and/or mobile telecommunication services in a manner that is available, accessible and affordable" as an indicator that telecommunication services cover an area. Chiha et al. (2020), Montenegro and Araral (2020), and Salemink and Strijker (2018) defined it as the presence of internet (mobile broadband) services in the area. Loo and Ngan (2012) referred the mobile coverage gap to digital divide represented by the number of telecommunication subscriptions and the available internet bandwidth in the area. Prieto Egido et al. (2020) implied that the telecommunication coverage equals the cellular or fixed network's presence. Park et al. (2019) used connectivity as the unit analysis of telecommunication coverage and referred coverage gap as digital exclusion.

Gathering all views from the literature, we decided to define mobile network coverage as the presence of mobile telecommunication services in a manner that is equally available and affordable for everybody as needed. The equality characteristics are adopted from (ITU, 2013), and we focused on the 'available' and 'affordable' as the coverage area is our main concern, but it will be no use if the population cannot afford the service. This concept means that if the average mobile telecommunication service in a country is telephony and 1 Mbps internet, then an area would be categorised as 'served' if the telephony and 1 Mbps internet services are available in that area and the local people can and are willing to pay for the services.

According to CovData, thousands of villages in Indonesia are not served by any mobile telecommunication. At least, five options can be used to decide the meaning of unserved villages based on the data, as described in Table 1.2. The table also informs the number of unserved villages according to each option. C, D and E were included after seeing that there are villages that have a 0.00 square kilometre settlement area in CovData. As the coverage analysis was done geospatially by Kominfo and the map settlement area was created using satellite imaging by BIG supplemented with manual rendering by Kominfo, some settlements might be undetected if they are too small (beyond the satellite image and eye sensitivity), if they are under trees (in the forest), if their shapes are uncommon, or if they are too scattered. Nonetheless, according to the data from Directorate General of Population and Civil Registration of the Indonesian Ministry of Home Affairs (Dukcapil), all listed villages have population and settlement areas. Assuming that this type of issue only happens if the settlement area is too small, CovData is considered to remain valid to be used in this research. The option

Table 1.2: Unserved villages counted based on various options of 'unserved village' definition

Method	Unserved village definition	Unserved villages
A	the village which has 0.00 square kilometre 2G, 3G and 4G coverage on all of its land area	3100
B	the village which has 0.00 square kilometre 2G, 3G and 4G coverage on all of its settlement area	6227
C	the village which has less than 100.00% 2G, 3G and 4G coverage on its settlement area and land area	5563
D	the village which has less than 50.00% 2G, 3G and 4G coverage on its settlement area and less than 100.00% 2G, 3G and 4G coverage on its land area	3039
E	the village which has 0.00 square kilometre 2G, 3G and 4G coverage on its settlement area and less than 50.00% coverage on its land area	4704

C is also the definition used by Ditdal in 2020 (PT Tekno Nusantara Kapital, 2020, p.143), while D was used by Ditdal in 2017 (Directorate General of Post and Informatics Implementation, 2017) and 2018 (Direktorat Penyelenggaraan Pos dan Informatika, 2018). Both option C and D implicitly include underserved villages in the villages categorised as unserved. It means, in 5563 unserved villages from option C, some villages actually has got mobile network signal in the part of its area. Option E is introduced to exclude the underserved villages while focusing on villages with no coverage on their settlement areas.

Method E is chosen to be used in this research for defining the 'unserved villages'. A village is categorised as unserved if any mobile network service has not covered its settlement area. However, as there are villages listed to have no settlement area in CovData and assuming that it is because the settlement area is too small, a village is not an unserved village if a mobile network covers at least 50% of its land area.

1.4 Knowledge gaps

Using the search term *mobile telecom coverage rural* in all search field combined with *digital divide* in the title, keywords and abstract and *mobile coverage gap rural* in the title, keywords and abstract on Scopus, 86 documents and 32 documents were resulted in, respectively. However, none of them provided an analysis of the cause of the mobile coverage gap problem. These terms, however, gave some interesting articles about the possible solutions for solving the mobile coverage problem in rural areas, such as (Anand et al., 2012; Arakpogun et al., 2017; Chiha et al., 2020; Park et al., 2019; Prieto Egido et al., 2020; Townsend et al., 2013; Zi et al., 2020). Using the same search term in Web of Science resulted in 4 and 22 documents, respectively, which most of them have also shown up on Scopus search. One additional interesting and a quite relevant article was from Prieger (2013) that mentioned income is positively associated with the number of broadband providers, and rural areas empirically (based on their study of mobile broadband provision within the US) are associated with a lower number of providers. It can be concluded that the existing literature lacks comprehensive knowledge about the cause of the mobile coverage problem in rural areas.

Another attempt was made to find the literature that discusses the cause of the mobile coverage problem in rural areas using the term *mobile coverage telecom** in the title, keywords and abstract on Scopus and filter out all subject areas except decision sciences, business, management and accounting, social sciences, multidisciplinary, arts and humanities, psychology and economics. It gave 58 articles, but none of them provides a discussion about the mobile coverage gap causes. The articles focused on the proposed solution analysis and description, while only shortly mentioned the causes of the problem related to the solution it proposed in the article's introduction without analysing them.

Most of the articles that discuss the possible solution for the mobile coverage problem in rural areas provided a short description of the cause of the mobile coverage problem occurring in the case study they were studying. However, the actual and detail problem was different between countries or even between rural areas. It shows that to understand the actual cause of the mobile coverage gap problem in a country, a study that specifically analyses the problem in that country and specifically on the rural area should be done.

Indonesia is one of the developing countries that have low mobile coverage in its rural areas. However, to the best of our knowledge, the study about the cause of the rural coverage problem, specifically in Indonesia, is not readily available. A deeper look at the country and the exact location is required to comprehend the actual cause of each country's problem. A deeper study on the country is necessary because different countries apply various regulations with different institutional structure and their level of telecommunication services penetration are not the same. Meanwhile, an in-depth study on the exact location is also critical as different locations may have different geographical and demographical situations, which may affect the penetration.

Therefore, the first research gap found was:

1: The lack of a comprehensive study about the cause of the mobile coverage problem in Indonesia's rural areas.

Various solutions are suggested from the literature to cope with the mobile coverage gap. Some of them are in the form of technological solutions (Chiha et al., 2020; Prieto Egido et al., 2020), some are regulatory (Arakpogun et al., 2017; Bhuiyan, 2004) and some are organisational (Heimerl et al., 2013; Prieto Egido et al., 2020; Salemink and Strijker, 2018). However, none of them provides comprehensive guidance on which solution is suitable for what situation and what required for its effectiveness. Therefore, the second research gap identified is:

2: The lack of comprehensive guidance of which solution in the existing literature is suitable for what situation and what required for its effectiveness.

Research by Heimerl et al. (2013) was the only article found that took a case study in a village in Indonesia and proposed a participatory society scheme for solving the problem. However, the authors themselves explained that the pilot project they did was not, technically speaking, legal. It used mobile spectrum that is supposed to be only used by the selected MNOs. Hence, the solution is not implementable rightfully. Therefore, the third research gap can be written as:

3: The lack of scientific study proposing solutions for the mobile coverage problem in Indonesia's rural areas.

Moreover, none of the literature solutions considered the stakeholders (market parties and relevant authorities) perceptions in the mobile telecommunication sector. For instance, the Small Rural Operator (SRO) solution proposed by Prieto Egido et al. (2020) suggested a new type of mobile operator to be established in the market after assessing its techno-economic viability. The paper mentioned that SRO would heavily depend on the cooperation of the existing MNOs for lending their vacant frequencies and sharing their core network. Nevertheless, the paper did not discuss the socio-technical aspect of the solution, such as the acceptance of the existing MNOs, which is the first and most thing needed to implement the solution. These aspects are important to be considered before implementing any solution since mobile telecommunication is a complex socio-technical system (Ubacht, 2020). If the stakeholders disagree with the solution, implementing it will be difficult (if not impossible). Furthermore, the national governments have important roles to play in improving the mobile network coverage expansion. They have instruments to align key policies, such as spectrum allocation, pricing, network sharing, license, and national fibre optic backbone network provision (Touchard, 2017). Right decisions about each policy area can lead to an enabling environment and commercially sustainable investment for operators, hence improving the coverage (Touchard, 2017). Therefore, we consider a solution to be adequate and impactful if it accommodates the actors' perceptions and is implementable by the policymakers. It leads to the fourth research gap:

4: Lack of stakeholders' perceptions analysis in the formulation of the existing literature's solutions.

For those reasons, we would like to conduct a case study research for creating a set of solutions to help Kominfo solve the mobile coverage problem in Indonesian rural areas. Some rural locations in Indonesia will be taken as the exemplary case in the research. The solution set would be derived from the available solutions, including technological, organisational and regulatory solutions in the literature. Relevant stakeholders will be engaged through interviews to evaluate the selection of solutions, in which their perceptions regarding the solutions will be taken into account.

1.5 Research questions

Based on the rationales mentioned above, we formulate the main research question:

"How can the Indonesian Ministry of Communication and Informatics advance the mobile coverage in Indonesian rural areas?"

Four sub-research questions to answer the main question are formulated as follows.

SRQ1: Why do mobile coverage problems occur in Indonesian rural areas?

Currently, there is a lack of a clear and comprehensive analysis regarding the cause of the mobile coverage problem in Indonesian rural areas. Therefore, the first sub-research question aims to discover the cause of the problem in general—regardless of the country— and then, specifically, in Indonesia.

SRQ2: What are the possible solutions to solve the mobile coverage problem in rural areas and their characteristics?

As there are many solutions provided in the literature to solve the mobile coverage gap problem, the second sub-research question aims to gather them all together and their characteristics. By characteristics, we refer to the requirements that make the solution implementable and achieve its objective. For example, the SRO solution (Prieto Egido et al., 2020) implied a requirement of the establishment of network sharing regulations in the country to implement it, while the GEO satellite-caching solution (Chiha et al., 2020) requires a minimum willingness-to-pay of the local people around 19 euro/month. Knowing this information will help in identifying the possible solutions for Indonesia in the next stage.

The solutions will be categorised into technology, organisational and regulatory. Technology solutions are about the employment of specific technology, such as the TUCAN3G solution from Martínez-Fernández et al. (2016). Organisation solution pinpoints the required and suitable actor(s) to roll out the technological means, such as the Small Rural Operator (Prieto Egido et al., 2020). And regulatory solutions refer to the required regulation adjustments, policy support or new regulations for implementing certain solution by certain actor(s) such as the Universal Service Funds (USF) from Arakpogun et al. (2017) and the coverage obligation (Bhuiyan, 2004).

SRQ3: Which solutions available in the literature can apply to Indonesia?

Not every solution provided in the literature may apply to Indonesia's situation. By cross-checking the characteristics of the available solutions from SQ2 and the case studies' situation (SQ1), the third sub-research question will be answered.

As Indonesia has numerous rural areas that are geographically and demographically different, several locations (2-4) will be selected as the exemplary cases to represent different requisite situations of the problem in Indonesia in this stage of the research. The situation in each location will be analysed first for answering this sub-research question. It will result in a set of preliminary possible solutions to Indonesia's problem, consisting of four to five different solutions for each location. These research results will subsequently be used to conduct the interview for the next stage.

SRQ4: What are the possible solutions to advance the mobile coverage in Indonesian rural areas that take actors perceptions into account?

The fourth sub-research question marks the most empirical part of this research and the outcome would lead to answering the main research question. The relevant stakeholders will be requested to provide opinions and weights regarding the preliminary list of solutions found in the previous stage. The requested opinions would include their preference regarding each solution, their vision about the feasibility to implement the solution, the negative impacts of the solutions, what is required to make the solution achieve its objective and the solutions' effectiveness. By incorporating the actors' perceptions, a set of solutions for each case would be presented. Here, a more generic process for assessing the solutions for situations will also be developed, which can be used in other countries or regions with similar problems.

By answering all the sub research questions, the main research question will be answered. Answer of each sub research question will be a building block of the main research question answer.

1.6 Research approach & methods

This section describes the research design. It explains the motivation of the choice to use qualitative exploratory case study as the approach. Furthermore, it also elaborates the research methods, its source of information and data collection method used in each stage, and the expected deliverables. It also explains the interviewees selection in the last subsection.

1.6.1 Qualitative exploratory case study

The goal is to formulate a set of solutions applicable to Indonesia to solve its mobile coverage gap. A qualitative exploratory approach, combined with a case study approach, will be employed in this research. The research questions focus on the 'what' aspect shows that the research is exploratory (Yin, 2009). The exploratory approach explores the possible solution in the literature to solve the mobile coverage gap problem in rural areas. However, the main research question and sub-research questions 1 and 4 are 'how' and 'why', leading to the case study as a complementing approach.

A case study is a research approach that generates an in-depth, multi-faceted understanding of a complex issue in its real-life context (Crowe et al., 2011). Yin (2009) explained that the case study approach is favourable to research that poses question type 'how' or 'why', focuses on contemporary events and lacks control on the events' behaviour. Part of this research focuses on identifying the causes of a problem and empirically understanding the actors' perception. Furthermore, this research focuses on contemporary events (i.e., the adoption of a solution to solve the mobile coverage gap problem) instead of historical events, and the researcher cannot manipulate the events' behaviour. Therefore, a case study approach will also be employed in this research.

An embedded case study is chosen as the research design for the case study. An embedded case study is a case study where multiple units of analysis are studied within the case (Yin, 2018). Here, Indonesia's rural mobile coverage is the case in which some rural villages will be selected as the units of analysis.

1.6.2 Research methods

The sub-questions are answered with different research methods, sources, data collection methods and deliver different outcomes presented in Table 1.3. Extensive literature research will be conducted for answering SQ1 and SQ2. A sufficient number of journal articles that discussed and suggested solutions for improving mobile coverage in rural areas will be considered and reviewed. This part explores the available solutions and the requirements for each solution to be implementable and achieve its aim. This part might result in an overview table of possible solutions and requirements. ATLAS.ti will be employed here for coding the data from those articles.

Table 1.3: Research design

Sub-research question		Research method	Sources	Data collection method	Deliverables
SQ1	What are the causes of mobile coverage problems in Indonesian rural areas?	Literature study, desk research, statistical expert review	Scientific journals, reports, websites, news articles, a statistical expert	• Literature review on the cause of the mobile coverage gap or digital divide in rural areas in general • Statistical analysis on the Indonesian empirical data, • Correlation test, and • Data coding	• The causal relation diagram of mobile coverage problem globally • The key factors causing mobile coverage gaps in Indonesia
SQ2	What are the possible solutions to solve the mobile coverage problem in rural areas and their characteristics?	Literature study	Scientific journals, reports, books	• Literature review on the solutions to solve the mobile coverage problem in rural areas, and • Data coding	List of possible solutions, their type, requirements and challenges
SQ3	Which solutions available in the literature can apply to Indonesia?	Desk research, literature study, qualitative analysis	Results from SQ2, regulation documents, ministerial and regional data (about the coverage level, demographic, infrastructure establishments and relevant aspects)	• Literature review on the case's and exemplary cases' characteristic in terms of the contexts and requirements of the possible solutions, and • Develop a set of preliminary solutions	A set of preliminary solutions to solve the mobile coverage problem in each exemplary case
SQ4	What are the possible solutions to advance the mobile coverage in Indonesian rural areas that takes actors perceptions into account?	Desk research, qualitative analysis, interview	Reports, websites, scientific journals, news articles, individuals	• Interview with the key person of the relevant divisions in Kominfo and MNOs • Select the solutions	• List of potential side effects, influential factors, risks perceived by actors and the preference score of the preliminary solutions • Proposed solution

Moreover, a statistical data analysis will be done for answering SQ1. To find the causes of the mobile coverage problem in Indonesia, Indonesian empirical data, derived from reports, websites and news articles, will be used. A correlation test, a statistical analysis method to identify the correlation between factors, reviewed by a statistical expert, will be used to conclude what the key factors are.

After the possible solutions from the literature found, they will be examined to identify which solutions are applicable for each exemplary case. The examination will particularly consider each solution's context and requirements (SQ2) and Indonesia's problem (SQ1). Therefore, to answer SQ3, some villages will be selected as the exemplary cases and a thorough investigation of the exemplary cases' situation regarding each solution's requirement and context will be performed. As part of SQ3, each exemplary case's situation and Indonesia's national situation will be analysed using governmental reports, news articles and websites through a desk research. This investigation may exploit documents of the existing regulations and ministerial data (both public and internal). The ministerial data will be mainly from Kominfo about, but not limited to, the current mobile coverage level, demographic and infrastructure establishments.

In complex socio-technical systems, the decision arena consists of multiple actors with conflicting interests. Thus, decision-making processes are not merely based on the feasibility and the performance of the proposed solution itself, but also (in some cases, majorly) might be influenced by the actors affected by the decision. A stakeholder analysis through literature research and (online) interviews will be conducted to understand the relevant actors' perceptions of the previous stage's preliminary solutions. Moreover, the preliminary solutions will get weighted by relevant actors based on which the final set of solutions will be formulated. The actors include, but not limited to, the relevant departments in Kominfo and the mobile network operators. By answering SQ4, we can derive final set of solutions for each exemplary case explained with the potential side effects and influential factors associated with each preliminary solution perceived by the stakeholders. The description of the interviewees selection can be found in the next subsection.

To evaluate and validate the outcome of each stage, the sub-coordinator of the Telecommunication Network Evaluation section of Kominfo and other relevant actor review and provide feedback for each research's chapter. A person with the relevant knowledge of MNOs' perspective as he is leading the network operation nationally in one of the MNOs in Indonesia took part in reviewing Chapter 2.

1.6.3 Selection of interviewees

The interview respondents are from the Indonesian Ministry of Communication and Informatics (Kominfo) and Indonesian MNOs. The list is provided in Table 1.4. Figure 1.3 shows the organisational hierarchy of the Ministry of Communication and Informatics (Kominfo).

Table 1.4: List of interviewees

Interviewee	Organisation	Position
1	Ministry of Communication and Informatics	Sub-Coordinator for the Allocation of Fixed Service
2	Ministry of Communication and Informatics	Sub-Coordinator for Special Telecommunications and Telecommunication Network Evaluation
3	Ministry of Communication and Informatics	Coordinator for Special Telecommunications and Telecommunication Network
4	Ministry of Communication and Informatics	Licensing Analyst for Network Operation Management
5	Ministry of Communication and Informatics	Head of Lastmile/Backhaul Infrastructure Division (BAKTI)
6	Ministry of Communication and Informatics	Coordinator of Spectrum Allocation Arrangement for Fixed and Land Mobile Services
7	Mobile Network Operator	National Vice President of Fault Analytic and End-to-End Performance
8	Mobile Network Operator	West Jabotabek Project Deployment Team

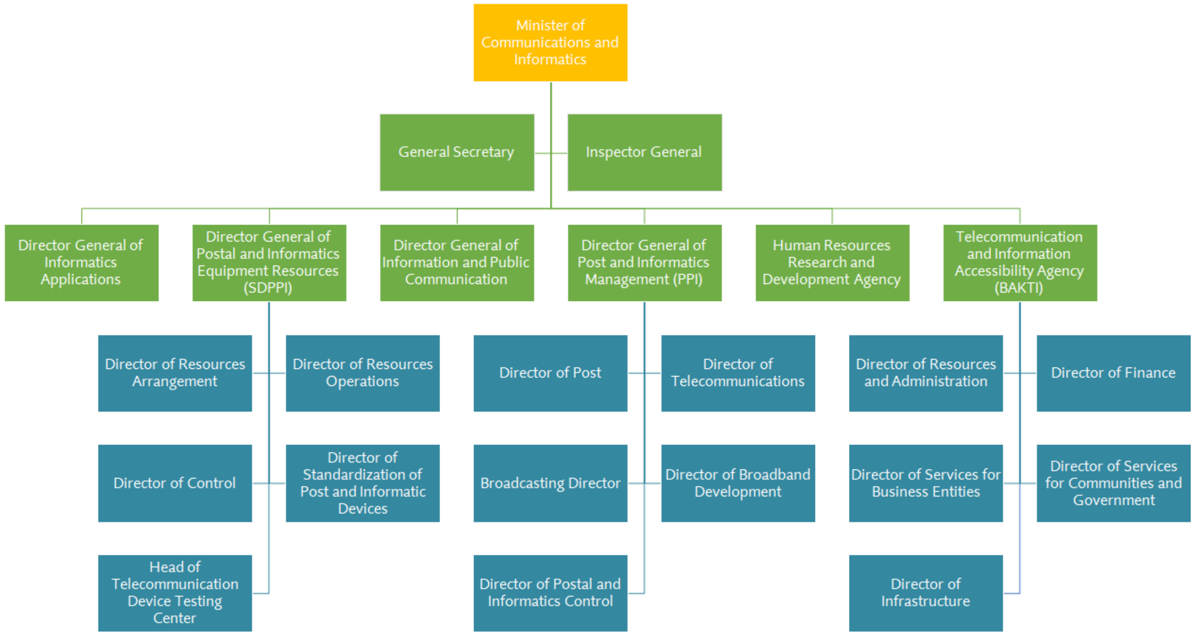

Figure 1.3: The organisational hierarchy of the Ministry of Communication and Informatics (Kominfo) according to Permenkominfo Number 8 of 2018 and Permenkominfo Number 3 of 2018

Six representatives from four different directorates in Kominfo are selected as the interviewees. These directorates are considered the most relevant and interrelated sections in Kominfo regarding mobile network deployment in rural areas. Interviewees 1 and 6 are from the Directorate of Resources Arrangement, which is responsible for carrying out the formulation and implementation of policies as well as monitoring, evaluating, and reporting in the field of structuring the use of the radio frequency spectrum. Many solution options involve the unconventional use of spectrum, such as VillageCell, which demands GSM bands locally and unlicensed bands for backhaul link in Tampang Muda village. Also, there is 'a taxation policy that foster investment in rural areas' proposed as a regulatory solution in some arrangements about the possibility of reducing the spectrum fee. Hence, knowing the perspective of the Directorate of Resources Arrangement on the solutions arrangements is essential.

Interviewee 2 and 3 are from the Directorate of Postal and Informatics Control. The directorate of Postal and Informatics Control is responsible for making and executing the policy on telecommunication network monitoring and evaluation, including the QoS evaluation, telecommunication BHP and USF. Therefore, this directorate perspective regarding all the regulatory solutions proposed in the solution arrangements is valuable.

Interviewee 4 is from the Directorate of Telecommunications. Telecommunication operational licensing, coverage obligation and technical standardisation are some of the Directorate Telecommunication authority. Its perspective is then considered relevant to evaluate the overall solution arrangements proposed.

BAKTI as the main actor for rural network development in Indonesia, currently has the most influence and interest in finding the most efficient way to enhance the mobile network coverage in rural areas. Hence, Interviewee 5's opinion is taken into account.

Two people from different MNOs with different roles are involved in representing the MNO's perspective. They come from two leading mobile network operators that have been established for more than 15 years. These MNOs also operate in various mobile spectrum bands. Moreover, the respondents have been working in the mobile network industry for around ten years. Therefore, their knowledge is considered sufficient and may represent Indonesian MNOs. However, we acknowledge that only two representatives from the MNO side might not be fully representing. Some attempts were made to get two more MNOs (the ones with the two lowest market share and spectrum ownership), but they could not join due to schedule issues.

1.7 Research flow

Figure 1.4 illustrates the flow of the entire research. The research begins with literature review to scope and demarcate the problem. Afterwards, literature study about the cause of the problem is conducted. In parallel, literature study that explores the available solution is also done. Both literature studies are incrementally build up each other. Chapter 4 concludes the findings in Chapter 2 and 3 into a set of preliminary solutions for Indonesian mobile coverage problem. These solutions are then discussed with Kominfo and MNOs to decide which solutions are feasible and which are not, why they are so, and what their perceptions regarding the solutions are. Considering all stakeholders' input, the final proposed solutions are then offered in Chapter 5.

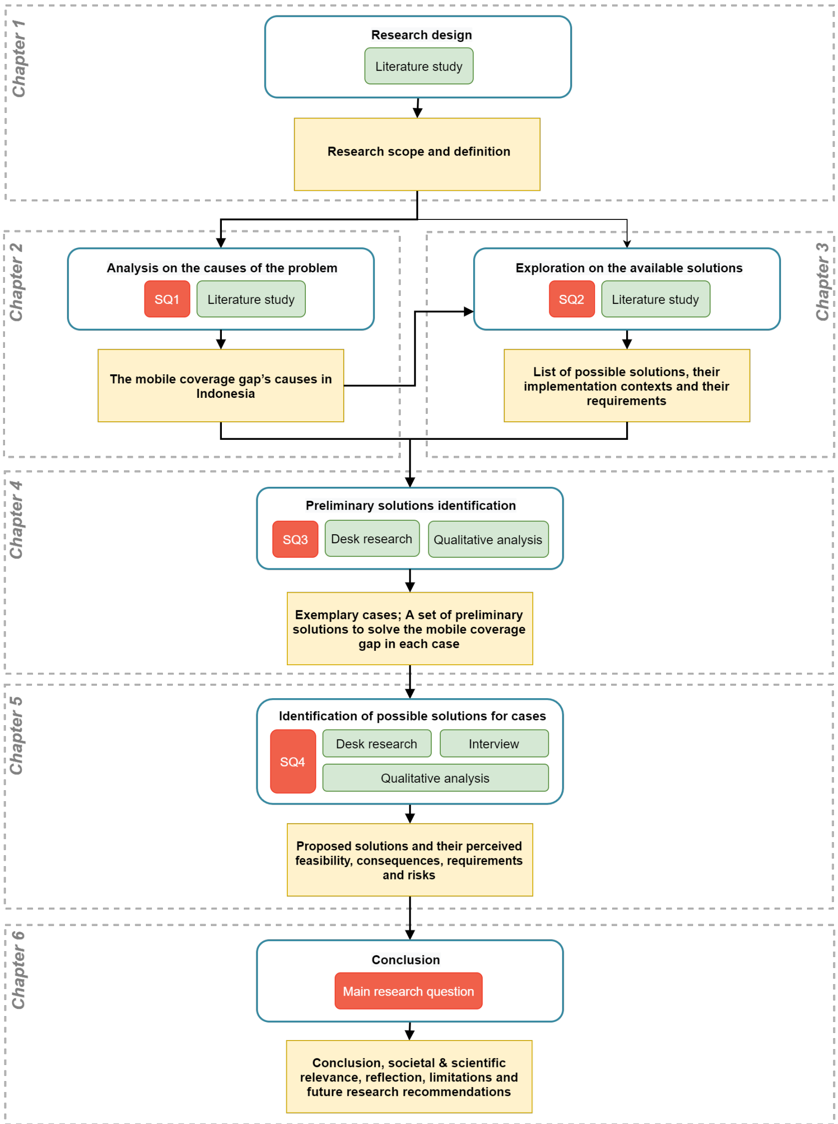

Figure 1.4: Research flow diagram

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Chapter 2

Problem Understanding

As discussed in Chapter 1, there is currently a lack of clear comprehensive knowledge about the cause of the mobile coverage problem in Indonesian rural areas. This chapter, therefore, aims to understand why mobile coverage problems occur in Indonesian rural areas and specifically to answer the SQ1: "*What are the causes of mobile coverage problems in Indonesian rural areas?*". Figure 2.1 illustrates the conceptual flow of this chapter. First, an extensive literature review is done to comprehend what can cause mobile coverage gaps as suggested by the existing literature. Based on that, key factors of the mobile coverage problem are identified. Next, analysis on the empirical data and relevant documents of Indonesia associated with those factors is conducted to verify whether these global key factors also apply to Indonesia. At the end of this chapter, a conclusion explaining the cause of mobile coverage problems in Indonesia is presented.

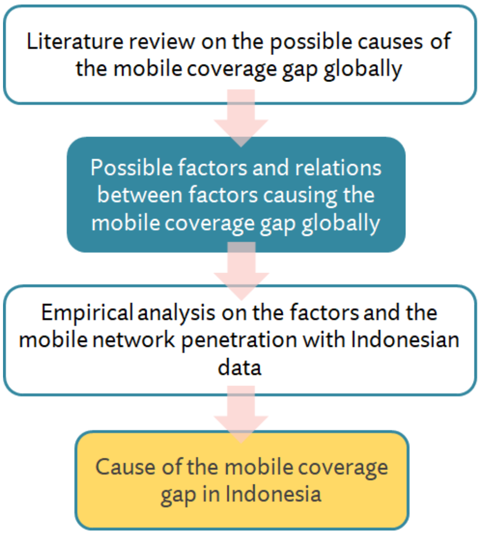

Figure 2.1: Research flow of Chapter 2

2.1 Causes of the mobile coverage gap in rural areas in general

The lack of coverage in rural areas is a consequence of a basic economic challenge. The strong profit motives of the major MNOs limit their investment in rural connectivity because rural populations in developing countries have high poverty rates, making them an unprofitable customer segment (Cruz and Touchard, 2018; Galperin and Bar, 2007; Jha and Saha, 2016; Prieto Egido et al., 2020). Even in developed countries, this also happens but more about the broadband services, not about the basic mobile services, i.e. telephony and SMS (Prieger, 2013; Roberts et al., 2017; Salemink and Strijker, 2018; Townsend et al., 2013) as it stems from a higher level of telecommunication penetration (Arakpogun et al., 2017). Moreover, MNOs are not willing to invest in small communities because of the high opportunity cost of not deploying the network in the urban area (Trendov et al., 2018) and high investments are required to maintain their market share in urban areas in which aggressive competitions among operators occurred (Heimerl et al., 2013). The MNOs' profit motives, then, are exacerbated by the difficulties for deploying networks in rural areas, such as the challenging geographical position, which makes them hard to be accessed, the lack of energy grid, challenging terrain types (e.g., rainforests or mountains) and the underdeveloped road networks (Heimerl et al., 2013; Khaturia et al., 2020; Prieto Egido et al., 2020; Touchard, 2017). These difficulties may not only hamper the deployment of network infrastructures but also drive up the deployment costs. As investment in telecommunications infrastructure plays the major role in coverage expansion (Arakpogun et al., 2017; Hudson, 2006), coverage could not be expanded without it and could be hindered if the cost is too high. Deploying infrastructure outside the urban and suburban areas can be twice as expensive (Cruz and Touchard, 2018; Rendon Schneir and Xiong, 2016; Tyler et al., 1995), while revenue opportunities are as much as ten times lower (Cruz and Touchard, 2018; Touchard, 2017). The combination of high prices of deploying infrastructure and weak demand for mobile internet services in rural populations deeply affects the business case for MNOs to deploy network infrastructure and results in a supply-demand equilibrium with low mobile network coverage in rural areas.

The commercial orientation of MNOs and the mobile communication industry's competitive environment are the results of telecommunication market liberalisation & privatisation enacted by the government. Shifting from a state-owned monopoly to a private and liberal industry is a typical trajectory of the telecommunication market industry in many countries (Arakpogun et al., 2017; Berg and Hamilton, 2002; Chavula, 2013; Gutierrez and Berg, 2000; Montenegro and Araral, 2020). In the beginning, as the telecommunication service was considered a vital and essential need of society, the government tried to assure its deliverance and performance via its state-owned company, which monopolised the sector throughout the nation (Montenegro and Araral, 2020). However, shown by the studies in Bangladesh (Bhuiyan, 2004) and Africa (ITU, 1999; Minges, 1998; Whitehead et al., 2011), the limited technical expertise and investment capacity of the government led to low teledensity and left the telecommunication service performance much to be desired as the telecommunication needs grew. The state-owned telecommunication operators' bureaucratic structure increased the management costs and placed a burden on the available funds (Bhuiyan, 2004). Due to these limitations, to extend the telecommunication services to the unserved and underserved areas, governments turned to the World Bank and other international bodies for support (Brook and Irwin, 2003; Sutherland, 2014; Wanjiku, 2014). At the heart of the conditions for granting these supports was the need to introduce reforms, including the mobile telecommunications sector's liberalisation (Sutherland, 2014; Wanjiku, 2014). Other than that, liberalisation and privatisation were also the popular recommendations for reducing the government burden in service provision as it could attract foreign investment in the telecommunication sector and allow private entrepreneurs to contribute to network development (Bhuiyan, 2004). Although the liberalisation and privatisation have increased access to mobile network services in countries worldwide, the services are still limited to customers in urban areas.

Townsend et al. (2013) and Wright (1995) saw connectivity as the essential protector against the depopulation of rural areas. The wide range of telecommunication services such as public e-services, e-learning, e-mail, telemedicine and online social networking help rural areas to sustain themselves. Without these services, people would be pushed to go to cities where the essential services and agendas happen and leave the rural to avoid unnecessary commuting. The lack of telecommunication services in rural areas leads to urbanisation, making rural areas less populated, hence less economically attractive (Cruz and Touchard, 2018; Jha and Saha, 2016; Wright, 1995). The lower the population, the higher the economic challenge, the harder it would be to provide telecommunication services in rural areas. Without telecommunication service in rural areas, the digital divide between the urban and rural areas get higher and, subsequently, the rural population's poverty rates would be increased (Cruz and Touchard, 2018; Prieto Egido et al., 2020).

MNOs' profit can also influence the network deployment rate of MNOs, particularly in rural areas. The more profit they make, the more budget they can spend for building networks (Cruz and Touchard, 2018). The more investment they put on establishing network infrastructure, the better network coverage can be resulted in. Conversely, limited profit contributes to limited investment budget. The more limited the budget they have, the more they incline to avoid the economically unattractive and risky areas like rural. It means, having more available budget to spend increases the profitability of rural areas perceived by MNOs. Increasing the profit for MNOs can be done both by increasing the usage of the existing network and decreasing their expenditures i.e., operational costs, network installation costs, taxes, etc. The low quality and affordability of telecommunication services in rural areas (could be shown by the relatively higher price, insufficient voice call quality, or low data rates) could decrease the services' use. The low usage means a low return on investment (RoI), hence profit for the MNOs. Furthermore, the low RoI could create reluctance on the MNOs to maintain their existing networks in those areas. Surana et al. (2008) added that most of the deployed networks in rural areas do not stay operational over the long haul. The study showed that MNOs encounter various challenges in maintaining the network in rural areas due to environmental issues, location's difficult accessibility, and power instability, leading to more often components' failure/break and longer downtime. Subsequently, these situations increase the MNOs operational costs for travelling to the location and to replace the components more often and decrease the revenue due to the too long downtime. Consequently, many failed sites in rural areas are abandoned, and MNOs are getting a deterrent to deploying sites in other rural areas. However, it turns out that MNOs' financial capacity is not the only thing that affect the sustainability of a site, but also the local support. Heimerl et al. (2013) found through their study that if locals support a network establishment, they can help maintain and repair the network.

From the aforementioned information, a diagram (Figure 2.2) was made to illustrate the causal relation of the factors of the mobile coverage gap problem in rural areas. The diagram depicts the causality of mobile network deployment from an economic perspective. It captures the factors that influence the mobile network service availability, quality and affordability by the nature of commercial orientation. The following paragraphs describe the diagram. Based on that, Table 2.1 summarises the factors that can influence the mobile coverage gap problem in rural areas.

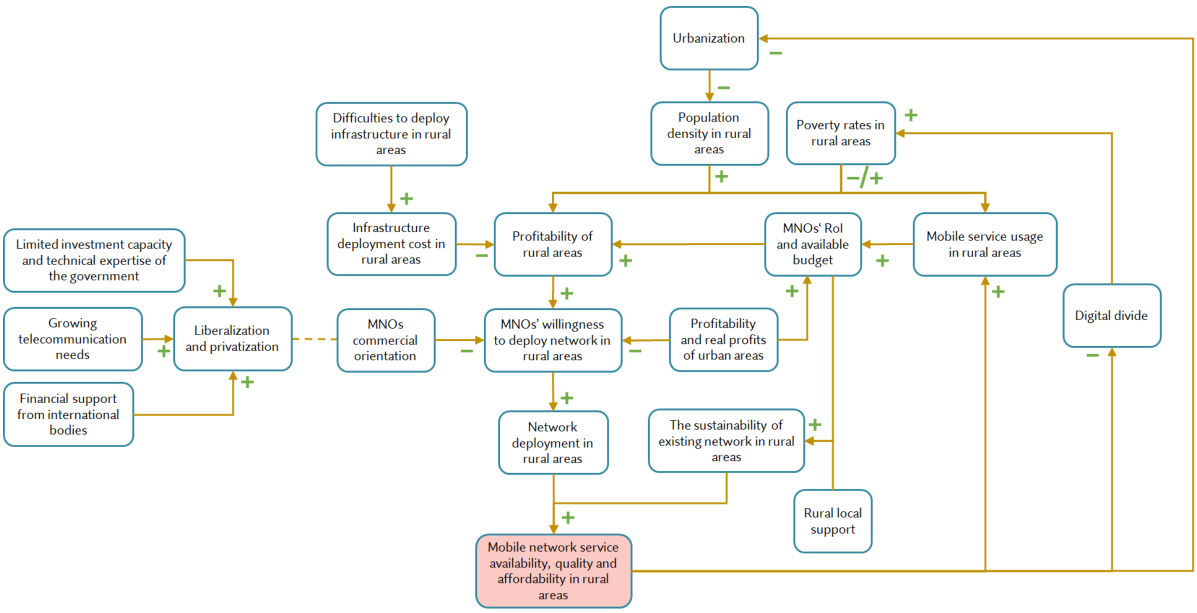

Figure 2.2: Factors of the problem and their relations

The mobile network coverage in rural areas would be better if the network deployment in the areas were

Table 2.1: Potential key factors and indicators of the mobile coverage gap problem in rural areas

Category	Factors	Indicators
Areas' profitability	Area's potential revenue	Poverty rates, population density
Areas' profitability	Network deployment cost in the area	Electricity readiness, road accessibility, topography
Areas' profitability; Sustainability of the existing network	MNOs' financial capacity	EBIT
Sustainability of the existing network	Rural local support	Community-led network, vandalism
MNOs commercial orientation	MNO's institutional position	Coverage obligation policies

increased, and if the existing network in rural areas were properly maintained. From a commercial perspective, network infrastructure will only be deployed in an area if MNO is willing to do so. Furthermore, by nature, due to MNOs' profit orientation, they will only build or maintain a network and spend budget on that if they see value for their investment.

At least five factors are influencing MNOs' willingness to deploy a network in rural areas. They are categorised into three: areas' profitability, sustainability of the existing network and MNOs commercial orientation. The first category consists of areas potential revenue, the network deployment cost in the areas and the MNOs' financial capacity. Driven by their profit orientation, MNOs will only be interested in building a site in rural areas if they are assured that the cost (capital and operational) for building that site does not exceed its potential revenue and there is a profit they can gain from the site. The profitability of rural areas relates to the potential revenue MNOs can get that is heavily influenced by the local population's poverty rates (Jha and Saha, 2016). It also relates to the overall RoI of MNOs. When MNOs RoI is higher, which is also influenced by the profitability of urban areas, the higher financial capacity they have, the more money MNOs can invest in establishing and maintaining a network in rural areas (Cruz and Touchard, 2018).

The deployment cost in rural areas is the capital and operational expenditure an MNO needs to build a rural area site. It includes the costs for transporting network components to the site location, the electricity costs, the network component costs, the maintenance costs, etc. When the road access is not well-established, the deployment cost is usually higher as MNO needs to use special transportation mode, such as helicopters, to deliver the components to the location. When the power grid is not readily available in the area, the electricity cost is usually higher as they have first to establish the power source (hydropower, solar PV or electrical generator from gasoline), and they have to provide maintenance more often as the site fails more often (Surana et al., 2008). The maintenance cost may also be higher the more remote the location as it will require more time and cost to reach the location (Surana et al., 2008).

On the other hand, MNOs also consider the profitability of urban areas before deciding where to invest. This factor prescribes MNOs whether to prioritise and allocate investment to urban areas or not. It has been commonly understood that urban areas offer a substantial profit per site for their high-density and high-income population, while rural areas' profitability is uncertain. MNOs will naturally compare the benefits of investing in urban areas and rural areas. Despite all risks and difficulties, rural areas actually can also offer advantages to MNOs, i.e., to gain new customers and expand their market areas (Cruz and Touchard, 2018). A study in Indian telecommunication showed that when urban areas are saturated and give low average revenue per user (ARPU), MNOs will be encouraged to seek out markets in the rural areas (Mani, 2012). However, new MNOs or MNOs that are not yet financially mature might prefer to invest in urban areas to stabilise their business first and avoid risks.

The second category is related to the sustainability of the existing network. The mobile network coverage in rural areas would be better if the existing network in rural areas were properly maintained. Two factors influencing the sustainability of the existing network are the site owner's financial capacity and the support from the local communities.

The third category is the MNOs' commercial orientation. It is affected by the MNO's institutional position. Just as the government shaped this orientation with the telecommunication liberalisation and privatisation policies in the past, MNOs' institutional position is heavily influenced by the government's national regulation. For instance, the enactment of telecommunication obligation, such as coverage obligation, could help in pressing the level of MNOs' commercial orientation in influencing their willingness to deploy networks in rural areas because it creates a new 'value' for MNOs other than profit, which is compliance. One success story in using coverage obligation for improving the rural mobile network coverage is Brazil, which started the policy in 2012 (Cruz and Touchard, 2018). Brazilian telecoms regulator auctioned spectrum licenses including obligations to extend 4G coverages to all 5570 municipalities before December 2019 and allowed infrastructure sharing between MNOs for complying coverage in rural areas. In 2017, 4G service has been served in more than 3000s municipalities, three times higher than the target.

However, the actual and detail problem was found to vary between countries or even between rural areas. For example, Arakpogun et al. (2017) implied a plethora of unserved and underserved rural areas in many countries in Africa due to the poor implementation of their USF. While in Bangladesh, Bhuiyan (2004) mentioned that the telecommunication network failed to expand as expected to rural areas due to a lack of government policy supports, such as coverage obligation and cross-subsidisation. Ayala et al. (2018) explicitly mentioned that the main reason why Mexico has less telecommunications services coverage than other countries with similar development levels is the domination of two operators in the fixed and mobile telephony markets. On the other hand, on Heimerl et al. (2013), there was no mobile coverage in a Papua's village because there was no village-wide electricity nor terrestrial backhaul network around this village. This information shows that to understand the actual cause of the mobile coverage gap problem in a country, a study that specifically analyses the problem in that country and specifically on the rural area should be done. For that reason, an analysis of the mobile coverage gap problem, specifically in Indonesia's country, will be conducted in the following section.

2.2 Causes of mobile coverage problem in Indonesia

To begin with, it is crucial to get a glimpse of the mobile network operation in Indonesia. Currently, there are seven MNOs operated in Indonesia under six brands. These MNOs are also the mobile service providers as Indonesia does not have any mobile virtual network provider. The operation of each MNOs are guaranteed under a specific license, one for each MNO, and is subject to be evaluated every five years (GR Number 52 of 2000, Article 67). Each MNO may have different radio spectrum allocations (as a result of auctions and beauty contests in the past), but they are all technologically neutral [1]. Table 2.2 summarises all operating MNOs in Indonesia, and Table 2.3 shows the number of cellular sites operated by each MNO by Q2 2020.

As seen in Table 2.3, besides the six MNOs, some cellular sites are owned by BAKTI (the Indonesian Telecommunication Accessibility Agency). BAKTI is an agency under Kominfo that is responsible for administering Indonesian USF. Some of the collected USF is used to established cellular sites in rural areas. BAKTI cooperates with MNOs to operate and provide mobile network services on the sites.

Section 2.1 (Table 2.1) informed that there are key factors affecting the mobile coverage level in an area: the area's potential revenue, the deployment cost, the MNOs' financial capacity, local support and MNO's institutional position. These factors can be associated with specific indicators, i.e. the area's potential revenue

[1] this clause is mentioned in the licenses

is indicated by the poverty rates and population density of the area, the network deployment cost is associated with the electricity readiness, road accessibility and the area's topography. Despite its deficiency, the MNOs' financial capacity can be proxied by examining their earnings before interests and taxes (EBIT). Meanwhile, MNO's institutional position can be evaluated by looking at the relevant compliance policies, such as coverage obligation policies. Lastly, the rural local support can be indicated by the presence of policies or mechanisms to involve local residents in the network operation and the events showing clashes or collaborations between MNOs and local communities.

Table 2.2: Overview of Indonesian mobile network operators

Company name	Service brand	Operating in frequency band(s)
PT Telekomunikasi Selular	Telkomsel	800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2300 MHz
PT Indosat Ooredoo, Tbk	Indosat	800 MHz, 900 MHz, 1800 MHz, 2100 MHz
PT XL Axiata, Tbk	XL	800 MHz, 900 MHz, 1800 MHz, 2100 MHz
PT Hutchison Tri Indonesia, Tbk	Tri	1800 MHz, 2100 MHz
PT Smartfren Telecom, Tbk	Smartfren	800 MHz
PT Smart Telecom		2300 MHz
PT Sampoerna Telekomunikasi Indonesia	Net1	450 MHz

Table 2.3: Cellular sites ownership per technology by Q2 2020

Site owner	#2G sites	#3G sites	#4G sites	Total
Telkomsel	37132	46649	58135	141916
Indosat	20525	20664	20741	61930
XL	21287	32442	33188	86917
Tri	14029	24815	24889	63733
Smartfren	0	0	5536	5536
Net1	0	0	599	599
BAKTI	964	0	551	1515
TOTAL	93937	124570	143639	362146

It is worth to notice that since there is no quantitative indicator to represent the last two factors (MNO's institutional position and rural local support) per province, finding correlation between the coverage level per province and those factors becomes unreasonable. Therefore, as the mobile coverage level in Indonesia is still perceived problematic, it is assumed that the current condition regarding the factors rural local support and MNOs' institutional position has caused the mobile coverage problem in Indonesia.

The following subsections provide analysis on each indicators of the aforementioned indicators. Subsections 1 aims to find correlation between the factor and the mobile coverage level, and to decide whether or not the factor, as identified in Section 2.1, causes the mobile coverage problem in Indonesia. The remaining subsections aim to analyse the existing situation in Indonesia pertaining to the indicators coverage obligation policies and local community supports which would be used to identify the flaws that might cause the problem.

2.2.1 Population density, poverty rates, electricity readiness, road accessibility, area's topography and MNO's financial capacity

Here, correlation between factors of the mobile coverage problem in rural areas and an indicator of the mobile coverage problem will be identified using Indonesian empirical data to prove whether those factors also the cause of the Indonesian rural areas' coverage problem. The factors are poverty rates, population density, electricity readiness, road accessibility, the area's topography and the MNOs' financial capacity. For factors poverty rates, population density, electricity readiness, road accessibility and area's topography, the number of unserved villages per province according to CovData will be used as the indicator of the mobile coverage problem. Meanwhile, for factor MNOs' financial capacity, the percentage of the MNO's site located in rural provinces will be used as the indicator for the mobile coverage problem. It will be compared to the MNO's EBIT.

Table 2.4: The correlation between relevant indicators

Factor	Indicators	Results			
		SCC	Correlation strength	m	Description
Population density	Population density per province vs. the number of unserved villages per province	-0.755	Strong	-	The denser the province, the less unserved villages can be found
Poverty rates	Regional gross domestic income per capita (PDRB) vs. the number of unserved villages per province	0.271	Weak	+	The more unserved villages were found in a province with a higher income
	The percentage of poor population per province vs. the number of unserved villages per province	0.140	Weak	+	The more unserved villages were found in a province with a higher percentage of poor population
	The number of villages without kiosks per province vs. the number of unserved villages per province	0.234	Weak	+	The more unserved villages were found in a province with more villages without kiosk
Electricity readiness	The number of households in a province without electricity grid vs. the number of unserved villages per province	0.462	Moderate	+	A less mobile network coverage problem is usually found in areas where the electricity grid is more available for households
	the number of villages without electricity in a province vs. the number of unserved villages per province	0.527	Strong	+	A less mobile network coverage problem is usually found in villages with electricity
Road accessibility	The percentage of solid road of all available roads per province in 2014 vs. the number of unserved villages per province	-0.646	Strong	-	The more unserved villages can be found in areas that are less accessible via land route
Topography	The number of villages located on slopes or valley per province in 2018 vs. the number of unserved villages per province	0.382	Moderate	+	The more unserved villages can be found in areas consist of more villages with difficult terrain
MNO's financial capacity	MNO's EBIT vs. the percentage of rural sites of each MNO	0.600	Strong	+	MNOs with a better financial capacity invest more in rural areas

Finding the correlation is done in two steps: 1) Calculating the Spearman Correlation Coefficient (SCC) to test the correlation, and 2) Regression analysis. SCC is widely known method to measures the strength and direction of linear relationships between pairs of variables that is more robust to outliers (Mukaka, 2012). Further explanation on SCC and regression analysis can be found in Appendix C. Here, a pair of variables would be the factors' indicator and the number of unserved village per province. Knowing the SCC, based on Cohen (1988)'s guideline, the correlation can be categorised as weak, moderate and strong as follows:

- |SCC| < 0.3 is weak correlation
- 0.3 ≥ |SCC| < 0.5 is moderate correlation
- 0.5 ≥ |SCC| is strong correlation

The positive and negative sign shows whether the variables are positively or negatively correlated. To enhance the result, a regression analysis is done by creating a linear trendline based on the scatter plot of data from a pair variables and deriving the equation of that linear trendline. The equation of the linear trendline would be $y = mx + b$. The sign of the m value (positive or negative) would be checked if it affirms the SCC's sign. Step 2 is also done to provide a quick visualisation regarding the correlation. Table 2.4 summarises the correlation between relevant indicators.

The correlation test result shows that all factors, except poverty rates, have a moderate to strong correlation to the mobile coverage problem in a province. The m values from the regression analysis also affirm the SCC's sign, hence validating the connection between variables. Further elaboration on each factor's analysis is presented in Appendix C.

2.2.2 Coverage obligation policies

In Indonesia, MNOs need to obtain a license to operationalise their mobile network and to operate in particular spectrums. According to Law of the Republic of Indonesia Number 36 of 1999 regarding Telecommunications, Article 11, the operation of telecommunications networks may be carried out after obtaining a license from the Minister of Communication and Informatics. And based on Article 33, the use of radio frequency spectrum shall be based on acquiring a license from the government. The license itself is valid and eligible for nationwide network roll-out. This obligation was then further specified in the Government Regulation (GR) Number 52 of 2000 regarding Telecommunications Operation that obliges all telecommunication network operator to deploy and/or provide telecommunication networks (Article 6), and the operational licenses are evaluated once in five years (Article 67). The latter article also mentions that the Minister imposes an administrative sanction for any non-conformity based on the evaluation result.

The coverage obligation is stated in the spectrum licenses started in 2020. Spectrum licenses are subject to evaluation every ten years and can be extended once. All MNOs' spectrum licenses that were due in 2020 were extended and renewed. In 2020, unusually, the license for spectrum bands 800 MHz, 900 MHz and 1800 MHz for all MNOs were renewed but are subject to be evaluated in 2021 and 2020 for their coverage obligation attainment. In their new spectrum licenses, each MNO is obliged to deploy LTE sites in a certain number of villages/subdistricts by 2021 and 2021. The targeted villages', whose name are explicitly mentioned in their license, are defined by the government by considering the unserved and underserved villages in Indonesia. The punitive mechanism, according to Permenkominfo Number 5 of 2019 can include the refusal of the spectrum license extension. However, these new licenses do not yet include spectrum 2100 MHz, 2300 MHz and 450MHz, and the license for Telkomsel and Smartfren can only be revoked in 2030. Without any punitive mechanism, it means these MNOs have not been required to comply with their coverage obligation, which could lead to the coverage obligation noncompliance.

The coverage obligation for MNOs is also stated in their operational and spectrum licenses. Each MNO has a valid operational license at a time. As mentioned in Article 67 GR Number 52 of 2000, the operational license is only valid for 5 years, and so is the coverage obligation. The coverage obligation normally will be renewed every five years. The coverage obligation mentioned in the spectrum license is meant to be adopted in the operational license, too. But as of March 2021, the latest version of the mobile network operational license explicitly states the coverage obligation per year in terms of:

a. Minimum number of sites (2G, 3G and/or 4G) per province deployed, still on-air and owned by MNO until a certain year;

b. Number of municipalities per province covered by MNO's network services until a certain year; and
c. The number of villages-subdistricts per province covered by MNO's network services until a certain year.

Here, the site is counted per technology. A transceiver tower that serves 2G, 3G and 4G services is counted as three sites. Table 2.5 shows the example of how coverage obligation for MNOs is stated in their licenses.

Table 2.5: Example of MNO's current coverage obligation

Site deployment obligation by the year 2020						
No	Province	Total in the Province		Coverage Obligation		Minimum Number of Sites
		Municipalities	Villages/Subdistricts	Municipalities	Villages/Subdistricts	
1	West Sumatera	19	1148	18	1000	650
2	...	...	...	...	...	...
...	...	...	...	...	...	...
Total		514	83218	405	57804	32678

However, until this date (March 2021), there is no mechanism for applying the sanction nor the form of sanction if the MNO does not fulfil the obligation. Although the first mobile network operational license was released in 2003, the punitive mechanism was just started in 2014 after the Regulation of Communication and Informatics Minister (Permenkominfo) Number 11 of 2014 regarding the Procedures of Fine Administrative Sanction Imposition on Telecommunication Operators established. This ministerial regulation was established following the GR Number 7 of 2009 regarding Non-tax Revenue, specifying the fine sanctions per nonconformity. Yet, GR Number 7 of 2009 was repealed in 2015 and replaced by other GR that does not mention any sanction for operators' nonconformities. In other words, the punitive mechanism of Permenkominfo Number 11 of 2014 and GR Number 7 of 2009 did not have the time to be applied to mobile network coverage obligation. In February 2021, another GR states the Minister of Kominfo imposes administrative sanctions, including administrative fine against MNOs that failed to fulfil their coverage obligation. Nonetheless, the the imposition procedures of administrative sanctions, including fines and the exact amount of fine was not yet specified.

Examining the coverage obligation from one MNO's operational license, which has the biggest obligation among all MNOs, the unserved villages seem to be rarely included in the obligation. The total number of villages obliged to be covered is mostly less than the number of already served villages. For example, using method E, Central Sulawesi is known to have 1940 out of 2017 villages already covered by mid-2020. Meaning, 2G, 3G or 4G service has covered at least 50% of the village's land area and/or has been presented in some of its settlement areas. However, for Central Sulawesi, the MNO is only obliged to provide coverage in 1729 villages by the end of 2020 and 1741 villages by 2023. The same goes with other provinces with unserved villages, except for West Nusa Tenggara, Bengkulu and Aceh. More comparison of other provinces can be found in Table 2.6. Since the coverage obligation does not state which villages to be covered, MNOs are free to choose where to deploy their network and still comply with their obligations. The other six MNOs all have a smaller number of villages obliged to be covered.

The numbers of coverage obligation stated in the MNOs' licenses are much smaller than the actual mobile network coverage level—even the coverage obligation in the next 3 years is smaller than the current coverage level. If they choose to establish their network in villages already covered, then the coverage obligation imposed in the existing mobile network operational license is ineffective to push the mobile coverage to the unserved areas. Fortunately, this shortcoming has been addressed by the new spectrum license released in 2020.

The existing coverage obligation policies stated in their operational licenses are not effective. It is due to several reasons:

Table 2.6: Comparing the obligated number of villages and the already covered villages

Province	#All villages	#Unserved villages	#Served villages	MNO's obligation by 2020		MNO's obligation by 2023	
				#Villages	More than Served Villages?	#Villages	More than Served Villages?
Papua	5449	3103	2346	1386	No	1413	No
West Papua	1821	751	1070	575	No	602	No
Maluku	1230	176	1054	605	No	614	No
Central Kalimantan	1571	116	1455	1336	No	1357	No
North Kalimantan	481	105	376	229	No	238	No
Central Sulawesi	2017	77	1940	1729	No	1741	No
North Maluku	1177	63	1114	814	No	838	No
West Sulawesi	648	53	595	549	No	552	No
East Kalimantan	1037	53	984	909	No	933	No
West Kalimantan	2130	51	2079	1806	No	1815	No
South Sulawesi	3045	38	3007	2951	No	2957	No
Southeast Sulawesi	2285	35	2250	2071	No	2080	No
North Sumatera	6089	24	6065	5821	No	5830	No
Aceh	6488	19	6469	6499	Yes	6499	Yes
South Kalimantan	2008	13	1995	1978	No	1978	No
Jambi	1562	7	1555	1502	No	1502	No
Lampung	2640	4	2636	2590	No	2590	No
Riau Islands	417	3	414	364	No	364	No
North Sulawesi	1836	3	1833	1714	No	1726	No
South Sumatera	3240	3	3237	3201	No	3204	No
East Nusa Tenggara	3350	2	3348	3076	No	3079	No
Riau	1851	2	1849	1745	No	1751	No
West Nusa Tenggara	1135	1	1134	1136	Yes	1137	Yes
Bengkulu	1513	1	1512	1518	Yes	1521	Yes
Bangka Belitung Islands	391	1	390	377	No	377	No
TOTAL	55411	4704	50707	46481		46698	

- The policies have not obliged MNOs to cover the unserved villages,
- The total number of villages mentioned in the coverage obligation is less than the number of already served areas (the actual mobile network coverage level),
- MNOs are allowed to choose the site location freely as long as they meet the total obligation number, and
- Lack of applicable punitive sanctions for any obligation's nonconformity.

To summarise, the existing coverage obligation policies implemented by Indonesian government can be effective in solving the coverage problem, especially after the new spectrum licenses are released. The coverage obligation stated in the newest spectrum licenses have explicitly included some of the 4704 unserved villages. Meanwhile, the license regime for the existing operational license is considered ineffective and the applicable evaluation and punitive mechanisms for any obligation's nonconformity are still lacking.

2.2.3 Local community support

Currently, Indonesia has no regulation or policy that promotes explicitly local support in deploying the rural network. According to Law of the Republic of Indonesia Number 36 of 1999 regarding Telecommunications, Article 8 and 11, only *legal entities* granted (by the minister of IMCI) with a license to provide and operate mobile network are allowed to establish mobile network cellular in Indonesia. Moreover, according to Permenkominfo Number 1 of 2010 regarding Network Telecommunication Operation, the network telecommunication operations which require specific radio spectrum allocation and/or network access code are allowed only for limited operators chosen through a selection mechanism. Hence, an individual or group cannot initiate a network deployment, and a community-led network is not yet allowed by law. Furthermore, all mobile network spectrum is protected and can only be used with permission from IMCI (GR Number 53 of 2000 regarding Radio Spectrum Usage Article 17). Unauthorised use of licensed frequency may be imposed on sanctions.

Local residents support in maintaining the network is also lacking. Normally, if the site is located inside a residential neighbourhood, MNOs can ask for help (with some fees) from the resident living next to or close to it to report to them for any issue. However, it is limited to only physical and casual observation once in a while. If the site is located on open ground, vandalism and thefts can still happen. The latest and quite big vandalism event happened on January 2021, in which unscrupulous people burned down two microwave towers in Papua. Between the end of December and January 2021, there were around 174 vandalism cases on the Palapa Ring Timur network, ranging from destructing fibre optics, burning devices to threatening project workers (CNN Indonesia, 2021). In fact, vandalisms did not only occur in Papua but also in other areas. Local people often damage the network to steal the cable pole and/or cables (Jatmiko, 2021).

2.3 Discussion

Section 2.2 revealed the influences from some factors of the mobile coverage problem found in the literature on Indonesia's mobile network coverage problem. By looking at the variables which have the **moderate to strong** correlation to the number of unserved villages in a province, the population density, electricity readiness, road accessibility and topographic type of the area potentially prescribe the mobile coverage available in an area. These factors represent the economic aspects of an area. Moreover, the correlation test result regarding the MNO's financial capacity also showed that, although not straightforward, the higher earnings an MNO has, the preferable rural network deployment for them. It means economic challenges undeniably cause the mobile coverage problem in Indonesia.

It also showed an interesting finding that there is an uncertain connection between mobile coverage availability and the poverty rates of Indonesia's area. That is because the correlation test results showed **weak** and inconsistent correlation between the three poverty rates variables and the number of unserved village. The correlation between PDRB per province & the number of unserved villages per province was shown to be positive, which means the more unserved villages were found in a province with a higher income. On the contrary, from the SCC values of the remaining pairs (the percentage of poor population per province & the number of unserved villages per province and the number of villages without kiosks per province & the number of unserved villages per province), the more unserved villages were found in a province with a higher percentage of poor population and in a province with more villages without kiosk. In other words, the first variable pair's SCC shows that the more mobile coverage problems were found in a province with a lower poverty rate, while the remaining pairs' SCC show the opposite. It can be meant that local's income level is insignificant for MNOs to consider in selecting the areas to invest in or the low-income areas were actually covered by USF (note that there are around 1800 sites established by the government using USF). Nevertheless, if the latter is the case, logically, this behaviour should also appear on the other factors. Therefore, it is concluded that there is no correlation between the number of unserved villages in a province and the province's poverty rates.

The causal relation diagram in Figure 2.2 is then modified accordingly into Figure 2.3. The factors and relations between factors are confirmed based on the result of Subsection 2.2. On top of that, it also has been validated by a person with the relevant knowledge of MNOs' perspective as he is leading an MNO's network operation nationally.

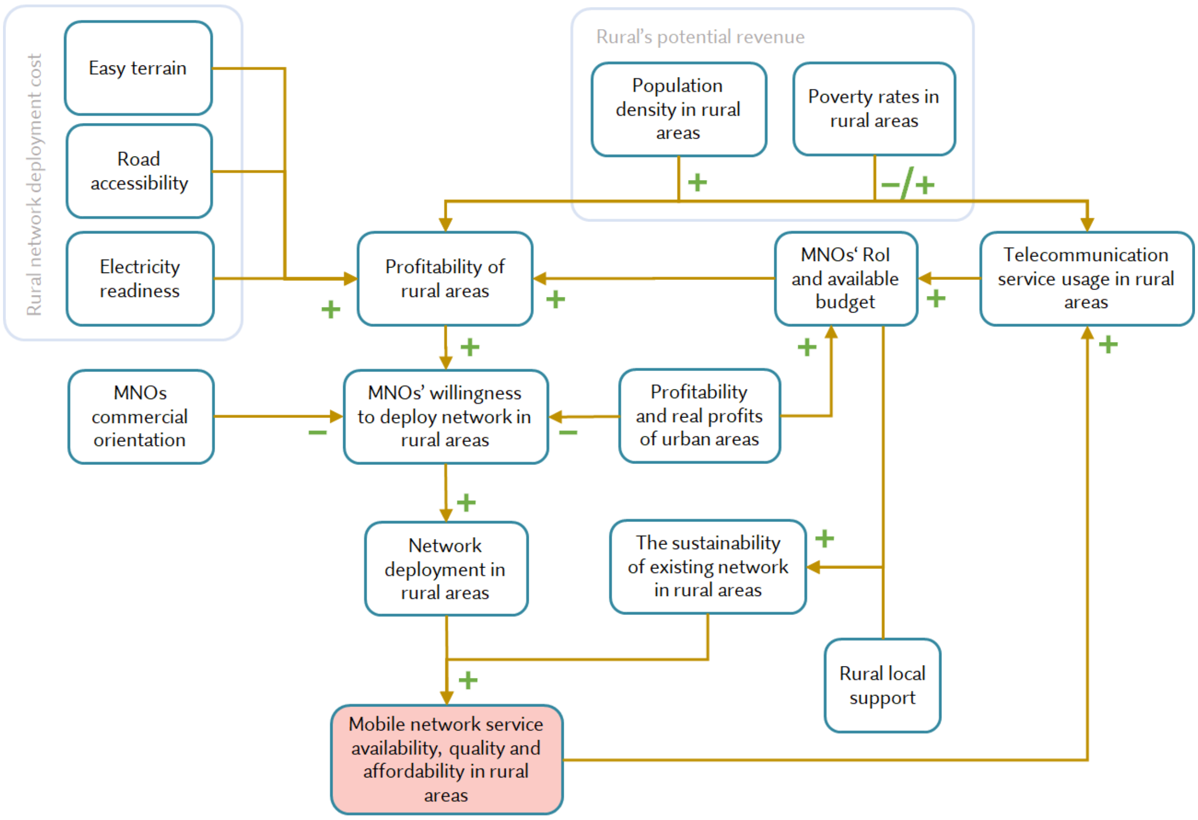

Figure 2.3: Cause of the mobile coverage problem in Indonesia

Despite the difficulty of quantitatively correlating rural local support and mobile network availability, quality, and affordability in rural areas, the current regulations and news in Indonesia show that both incentives and permission from the government for community-led initiatives and local support on maintaining telecommunication network infrastructures are still lacking. This condition can be the reason why vandalism occurs a lot, especially in Indonesian rural areas, which lead to the unsustainability of the established networks.

The number of unserved villages is mostly higher in areas with low population density, lack of electricity service, difficult access by land and challenging terrains. Moreover, in the areas where vandalism and thefts are frequently performed by local people, showing a lack of local support, mobile network infrastructures are less likely to sustain. Therefore, the conditions of the area, i.e., its population density, electricity readiness, income level, road accessibility, topography and local support majorly cause the problem in the area.

Meanwhile, although the newest spectrum licenses released in late 2020 have been formulated with specific unserved villages to cover, the existing coverage obligation policies applied to MNOs are not yet supplemented with evaluation and punitive mechanisms. Thus, it can be concluded that there is still room for compliance policies improvements in Indonesia.

It is important to note that the profitability of urban areas and poverty rates are not further considered the key factors influencing mobile coverage in rural areas. That is because they have both negative and positive impact on the rural areas' mobile network development according to the literature. Especially for the poverty rates, it is also according to the statistical data. Therefore, any measure on these factors would be ineffective to solve the problem in Indonesia.

Furthermore, the MNOs' financial capacity is also shown to be influential in promoting rural network deployment and maintenance by the respective MNOs. By comparing the portion of MNO's rural sites and their EBIT in the previous year, we identified that the MNO with a higher EBIT tends to possess a higher portion of rural sites. It means the higher income they have allows them to maintain their existing network in rural areas and/or makes them more willing to expand the network to rural areas.

2.4 Conclusion

This chapter aims to answer the question *"Why do mobile coverage problems occur in Indonesian rural areas?"*. Literature study on scientific articles discussing the problem in various countries, desk study on the existing regulations and recent news in Indonesia and data analytic on Indonesian mobile network coverage, site data, MNOs financial reports and statistical data were done for answering the question.

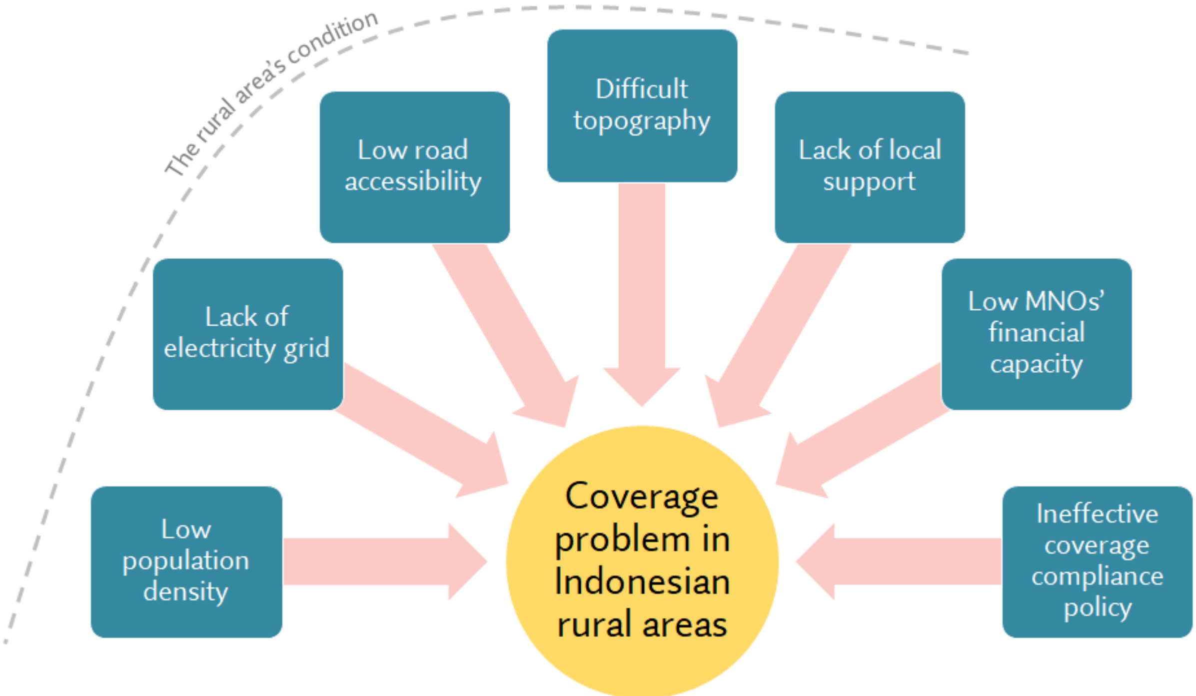

Figure 2.4: Key factors of the mobile coverage problem in Indonesia

Based on the data and method we used, we concluded that population density, electricity coverage, road accessibility, topography and MNOs financial capacity are some of the potential causes of the problem in Indonesia. The population density, electricity coverage, road accessibility, topography and income level represent the area's conditions. The data also showed that at the provincial level, the poverty rate has little to no influence on the province's mobile coverage availability. We used Spearman Correlation Coefficient and linear regression analysis to analyse the data, and we did not go into detail statistical analysis since it is not the core of our study.

Moreover, we also found that there is inadequate policy establishment pertaining to mobile coverage enhancement in Indonesia. The existing coverage obligation policies in the operational licenses are considered sub-optimal in improving mobile network coverage to the unserved areas as they do not clearly oblige MNOs to cover the unserved villages, the number of villages in the obligation is less than the number of already served villages, the MNOs are allowed to choose the site location freely and no punitive sanctions for any nonconformity. The government introduced a coverage obligation in the new spectrum license in 2020, which obliges MNOs to cover specific unserved villages. However, the result of this new policy is yet to be evaluated.

The coverage problems in Indonesian rural areas may also be because of the lack of local support in maintaining the existing network. The lack of local support is shown by the high occurrence of vandalism and theft on network infrastructure, especially in rural areas. Figure 2.4 summarises the key factors causing the mobile coverage problems in Indonesian rural areas.

Therefore, in order to improve the mobile coverage in Indonesian rural areas effectively, the solution options should, at least, address one of the causes mentioned earlier. The solution options identification will be conducted in Chapter 3 by first exploring suggested solutions exhaustively in the literature.

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Chapter 3

Available Solutions

Mobile telecommunication is not a new field of study. A plethora of studies have been conducted worldwide in discovering ways to promote better availability, quality and affordability of mobile network services in many countries. This chapter inventorises the solutions to deal with the mobile coverage problem in rural areas from the existing literature.

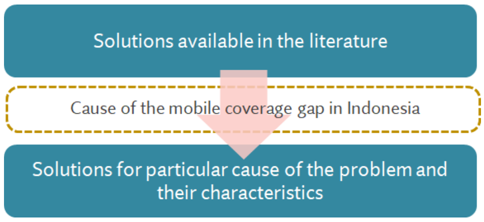

Figure 3.1: Research flow of Chapter 3

This chapter will answer the sub-research question 2: *"What are the possible solutions to solve the mobile coverage problem in rural areas and their characteristics?"*. By characteristic, it refers to the key factor(s) causing the mobile coverage problem in Indonesia the solution is addressing and its classification, requirements and challenges. Addressing the findings in Section 2.4 of Chapter 2, it will enlist the possible solutions in the literature that aims to improve mobile network coverage in rural areas or to reduce the digital divide. First, each of all solutions will be shortly explained in each subsection of section 3.1. A more elaborate information of each solution can be found in Appendix B. Next, in Section 3.2, an assessment of the listed solutions concerning the findings of the cause of the coverage gap problem in Indonesia will be presented, and a table that summarises those solutions will be provided. Figure 3.1 illustrates the flow of this chapter.

3.1 Descriptions of the available solutions

An extensive literature study is conducted for this stage. Scopus is used as the primary database for literature searching and supplemented by Researchgate. Several search terms are used to gather relevant articles as described in Table 3.1.

Twenty-five relevant articles were found from a systematic search in the Scopus database and an arbitrary search on Researchgate. The first search term resulted in fourteen relevant articles contributing to the candidate solutions for the coverage problem in rural areas. The remaining articles were found to not addressing the mobile coverage problem nor suggesting solutions for the problem, but reviewing some mobile applications for rural populations (such as malnutrition app and app for boosting law-making participation) or analysing the impact of the mobile coverage to the rural populations, or about new ICT technologies (irrelevant to mo-

Table 3.1: Literature search on Scopus

Search terms		Resulted documents	Relevant documents
1	TITLE-ABS-KEY (mobile AND coverage AND rural AND "telecom*" AND ("solution*" OR "solve*")) AND (LIMIT-TO (LANGUAGE, "English")) AND (EXCLUDE (SUBJAREA, "MEDI") OR EXCLUDE (SUBJAREA, "PHYS") OR EXCLUDE (SUBJAREA, "BIOC") OR EXCLUDE (SUBJAREA, "EART") OR EXCLUDE (SUBJAREA, "CHEM") OR EXCLUDE (SUBJAREA, "IMMU") OR EXCLUDE (SUBJAREA, "VETE"))	57	14
2	TITLE-ABS-KEY (mobile AND rural AND "telecom*" AND ("govern*" OR "polic*" OR "regulat*")) AND (LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "ECON") OR LIMIT-TO (SUBJAREA, "ARTS") OR LIMIT-TO (SUBJAREA, "PSYC") OR LIMIT-TO (SUBJAREA, "MULT"))	88	8

bile coverage penetration in rural areas, such as anti-spoofing technology and geo-locating techniques) that make use of the cellular network features. All the fourteen articles suggested technical solutions for the problem. Therefore, some more attempts with other key terms were made to find non-technical solutions. The second search term resulted in eight relevant articles, one of which is technical. By searching on Researchgate, three relevant articles were found. More complete review results can be found in Appendix A.

The identified solutions are classified into three types: technology, organisation and regulatory. Each type is defined as follows:

- Technology: Solutions that discuss network architecture and the use of specific equipment for addressing the key factors
- Organisation: Solutions that provide an introduction of new actors or involvement of certain actors in addressing the problem
- Regulatory: Solutions that mainly about governmental interventions in the form of new/modification of regulations and/or policies

The technology solutions have subtype: access, backhaul, power and support. Access technology refers to the technology used to connect the network to the user, such as femtocell, OpenBTS and UAV. While backhaul technology refers to the technology for connecting the site in rural areas to the core network, such as fibre optic, wireless terrestrial link and satellite. Power technology, including the solar power and electricity grid, specifies the type of power source. Lastly, support technology refers to any technology for the supporting system of the rural network, such as battery and maintenance system.

The twenty-five relevant articles gave in total 21 different solutions. Eight technology solutions, four organisation solutions and nine regulatory solutions. Each solution will be shortly described in the following subsections. Further explanation regarding each solution can be found in Appendix B which consists of the problem it addresses, its general definition, its potential benefits and its potential challenges.

In this section, there are Subsection 3.1.1, Subsection 3.1.2 and Subsection 3.1.2 that will present technology solutions, organisation solutions and regulatory solutions, respectively. In each subsection, a table that summarises all solutions will be provided first, which then is followed by a brief description of each solution.

3.1.1 Technology solutions

Table 3.2: Summary of Technology solutions for mobile coverage problem in rural areas

No.	Solution name	Key factor addressed and the measure to address it	Solution type	Characteristics	Source
1	TUCAN3G	Low density - femtocell and unlicensed terrestrial backhaul Electricity - solar power Topography - high towers Local support - employing local community to maintain and repair the network	Technology (access, backhaul and power)	Requirements (Local) • Between 400 and 1000 inhabitants in the targeted community. Public fund support is needed when it is lower and femtocell would not be suitable when it is higher. • Suitable for rural regions that consist of several smaller settlement areas. • Local support to help maintain the network. Requirements (National) • Regulations that allow the use of Wi-Fi bands for backhaul transmission. In countries where it is forbidden, WiMAX is the only low-cost alternative. Challenges • A complex traffic and QoS management.	(Martínez-Fernández et al., 2016; Prieto Egido et al., 2020; Rey-Moreno et al., 2011; Simó-Reigadas et al., 2019)
2	Cached GEO-satellite backhaul	Low density - caching the traffic Road accessibility - the use of satellite backhaul Topography - the use of satellite backhaul	Technology (access, backhaul and power)	Requirements (Local) • Users' WTP around 19 euros per month. • If macro-cell is used, 1050 users for one tower (14 person per sq km). • Electricity grid. • If macro-cell is used, the area should not be mountainous or in a rainforest.	(Borst et al., 2010; Chiha et al., 2020; Philip et al., 2017; Wang et al., 2017; Wright, 1995)
3	Unmanned Aerial Vehicle (UAV)	Low density - UAV that can target on specific settlement areas, is easy to maintain and flexible results in a cost-effective investment Electricity - solar power Road accessibility - simple network components Topography - the use of aerial transceivers which do not need towers	Technology (access, backhaul and power)	Challenges • Ensuring the correct number of SPs, batteries, ground sites and UAVs, the optimum distance between the UAV and the ground site, UAV's trajectory, recharging schedule and interference management are essential to make the network economically feasible and well-perform.	(Chiaraviglio et al., 2019; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Ilcev and Singh, 2004; Zhang et al., 2019)

Table 3.2: Summary of Technology solutions for mobile coverage problem in rural areas

No.	Solution name	Key factor addressed and the measure to address it	Solution type	Characteristics	Source
4	VillageCell	Low density - openBTS and free of charge voice call Road accessibility - simple network components Topography - localized and small scale network	Technology (access and backhaul)	Requirements (Local) • Technically skilful personnels in the local community. • Villagers prefer local calls to long-distance ones and prefer voice calls instead of internet services. Requirements (National) • Government permission to use GSM bands for its radio access and number blocks when VillageCell is run by non-MNO. Challenges • The network arrangement can be tricky to balance the routes due to the limited in capacity of OpenBTS and Asterisk. • If the electricity grid is absent in the area, further investigation is needed to identify the suitable power source.	(Anand et al., 2012)
5	Store-and-Forward network	Low density - providing one central point for all population to get service access without using MNOs investment as it utilise the existing internet access point and public transportation infrastructure	Technology (access)	Requirements (Local) • Public transportation or other routine transportation activities that can carry an MDTN server.	(Palazzi et al., 2011)
6	Solar power source	Electricity - solving the issue of power grid absence in rural areas Low density - by reducing the MNOs' OPEX per site in rural areas	Technology (power)	-	(Kabir et al., 2018; Martínez-Fernández et al., 2016; Rey-Moreno et al., 2011; Thakur, Mishra, et al., 2017; Thakur, Narayan Swain, et al., 2017)
7	Battery performance prediction model	Electricity - improving the performance of the network by reducing the network faulty due to battery issues Low density - by reducing the MNOs' maintenance cost per site, by increasing the site's uptime hence increasing the site revenue	Technology (support)	Challenges • This solution is not off-the-shelf, which means that it is not available to purchase on the market.	(Fan et al., 2016)
8	Ambient Network	Low density - traffic routing optimisation can reduce the MNOs' maintenance cost and backhaul rent fee per site	Technology (support)	Challenges • The algorithm is site-specific and not off-the-shelf, which means that it is not available to purchase on the market.	(Grampín et al., 2007)

TUCAN3G TUCAN3G proposed a solution for bringing connectivity to isolated rural areas in developing regions using wireless multi-hop unlicensed bands (WiFi for Long Distances or WiLD) and/or WiMAX for backhaul and femtocells for the access network (Martínez-Fernández et al., 2016). TUCAN3G has been deployed in Peru covering an end-to-end distance of around 450 Km through sixteen hops since March 2007 (Rey-Moreno et al., 2011). The femtocells, shared backhaul and unlicensed bands allows the network to be commercially sustainable.

Cached GEO-satellite backhaul network Satellite connectivity has been suggested in many studies (Chiha et al., 2020; Philip et al., 2017; Wright, 1995) to solve the connectivity problem in remote and rural areas as it can cover almost any location under its global coverage area, flexible and does not involve large infrastructure deployment (such as towers and big antennas). However, the operational cost for using an end-to-end satellite solution might, in many cases, not be cost-effective (Chiha et al., 2020) since the cost per Mbps for satellite backhaul is very high. Chiha et al. (2020) proposed a hybrid satellite-wireless solution to deliver broadband to rural areas based on caching strategy. To reduce the amount of traffic carried out via satellite link and decrease the OPEX, it proposed to cache a percentage of the popular contents on edge. This way, the end-users do not have to download it from a central location in the network but the edge network.

Unmanned Aerial Vehicle Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) presented an optimised and cost-effective mobile network architecture based on Unmanned Aerial Vehicle (UAV) powered by solar panels to provide 5G coverage in low income and rural areas. UAV is a remotely controllable vehicle that flies at low altitudes, moves over a territory and carries radio cells. UAV-cells can provide flexible and targeted coverage by only serving zones where the users are located. According to Chiaraviglio et al. (2019), the use of UAV as the access network for 5G can reduce the costs compared to using fixed base stations. The network deployment is also less complicated as fewer physical infrastructures involved in the network.

VillageCell VillageCell is specifically tailored to the rural villages spatial layout and rural population's lifestyle that emphasise the need for real-time voice communication (Anand et al., 2012). Many rural networks cannot be sufficiently served by MNO's voice call services even within a single village due to its complexity, high cost and uncertain profitability (Anand et al., 2012). Through their study in two rural villages in South Africa, Anand et al. (2012) found that rural people prefer local voice and intra-village communications to global connectivity. GSM (2G) mobile network was employed in conjunction with local area network as a backbone, using Software Defined Radio (SDR) as the transceiver controlled by OpenBTS, Wi-Fi as the main backhaul and Private Branch Exchange (PBX) as the traffic controller. The VillageCell also interconnects to the global telephone system via satellite gateway.

Solar power source Kabir et al. (2018), Martínez-Fernández et al. (2016), and Thakur, Mishra, et al. (2017) studied the possibility to use a solar PV system to be the primary source of electricity for network infrastructures in rural areas. Based on Kabir2018's case study, they concluded that the electricity generated by their solar power system is reliable and sufficient to meet the site's energy demand at a low cost. Martínez-Fernández et al. (2016) also found that solar power was able to be the only power source for the mobile network, including access and backhaul network.

Battery performance prediction model Battery is a vital component of a site, and MNOs will always try to ensure its performance. Seeing the significance of batteries for rural networks, Fan et al. (2016) suggested a model to predict the battery voltage and lifetime accurately. It is based on Multi-Instance Multi-labels Learning (MIML) algorithm. The prediction enables MNOs to timely schedule battery maintenance and replacement to minimise the service interruptions caused by power outages. The model can improve the mobile network service availability up to 18.09%.

Store-and-Forward network Mobile Delay/Disruption Tolerant Network (MDTN) is an opportunistic networking or a store-and-forward communication model, proposed by Palazzi et al. (2011), that connect mobile users in an ad-hoc fashion to internet services by leveraging on public vehicles' mobility to reach an internet access point (AP). Public buses with onboard Wi-Fi AP are used as the carrier nodes. The buses have routes going to and from rural areas and city centre (or the locations with Wi-Fi services available). Wi-Fi connection was chosen instead of UMTS or other licensed technologies to minimise the users' usage cost and because an adequate level of penetration of mobile devices with Wi-Fi feature was found in the rural areas (Barela et al., 2016; Palazzi et al., 2011). This solution was proposed by considering the need for telecommunication service with the lowest cost possible that can be implemented quickly. The services it allows are sending and retrieving e-mail and uploading and downloading Internet resources (e.g. web page, multimedia document).

Ambient Network Grampín et al. (2007) proposed a solution to provide internet services to rural areas through a network that is cost-efficient and self-maintained, called Rural Ambient Network. Ambient Network is equipped with an algorithm that makes it autonomic, self-healing and capable of reacting to network events in an intelligent fashion. Without any end-user intervention, it can solve network issues that arise. Multinodes Wi-Fi and GSM network are considered suitable for this system (Grampín et al., 2007).

3.1.2 Organisation solutions

Table 3.3: Summary of Organisation solutions for mobile coverage problem in rural areas

No.	Solution name	Key factor addressed and the measure to address it	Solution type	Characteristics	Source
1	Community Cellular Network (CCN)	Local support - local ownership increases local supports on sustaining the network	Organisation	Requirements (Local) • Technically skilful and resourceful personnels in the local community and/or local governments. Requirements (National) • Permission to use MNO's unused frequencies both from the MNO and the government. • Regulations that allow CCN to interconnect to the existing networks. • Mechanism or regulation to derive support from local governments.	(Barela et al., 2016; Gieling, 2018; Heimerl et al., 2013; Philip et al., 2017; Prieto Egido et al., 2020; Rey-Moreno et al., 2011; Salemink and Strijker, 2018; Wade, 2015)
2	Small Rural Operator (SRO)	Low density - a specific operator that is responsible to cover low density areas allows a significant reduction on network installation and maintenance costs	Organisation	Requirements (National) • Public funds to support areas with too insufficient revenue potential or too difficult topography • A mechanism to accommodate private investment in rural areas that will be economically developed in the future Challenges • Initial agreements among MNOs and SROs might require a complex and time-consuming process. • Potentially lead to monopoly that can result in abuse of position and inefficient use of resource.	(Cruz and Touchard, 2018; Prieto Egido et al., 2020)
3	MVNO in rural areas	Low density - encouraging innovation for new services targeted for rural population MNO's financial capacity - increasing the revenue per rural site	Organisation	Requirements (National) • The existing MNOs' consents. Challenges • Under a particular framework, MVNOs existence can contribute to the decline of ARPU. • Getting the existing MNOs on board to allow MVNOs can be difficult as MVNOs may take over their users.	(Cricelli et al., 2011; Kiiski and Hämmäinen, 2004; Son et al., 2019)
4	Central and local authority's support	MNO's financial capacity - by reducing the MNO's overall expenditures Local support - by increasing the involvement of the local government	Organisation	Requirements (National) • Mandating the central authority to rule local authorities regarding mobile network deployment or its guideline's effect on local regulations, or mechanisms to incentivise local governments to voluntarily adopt the central authority's guidelines. • The governments need to conduct a preliminary assessment on the actual hurdles that MNOs face when seeking permits.	(Cruz and Touchard, 2018)

Community Cellular Network A community cellular network (CCN), also called as participatory society, community network paradigm (Prieto Egido et al., 2020), community-led model (Philip et al., 2017), regional/local governments and citizens' initiatives (Salemink and Strijker, 2018), local cellular network, bottom-up cellular network or inverse infrastructure (Heimerl et al., 2013), is a solution in which users provide themselves with telecommunications infrastructures for their internal communication and access to the Internet and to MNOs through common gateways (Prieto Egido et al., 2020) to provide sustainable mobile network service in economically unattractive areas. This solution allows local owners and operators to have the freedom in deciding the network's properties, such as its design, operation, offered service, pricing and billing policies (Barela et al., 2016). There are two kinds of schemes to implement this solution: 1) by fully relying on the local community, as used by Heimerl et al. (2013), Barela et al. (2016) and Rey-Moreno et al. (2011); 2) by local government's support and usually initiated by the local governments as implemented in the Netherlands (Salemink and Strijker, 2018). Researchers have found that this solution can actually have lower costs by leveraging the local existing infrastructure (Galperin and Bar, 2007). It also promotes the local ownership which incentivises local communities to support and maintain the network (Heimerl et al., 2013).

Small Rural Operator Small Rural Operator (SRO), also called Single Wholesale Network (SWN) (Cruz and Touchard, 2018), aims to fulfil the demand for mobile network service in rural areas, where MNOs are usually unwilling to invest. Prieto Egido et al. (2020) proposed SRO to be an operator that is responsible for deploying and maintaining mobile network infrastructure (access and backhaul network) in rural areas, while the core network is owned and operationalised by MNOs (Prieto Egido et al., 2020). The rural users pay the service costs to MNOs and MNOs pay a percentage of the revenues generated by the SRO's network to SRO. This solution may allow better profitability for the operator in rural areas. By becoming the only operator in the area, SRO can fully take benefit from its market area (Prieto Egido et al., 2020). Since SROs specialise in deploying networks in rural areas, they will address the 'common' problem more efficiently. The network infrastructure it established can be offered to and used by more than one MNOs by employing RAN virtualisation (Prieto Egido et al., 2020). The use of RAN virtualisation makes SRO's networks more flexible and scalable, thus increasing profitability. Moreover, the SRO does not need to make expenses on advertising campaigns as it will be MNOs who has a relation with end-users, which contributes to reduced OPEX (Prieto Egido et al., 2020).

Mobile Virtual Network Operator in rural areas Unlike SRO, MVNOs (Mobile Virtual Network Operators) solution focused on increasing the existing network's usage, increasing the MNOs' RoI and the existing network's sustainability. Mobile network in rural and remote areas are known to be difficult to maintain (Surana et al., 2008), leading to high operational cost, while the revenue per site is much lower than urban sites due to the low population density. In typical situations, when the revenue is lower than the operational costs and no financial support from the government, the disadvantageous sites would be dismantled by MNOs. MVNOs can increase the ARPU by providing access service, which MNOs overlooked. In addition, they also can provide numerous services that may be too expensive for large MNOs to provide (Cricelli et al., 2011).

Central and local authority's support Local-level rules and regulations significantly affect the site deployment costs for MNOs. Although mobile networks are designed at the national level, they are built locally, obliging MNOs to comply with local (per region, province, municipality, district, and so on) rules when deploying, maintaining and upgrading their infrastructure (Cruz and Touchard, 2018). Cruz and Touchard (2018) argued that one of the critical inhibitors in coverage expansion to rural areas is the complexity of regulations and administrative processes to deploy infrastructure that leads to high administrative costs for site deployment/upgrade and even absence of coverage in rural areas. So, they recommend that relevant authorities, both central and local to be synergised and support the mobile network deployment in rural areas in the form of supportive regulations, policies, administration processes and permits. They identified that implementing this solution promises a more cost-effective mobile network investment that would benefit the mobile network industry in the long run.

3.1.3 Regulatory solutions

Table 3.4: Summary of Regulatory solutions for mobile coverage problem in rural areas

No.	Solution name	Key factor addressed and the measure to address it	Solution type	Characteristics	Source
1	Coverage obligated spectrum license	Low density - by applying it on coverage bands (sub-1GHz bands), reducing the spectrum price based on the compliance cost and preventing infrastructure duplication Compliance policy - by applying sanctions for non-conformities	Regulatory	Requirements (National) • The right spectrum price. Challenges • No exact rule to define the right spectrum price.	(Cruz and Touchard, 2018; Sridhar and Prasad, 2011)
2	Spectrum management	MNO's financial capacity - by reducing the MNOs overall expenditures	Regulatory	Requirements (National) • Competition assessment and stakeholder consultation before neutralising the spectrum's technology to ensure a positive long-term effect on the market. Challenges • No formula that defines the correct spectrum price and license model. • MNOs may not want their 'spectrum repository' to be known by their competitors. • Changing the licensing regime would be uneasy.	(Cruz and Touchard, 2018; Lun et al., 2019; McDowell and Lee, 2003; Son et al., 2019; Sridhar and Prasad, 2011; Touchard, 2017; Valletti, 2001)
3	A taxation policy that foster investments in rural areas	MNO's financial capacity - by reducing the MNOs overall expenditures	Regulatory	-	(Cruz and Touchard, 2018; Touchard, 2017)
4	Infrastructure sharing regulatory	MNO's financial capacity - when promoted on rural deployment, it can increase the profitability per rural site and reduce the MNOs' overall expenditures Compliance policy - policy that encourage network sharing wherever necessary	Regulatory	Challenges • Designing and implementing it is particularly complex and requires technical capacity and political will for detailed design, monitoring and enforcement. • To do RAN sharing, especially on the existing sites, considerations on the tower's load capacity, space between antennas, tilt and height of antennas in the same tower, antenna configuration and site spaces are essential to make sharing feasible while maintaining QoS.	(Cruz and Touchard, 2018; Montenegro and Araral, 2020; Touchard, 2017)
5	Universal Service Fund (USF)	Low density - lowering MNOs' deployment costs on rural areas	Regulatory	Requirements (National) • A good oversight mechanism, stakeholder involvement and transparency. • Independent and skilful USF administrators of technical, economical and legal matters. • Pre-defined USF targets considering the actual market needs. Challenges • USF might be ineffective if there is an excessive bureaucracy.	(Arakpogun et al., 2017; Cruz and Touchard, 2018)
6	Public subsidy on rural network development	Low density - lowering MNOs' deployment costs on rural areas	Regulatory	Requirements (National) • Other measure/solution as its pair.	(Cruz and Touchard, 2018; Philip et al., 2017; Wright, 1995)
7	Relaxing the QoS standard for rural networks	Low density - by reducing the MNOs OPEX to maintain MTTR and service availability in rural areas Compliance policy - strict QoS may add reluctance from MNOs to deploy network according to their obligation as they are afraid to be penalized for the lower QoS	Regulatory	Requirements (National) • Clear definition about which areas are eligible for relaxation.	(Touchard, 2017)

Table 3.4: Summary of Regulatory solutions for mobile coverage problem in rural areas

No.	Solution name	Key factor addressed and the measure to address it	Solution type	Characteristics	Source
8	Information management system platform about network coverage	Compliance - the information can be used by the regulator to discuss the coverage obligation areas with MNOs and may make the obligation more attainable	Regulatory	-	(Touchard, 2017)
9	Direct public investment on critical enabling national infrastructure	Low density - via public investment on fiber optic backbone network, electricity grid and road access will potentially reduce the network deployment costs for MNOs Electricity - via public investment on power grid Road accessibility - via public investment on road access	Regulatory	Requirements (National) • A significant capital investment • coordination between institutions.	(Touchard, 2017)

Coverage-obligated spectrum license Closing the coverage gap cannot be achieved by relying on the industry alone but should be supported by government's intervention. Solely relying on the market will result in the exclusion of the unprofitable areas from the coverage and service. A coverage obligated spectrum license is one of the government's intervention. It is a license given to an MNO to use a specific spectrum, in which to be eligible for using the spectrum, the MNO should agree to fulfil the coverage obligation accompanying and stated in the license. Cruz and Touchard (2018) suggested the following considerations when implementing coverage obligation as a measure to promote coverage to rural areas:

- It should be included in the spectrum license conditions and only be applied to the low-frequency spectrum (< 1GHz), so MNOs acknowledge the obligation when bidding the spectrum
- Realistic and compliable obligation in terms of targets and timelines
- The license price or related tax should take into account the compliance cost
- The spectrum blocks with coverage obligation should be limited to prevent infrastructure duplication in the low revenue areas
- Government should allow infrastructure sharing to facilitate compliance.

Spectrum management Touchard (2017) argued that ensuring a sufficient quantity of spectrum available for mobile services at a reasonable price and under conditions that encourage long-term investment in mobile networks is essential for achieving the optimum level of commercially sustainable coverage. Spectrum is one of the cost items that majorly contributes to the MNOs overall expenditure. Hence, it affects MNOs financial capacity to develop network and mobile services affordability, including in rural areas. Cutting down the unnecessary expense as much as possible, leasing spectrum efficiently and ensuring MNOs can have sufficient spectrum whenever they need, in the end, will promote better and faster network penetration to rural areas (Cruz and Touchard, 2018). This solution focuses on the management of the spectrum used in the mobile network. It includes the recommendation in spectrum's licensing model, pricing and operation. To summarise, this solution proposed for the government to:

- make as much as possible spectrum available for mobile services, particularly the coverage bands
- set a low but effective spectrum price, particularly the coverage bands
- provide a clear spectrum roadmap for MNOs or publicly
- allow spectrum trading and spectrum sharing
- release spectrum in technology-neutral
- release spectrum through auction or beauty contest with long duration and assurance of renewal

A taxation policy that foster investments in rural areas The level of taxation directly affects mobile operators' financial ability to invest in infrastructure and coverage, while tax complexity and uncertainty may also affect future investment incentives and ease of doing business in the region (Touchard, 2017). Touchard (2017) argued that although taxation on the mobile sector supports the government in providing public services, it may harm socio-economic development in the long run due to its distortive impact on investment and consumption behaviour. Cruz and Touchard (2018) recommended the government to implement a tax policy that maximises the capacity and incentives of MNOs to invest in network infrastructure. The policy should non-discriminatorily eliminate sectoral taxes that distort the mobile communication market, impose taxes on profits instead of revenues to encourage reinvestment, include incentives such as import duties exemptions, and increase investor confidence by reducing complexity and uncertainty tax levels. GSMA's study (Touchard, 2017) on the effect of mobile sector-specific tax reform in the Democratic Republic of the Congo showed that the abolition of the excise tax on mobile services could potentially increase the mobile service market penetration by 5% in 2020 compared to the reference case without tax reform. Furthermore, those additional connections could potentially create around 3200 jobs and yield almost US$ 970 million or nearly 2% of GDP over the same time horizon (Touchard, 2017).

Infrastructure sharing Infrastructure sharing may reduce the network costs can be considered the potential solution for enhancing coverage to rural areas. Cruz and Touchard (2018) recommended both active and passive infrastructure sharing to be allowed under primary legislation and encouraged by regulators voluntarily. The implementation of mobile network sharing started in 2012 in Brazil to promote 4G services nationwide is one success story of an excellent mobile network sharing strategy. In 2018, 3039 Brazilian cities covered by the 4G service, which is three times the number of cities required by the coverage obligation (Touchard, 2017). Touchard (2017) suggested that the regulation regarding infrastructure sharing be also applied to third-party infrastructure owners, such as ducts, poles and towers. Often, these infrastructures are owned by public utility companies (i.e. electricity, gas or water companies) or transportation entities (roads, railways).

Universal Service Fund Universal Service Funds (USFs) are the collected levies from MNOs which are used to finance connectivity initiatives determined by the government (Cruz and Touchard, 2018) related to the ICT universal service for all its citizens or to encourage the network deployment in economically unattractive areas (Arakpogun et al., 2017). It is highly possible that after optimising the market commercially, the coverage gaps persist in some locations, thus needs public finance support. Usually, USF contributions are calculated as a percentage of MNOs' revenues and administered by the USF agency. According to Cruz and Touchard (2018) and Arakpogun et al. (2017), USF implementation should be:

- administered by an autonomous authority run by skilful personnel that is free from political interference;
- guided by a clear-defined legal and regulatory framework that is flexible, technology and service neutral;
- equipped with clearly specified and measurable objectives (in consultation with stakeholders), including coverage and service delivery targets;
- transparent in reporting the financial flows;
- able to work with other funding sources (e.g. Development Banks);
- efficient and innovative, with a focus on the sustainability of the proposed solutions;
- negotiable for MNOs to choose between paying the funds or investing directly in the USF-targeted areas;
- spent effectively and timely; otherwise, governments should phase out or pause collecting levies.

Public subsidy on rural network development Subsidies are financial support from the government in direct monetary grants or direct incentives, such as tax rebates. In addressing the coverage gap, subsidies rely on the operator's capacity to deploy infrastructure. Cruz and Touchard (2018) argued, to have an impact, subsidies must align the interests of MNOs and the government and must be allocated in a targeted, transparent and efficient way. The subsidy targets should be attractive for MNOs while also encourage coverage extensions to the areas of interest. The funds should also be allocated via a transparent public tendering process. They should also be administered and monitored as cost-efficient as possible.

Relaxing the QoS standard for rural networks QoS requirements such as network availability and dropped call rates are much harder to deliver in rural and remote areas (Touchard, 2017). If regulators oblige MNOs to comply with the same QoS requirements regardless of the network locations and set fines for the non-conformity, MNOs will be reluctant to develop a network in rural and remote areas. Touchard (2017) argued, since MNOs investment in rural areas help the governments delivering their digital objectives, governments should minimise the cause of MNOs' unwillingness to expand their network to those areas. It would include relaxing the QoS requirements for the network located in rural areas.

Information management system platform about network coverage Touchard (2017) suggested the authorised government establish an information system management platform consisted of information about coverage and the relevant infrastructure locations for the government to prevent network redundancies and for the MNOs to set a network plan effectively.

Direct public investment on the critical enabling public infrastructure Touchard (2017) suggested that, in addition to policy measures aiming for making rural areas more commercially viable, national governments should also consider directly invest in the essential national infrastructure that is supportive for mobile network development, such as electricity grid, high capacity fibre backbone network and road access. Improving these infrastructure's quality will indirectly promote network expansion because the lack of these infrastructure availabilities hinders the rural area's development according to the literature.

3.2 Discussion

Chapter 2 found that the key factors of the mobile coverage problem in Indonesian rural areas are the areas' *population density*, the *electricity readiness*, the *topography* and the *road accessibility*, the *MNOs financial capacity* in the areas, the *local support* and the implementation of *coverage compliance policy* in Indonesia. Based on the solution's description, each solution addresses one or more key factor(s) and has specific means used for addressing the problem. Column 'Key factor addressed and the measure to address it' in Table 3.2, 3.3 and 3.4 describes what cause of the problem the solution addresses. Table 3.5 summarises which solutions address what factor. This table can be used as a guideline to select the possible solutions based on the area's situation in the next Chapter.

Table 3.5 also shows that some key factors can only be addressed by certain type of solutions. For example, the key factor topography can only be addressed by technological solutions. It means, if the coverage problem in an area is only due to its difficult topographic position, such as in the rainforest or between highlands, leveraging regulatory or organisation solutions without technological solution will not solve the problem. Meanwhile, technological solutions will not be useful to solve the problem if the cause is the lack of financial capacity of MNOs. To illustrate this case, in the situation where MNOs are still struggling to reach the break even point of their investment and has insufficient budget to invest in rural areas, proposing technological solution without supplemented by organisation or regulatory solutions will not be effective. There is no coverage obligation as one of the regulatory solutions for the key factor *MNO's financial capacity* because forcing MNOs to invest in rural area with coverage obligation has never been recommended in the literature if MNOs financially incapable to do so. Forcing coverage obligation to rural areas without considering MNO's financial situation may result in a higher service cost for the users in those rural areas, affecting primarily the affordability of mobile services in the areas (Cruz and Touchard, 2018).

Furthermore, there are challenges and requirements identified in most of the solutions. The requirements are categorised into local and national. The *local requirements* refer to the requirements that need to be met by the rural areas in order to be able to implement the solution and get the result effectively, while the *national requirements* refer to the requirements to be fulfilled by the country or the national governments in the form of particular regulation establishment, governmental process and coordination between sectors or organisation. If *requirements* are things to be fulfilled *prior to* implementing the solution, *challenges* point out potential obstacles or difficulties during the implementation of the solution. They are mapped in Table 3.2, 3.3 and 3.4.

3.3 Conclusion

This chapter answers the sub-research question 2: *"What are the possible solutions to solve the mobile coverage problem in rural areas and their characteristics?"*. Characteristic refers to the key factor(s) causing the mobile coverage problem in Indonesia the solution is addressing and its classification and challenges. By conducting an exhaustive literature study on 31 relevant articles, 21 different possible solutions are identified. These solutions are classified into three types: technology, organisation and regulatory. Technological solutions address the problem using specific network architectures, technology and equipment. Organisational solutions address the problem by introducing a new actor or involving certain actors. Meanwhile, Regulatory solutions are mainly about governmental interventions in the form of new/modification of regulations and/or policies.

Each solution addresses one or more key factor(s) causing the mobile coverage problem in Indonesian rural areas. Table 3.5 maps which solutions address what causes. This table can be used as a guideline to select the possible solutions based on the cause of the problem.

Table 3.5: Solutions for each key factor

Key factor	Solution type	Solution name
Low population density	Organisation	MVNO in rural areas
		SRO
	Regulatory	Coverage obligated spectrum license
		Direct public investment on critical enabling national infrastructure
		Public subsidy on rural network development
		Relaxing the QoS standard for rural networks
		USF
	Technology	Ambient Network
		Battery performance prediction model
		Cached GEO-satellite backhaul
		Store-and-Forward network
		TUCAN3G
		UAV
		VillageCell
Lack of electricity grid	Regulatory	Direct public investment on critical enabling national infrastructure
	Technology	Battery performance prediction model
		Solar power source
		TUCAN3G
		UAV
Low road accessibility	Regulatory	Direct public investment on critical enabling national infrastructure
	Technology	Cached GEO-satellite backhaul
		UAV
		VillageCell
Difficult topography	Technology	Cached GEO-satellite backhaul
		TUCAN3G
		UAV
		VillageCell
Low MNOs' financial capacity	Organisation	MVNO in rural areas
		Central and local authority's support
	Regulatory	A taxation policy that foster investments in rural areas
		Infrastructure sharing regulatory
		Spectrum management
Lack of local support	Organisation	CCN
		Central and local authority's support
	Technology	TUCAN3G
Ineffective coverage compliance policy	Regulatory	Coverage obligated spectrum license
		Information management system platform about network coverage
		Infrastructure sharing regulatory
		Relaxing the QoS standard for rural networks

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Chapter 4

Selected Options

In the previous chapter, various solutions suggested in the literature to solve the mobile coverage problem in rural areas have been found. These solutions are either derived from studies on certain countries (case studies) or based on a model. Thus, the condition in which the solution was tested may not be the same as Indonesia's situation and may not apply to Indonesia.

This chapter will answer the sub-research question 3: *"Which solutions available in the literature can apply to Indonesia?"*. First, some unserved villages in Indonesia will be selected as case studies, and their situations will be elaborated. Three villages will be selected based on some criteria, and their specific conditions that need to be focused on when selecting the possible solutions will be explained in Section 4.1. Second, by analysing the mobile network situation in Indonesia nationally, all identified solutions from Chapter 3 will be filtered to exclude the solutions that are not applicable for Indonesia. The analysis of the identified solutions is presented in Section 4.2 and summarised in Section 4.3. Third, based on the village's conditions, some possible technology solutions will be selected for each village. That is because the local situations constrain only the technology solutions. It is known when performing study for Chapter 3 that some solutions cannot stand on their own; some solutions need to be supported with other solution(s) in order to be implementable and effective. Therefore, each solution arrangements will consist of more than one solution. After that, based on the selected technology solutions, the organisation solutions are picked. Lastly, regulatory solutions are selected to ensure the technology and organisation solutions implementable and achieve optimal results. These steps are performed on each village and will be elaborated in Section 4.4. At the end of this chapter, a conclusion that will answer the sub research question 3 will be presented. Figure 4.1 illustrates the flow of this chapter.

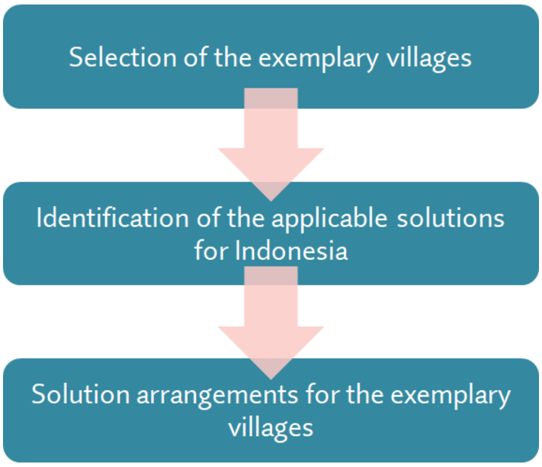

Figure 4.1: Research flow of Chapter 4

4.1 Selected villages as exemplary cases

Chapter 2 showed that the presence of mobile coverage in an area depends on the area's conditions. To be precise, the area's population density, topography, electricity readiness, road accessibility and local support affect the presence of mobile network service in that area. The area with a lower population density, lower electricity readiness, lower road accessibility, lack of local support and challenging topography tends to be unserved by any mobile network service. Furthermore, Chapter 3 showed that there are local requirements for implementing some solutions, particularly the Technological solutions. Local requirement refers to any requirement to be fulfilled by the rural areas or locations where the solution will be implemented. For example, in order to achieve its optimum benefits, the solution TUCAN3G requires the area to have between 400 and 1000 inhabitants as it is according to the femtocell's capacity, and local support to help maintain the network, and should be implemented in a rural region consisting several villages as its sharing backhaul technique affected its cost-effectivity significantly. Therefore, it becomes crucial to assess the actual condition of the unserved

Table 4.1: Number of unserved villages per province (Source: CovData (Ditdal PPI, 2021a))

Province	#Unserved villages
Papua	3103
West Papua	751
Maluku	176
Central Kalimantan	116
North Kalimantan	105
Central Sulawesi	77
North Maluku	63
East Kalimantan	53
West Sulawesi	53
West Kalimantan	51
South Sulawesi	38
Southeast Sulawesi	35
North Sumatera	24
Aceh	19
South Kalimantan	13
Jambi	7
Lampung	4
South Sumatera	3
North Sulawesi	3
Riau Islands	3
East Nusa Tenggara	2
Riau	2
Bengkulu	1
West Nusa Tenggara	1
Bangka Belitung Islands	1
TOTAL	**4704**

villages to see what solutions can help solve the mobile coverage problem.

According to Ditdal's data in Q2 2020, there are 4704 villages unserved by mobile network services. The 'unserved' here is defined as the condition in which 0.00 square kilometre 2G, 3G and 4G coverage is on the village's settlement area and less than 50.00% coverage is on its land area. The unserved villages spread over 25 provinces in Indonesia, as seen in Table 4.1.

Some of the villages among the 4704 unserved villages are picked for the exemplary cases to get a more detailed and actual situation of the unserved villages. The information about the actual situation of the villages would be used to select the possible solutions. Furthermore, the exemplary villages are meant to represent the majority of unserved villages in Indonesia. Nevertheless, at this point we are not able to show the representativeness of the exemplary villages to the Indonesian unserved villages through data.

The villages are selected based on specific criteria based on the key factors related to the area's conditions identified in Chapter 2 Figure 2.4. The identified key factors are: 1) the village's electricity grid availability, 2) local community's support, 3) the village's road accessibility, 4) the village's population density, and 5) the village's topography. The *local community's support* factor shall show the level of vandalism and thefts on mobile network infrastructure and the level of residents potential involvement in the established network's maintenance. Due to this study's time and resource limitation, only the aspects assessable with data and desk study are considered as the criteria for selecting the exemplary cases. Therefore, since the relevant data the local community's support is not available, it is left out from the criteria of the exemplary cases. The accessibility by the four-wheeled vehicles will represent the village's road accessibility. Therefore, the criteria are: 1) the electricity grid availability, 2) the population density, 3) the accessibility by four-wheeled vehicles and 4) the topography.

Three villages are selected. They are different in one or more criteria. The village's name, location, coverage level and conditions are summarised in Table 4.2. Their conditions are elaborated in the following subsections. To get the most actual conditions of the village, we use some (local) newspapers, such as Radar Tanggamus (Radar Tanggamus, 2020a, 2020b), AntaraNews (Adha, 2019), Jubi (Ariane, 2019), Papuapos Nabire (Suroso, 2017), Kompas (Putranto, 2016) and InfoPublik.id (Rahmat, 2021), and governmental data, such as villages information (Kemendesa, n.d.-a, n.d.-b, n.d.-c), national statistic (Badan Pusat Statistik, n.d.-g), report from BAKTI (PT Tekno Nusantara Kapital, 2020) and local authority documents (Pemerintah Kabupaten Kampar, 2019)

Table 4.2: Selected villages for exemplary cases

Village's name	**District**	**Municipality**	**Province**	**Population density (person/km^2)**	**Electricity grid availability**	**Accessibility by four-wheeled vehicles**	**Topography**
Unipo	Siriwo	Nabire	Papua	1.5	Yes	Good	Highlands
Tampang Muda	Pematang Sawa	Tanggamus	Lampung	86.7	No	Not available	Flat
Terusan	Kampar Kiri Hulu	Kampar	Riau	6.8	Yes	Not available	Highlands and rainforest

Source: (Dukcapil, 2016), BIG, (Adha, 2019; Badan Pusat Statistik, n.d.-g; Kemendesa, n.d.-a, n.d.-b, n.d.-c; Pemerintah Kabupaten Kampar, 2019; PT Tekno Nusantara Kapital, 2020; Radar Tanggamus, 2020a, 2020b; Rahmat, 2021)

4.1.1 Unipa village

Unipa village can be categorised as a rural area since its population density is lower than 100 people per km^2. Its total population by the end of 2016, based on Dukcapil (2016)'s data, is 797 inhabitants. According to CovData (Ditdal PPI, 2021a) the settlement area of this village is 0.07 km^2 while the total area of the village is 530.45 km^2. This very minuscular settlement area indicates that the local residences may sparsely be distributed over the village. According to its total number of inhabitants and total village's area, the population density in Unipa village is only 1.5 person per km^2.

Unipa or Unipo village is located in the District Siriwo, Kaimana Regency, Papua Province. Some other unserved villages surround it. Nine out of eleven villages surrounding Unipa are among the 4704 unserved villages.

There is a fibre optic line passing through the village, and there are two 4G sites around 30 km from the village. The line is owned by an optical fibre network operator Palapa Ring Timur (Ditdal PPI, 2020b). Based on the 2019-Q3 4G site data (Ditdal PPI, 2020d), the 4G sites belong to BAKTI.

The topography of Unipa village is mountainous. By observing the contour map of Unipa village area provided by Google Earth, it is known that Unipa village has an altitude above sea level ranging from <100 meters to above 3000 meters.

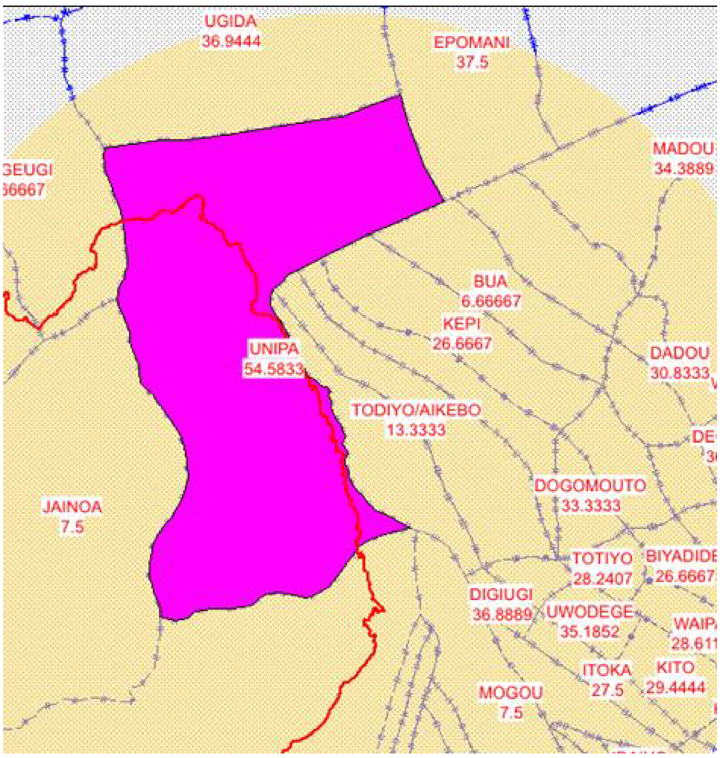

Figure 4.2: Unipa village's position (the red line is the optical fibre line)

The accessibility to Unipa village and its electricity availability is relatively good. According to PT Tekno Nusantara Kapital (2020), it is accessible via both water and land route from its nearby villages, and the land road can be traversed by four or more wheeled vehicles throughout the year. Most of the land route from and to the village has been solidified with gravels or rocks (Kemendesa, n.d.-c). However, most of the villages in district Siriwo can only be reached by a flight of about 35 minutes from Nabire (Ariane, 2019). Hence, it is concluded that there is no daily public/routine transportation from and to Unipa village yet.

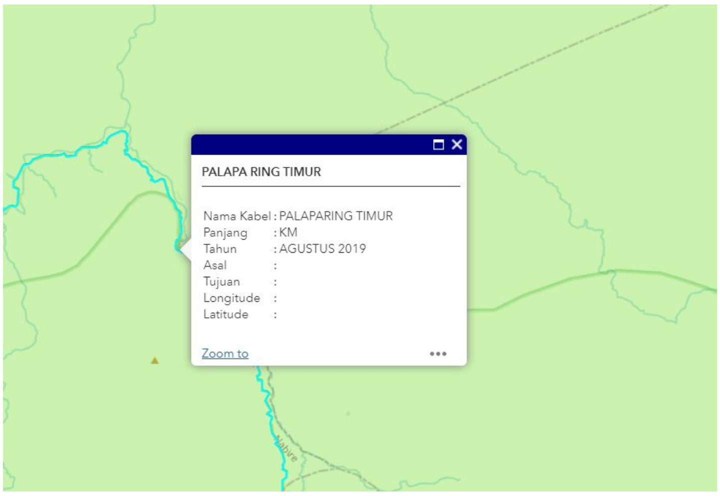

Figure 4.3: The Palapa Ring Timur's optical fibre line that is passing through Unipa village)

Moreover, most residents walk or use bicycle or motorcycle to travel from or to the municipality centre (Kemendesa, n.d.-c). Regarding electricity, more than 83% of the residents use electricity. PLN's electricity grid has served the village since 2017 (Suroso, 2017).

Unipa village is considered as economically potential by PT Tekno Nusantara Kapital (2020), the independent consultant employed by BAKTI. According to its report, Unipa village has three education facilities, three healthcare facilities and two small business units. The village's income is mainly from agriculture (collection of forest products) (Kemendesa, n.d.-c). Assuming that the WTP of the village's resident equals the Papua province's average rural household consumption of telecommunication per month, Unipo residents' WTP is estimated to be up to 186,464 rupiahs (Badan Pusat Statistik, n.d.-g).

4.1.2 Tampang Muda village

Tampang Muda village can be categorised as a rural area since its population density is lower than 100 people per km^2. Its total population by the end of 2016, based on Dukcapil's data, is 1282 inhabitants. According to CovData (Ditdal PPI, 2021a) the settlement area of this village is 0.092 km^2 while the total area of the village is 14.78 km^2. According to its total number of inhabitants and total village's area, the population density in Tampang Muda village is only 86.7 person per km^2.

Tampang Muda village is located in the District Pematang Sawa, Tanggamus Regency, Lampung Province. On its north, this village is adjacent to the sea, while on its south is the Bukit Barisan Selatan National Park. On the other sides, it is surrounded by some other unserved villages, i.e., Tampang Tua village, Martanda and Way Asahan village. The nearest existing cellular sites are located across the sea in Putih Doh village (Cukuh Balak district) village, around 30 km from Tampang Muda village, and in Sawang Balak island around 14 km from Tampang Muda village. The nearest fibre optic line is 44 km away from the village (Ditdal PPI, 2021b).

The topography of Tampang Muda village is relatively flat. Based on the Google Earth contour map, Tampang Muda village's altitude span from zero to around 100 meters above sea level.

The accessibility to Tampang village and its electricity availability is relatively poor. The village is not yet served by an electricity grid and uses mostly fossil-fueled electricity generator (Putranto, 2016; Radar Tangga-

Figure 4.4: Tampang Muda village's position

mus, 2020a). There is no access road to the village, only a soil footpath that cannot be passed during rain season (Radar Tanggamus, 2020b). Its primary mode of transportation is via sea with a travel time of 2 to 4 hours using a motor boat that daily commutes to Kota Agung pier (Radar Tanggamus, 2020b).

Tampang Muda village has three education facilities. The village's income is mainly from agriculture (rice) (Kemendesa, n.d.-a). In 2017, the village issued 61 poor certificates for its residents (Kemendesa, n.d.-a). The Lampung province's average rural household consumption of telecommunication per month in 2019 is 116,078 rupiahs (Badan Pusat Statistik, n.d.-g). This number can be considered higher than the actual WTP of Tampang Muda's residents.

4.1.3 Terusan village

Terusan village is another rural village in Indonesia. Its total population by the end of 2016, based on Dukcapil's data, is only 371 inhabitants. The settlement area of this village is 0.05 km^2 while the total area of the village is 54.36 km^2 (Ditdal PPI, 2021a). Like the previous two villages, this minor settlement area indicates that the local residences may be sparsely distributed over the village or located under the shade of trees. According to its total number of inhabitants and total village's area, the population density in this village is only 6.8 person per km^2.

Terusan village is located in the District Kampar Kiri Hulu, Kampar Regency, Riau Province. To be precise, the village is within the wildlife sanctuary area Rimbang Baling. Together with Subayang Jaya village, positioned on its south side, they are both the only unserved villages in Riau province (Ditdal PPI, 2021b). There are Sungai Santi and Koto Lama villages on their west side that are served quite well with 2G coverage. Petai village in their east side are well-served with 2G, 3G and 4G services with >90% coverage on its settlement area, while Aur Kuning village on Terusan village's north side is underserved only by less than 5% 2G coverage (Ditdal PPI, 2021a). From Ditdal PPI (2020b), it seems that the sites in Petai village are concentrated on its very east side that its signal could not reach to Terusan and Subayang Jaya villages.

The only way to reach the village is through Sebayang river using a canoe or a small motorised boat (Adha, 2019). As Terusan village and its neighbouring villages are all inside the protected forest, opening road access is not allowed by the Forestry Law of 1982 as it would require deforestation (Adha, 2019). Nonetheless, fortunately, at the end of 2020, all villages in Kampar Kiri Hulu district have been served by PLN's electricity grid, including Terusan village (Rahmat, 2021).

Figure 4.5: Terusan village's position

The topography of Terusan village is hilly and forestry. Based on the Google Earth contour map, Terusan village's altitude span from around 120 meters to 700 meters above sea level. As it is located inside a national forest area, there may be high trees around the village. There is no fibre optic line or existing site near the village. The nearest fibre optic line is on the radius of more than 30 km (Ditdal PPI, 2020b). There is actually two 4G sites within the radius of 15 km to the village (Ditdal PPI, 2020d), while the nearest fibre optic line is around 30 km.

Terusan village is categorised as highly underdeveloped (Kemendesa, n.d.-b). It has no education facility and only one healthcare facility. The village's income is mainly from agriculture (rubber). In 2017, the village issued 20 poor certificates for its residents (Kemendesa, n.d.-b). The Riau province's average rural household consumption of telecommunication per month in 2019 is 144,296 rupiahs (Badan Pusat Statistik, n.d.-g). This number can be considered much higher than the actual WTP of Terusan village's residents.

Based on the aforementioned descriptions, the conditions of the three villages are summarised in the following table.

4.2 The applicability of the identified solutions to Indonesia

All the solutions identified in Chapter 3 are capable of solving one or more key factors of the mobile coverage problem in Indonesian rural areas. As seen in Table 3.5, the cause(s) of the problem it addresses is specified in the column 'Key factor addressed and the measure to address it'. For example, the Ambient Network solution could solve the problem because the solution provides a traffic routing optimisation algorithm which could reduce the MNO's maintenance cost and backhaul rent fee per rural site. With a lower operational cost, networks in a rural area with low population density can still be profitable. The key factors listed were derived from Chapter 2, which represent the key factor of the mobile coverage problem in Indonesian rural areas.

Table 4.3: Summary conditions of the exemplary cases

Village	Unipa	Tampang Muda	Terusan
Location	Siriwo District, Nabire Regency, Papua Province (135.951854°, -3.570254°)	Pematang Sawa District, Tanggamus Regency, Lampung Province (104.692908°, -5.855382°)	Kampar Kiri Hulu District, Kampar Regency, Riau Province (101.040722°, -0.280314°)
Number of inhabitants	797	1282	371
Population density (people/km2)	1.5	86.7	6.8
PLN's electricity grid availability	Yes	No	Yes
Accessibility by 4-wheeled vehicles	Yes	No	No
Estimated resident's WTP (Rupiah/month)	186464	93262	144296
Topography	Highlands	Flat	Highlands and forests
Routine public transportation availability	No	Yes (once a day, motor boat)	No
Position among other unserved villages	Surrounded by 9 unserved villages	Surrounded by 3 unserved villages	Surrounded by 1 unserved village
Distance to the existing cellular sites or fibre optic line	0 km (FO), 31 km (site 4G BAKTI), 38 km (site 4G BAKTI)	14 km (site 4G BAKTI), 30 km (site 4G MNO), 44 km (FO)	13.54 km (site 4G MNO), 15 km (site 4G MNO), 30.1 km (FO)

Therefore, theoretically, those solutions can solve the mobile coverage problem in Indonesian rural areas.

However, the applicability of the identified solutions in Indonesia needs to be assessed. Some solutions possibly have been implemented, have been planned to be implemented, cannot be implemented, or not suitable for current Indonesia's situation. Moreover, assessing the solutions aims to illustrate what they would be when they are implemented in Indonesia. It also aims to analyse the requirements for implementing the solution in Indonesia by considering the existing regulation, governance and mobile sector organisation.

For assessing the applicability of each solution, all information discussed in the solution's description (as in Appendix B) will be compared to Indonesia's situation, and if apply, to the exemplary villages' situation as well. The information includes the requirements of the solution, the challenges, the type of service it provides, the availability of the technology in Indonesia, whether the same or similar solution has been implemented in Indonesia or not and so on. Only information mentioned in Appendix B, which is based on the reviewed articles, will be assessed. It is possible that not all information of the solution is mentioned in the reviewed articles since the reviewed articles might only discuss certain aspects of the solution. For example, regarding UAV, the reviewed articles (Chiaraviglio et al., 2019; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Ilcev and Singh, 2004; Zhang et al., 2019) did not mention about the social aspects, such as regarding theft and personnel skills in their papers. Hence, those aspects were not assessed here. A designated study is required to fully understand each solution that involves much more literature.

4.2.1 Technology solutions

TUCAN3G

TUCAN3G might be a solution to bring mobile network coverage to unserved villages close to each other. In provinces consisting of thousands of unserved villages, like Papua and Papua Barat (see Table 4.1, there is a high chance of finding villages located next to each other. Since the TUCAN3G model is suitable for areas with less than 1000 inhabitants (Prieto Egido et al., 2020), it is suitable for Indonesia that has many unserved villages with less than 1000 people, such as Unipa and Terusan. However, for areas with less than 400 inhabitants, Martínez-Fernández et al. (2016) explained that covering MNO's expense for establishing the backhaul tower with public fund would make the network commercially sustainable.

TUCAN3G might also be adaptable to the desired type of technology for the access network. Although the study of TUCAN3G in Section B.1.1 focused on 3G service, the concept is applicable to all standards, including 2G and 4G. Vardhan et al. (2014) showed that femtocell can be used for 4G service, too. Femtocells for 4G also has been commercially available.
Many areas in Indonesia are mountainous. Highlands can reduce the need for high towers (Prieto Egido et al., 2020). As a result, the need for a high tower to ensure LOS might be less in those areas. The less tower and the lower the tower height, the lower the CAPEX needed, hence the lower the development cost of the network and the more commercially sustainable the solution will be. The use of unlicensed backhaul also is not forbidden according to the Communication and Informatics Ministerial Decree Number 5 of 2005, as long as its transmit power is less than 100 mW and the EIRP is less than 36 dBm.

However, there are things to ensure first before using this solution. First, as it will employ Wi-Fi and WiMAX free bands, the network route passed by the backhaul network should be cleared from the use of these free frequency until some years in the future. Therefore, local governance and cooperation are needed to protect the long-distance multihop terrestrial backhaul Wi-Fi/WiMAX link from interference. Second, there should be a mechanism to maintain and repair the network efficiently so that the established network can stay operational in the long run. As Indonesian rural areas can be really remote and isolated, any measure that can minimise the need to visit the established site will significantly reduce the site's operational cost and make the site more sustainable.

Therefore, this solution is feasible to be implemented in Indonesia, particularly in areas with less than 1000 population. The feasibility is higher for rural areas in Papua island and the areas with highlands topography. However, it requires measures to protect the free-band backhaul link from interference and minimise the need to visit the location for maintenance. If it is implemented by an MNO in areas with less than 400 population, the provision of public subsidy on the backhaul tower is needed to make the network sustainable.

Cached GEO-satellite backhaul

As this solution uses 4G as the fronthaul network, it can be adopted by the Indonesian government who has a plan to ensure coverage in all villages in Indonesia with 4G services by 2022 (Setu, 2021). However, this solution took a case study in the European area (Chiha et al., 2020). Thus, there is a chance that this solution does not meet the cost requirement since it used European user's level of willingness to pay.

It offers a low-cost solution for 4G service, implying that it can be even more affordable for 2G or 3G services. However, this hypothesis should be assessed with WTP for 2G and 3G instead of mobile broadband. The study by Chiha et al. (2020) mentioned that this solution requires the resident's WTP around 19 euros per month, which is equals to around 330,000 rupiahs per month (European Central Bank, 2021). Meanwhile, based on Badan Pusat Statistik (n.d.-g), the province with the highest average rural household expense per month in 2019 is Papua Barat, 248,154 rupiahs per month. This expense, which can represent the average WTP of the resident's in the province, is much lower than what is required by the Cached GEO-satellite backhaul solution proposed by Chiha et al. (2020). Therefore, it can be concluded that for implementing this solution in Indonesian rural areas, financial support, for example in the form of public subsidy, is required.

The use of macro-cell this solution proposed constraints the village's population density. To achieve the low deployment cost as mentioned in the study, only the unserved villages that have at least 1050 users with a density of 14 people/sq km would be fit to use this solution (Chiha et al., 2020). As a result, the unserved villages in Papua and West Papua cannot apply this solution since these provinces have only 11 and 9 people/sq km, respectively (Ditdal PPI, 2021b). To be precise, Unipo village and Terusan village, which have a population density lower than seven persons per km^2, should not use this solution. Replacing macro-cell with smaller cells such as picocells or femtocells may be able to reduce the cost of RAN in the case of low density, and sparse population (Simó-Reigadas et al., 2019). Nonetheless, no literature found that shows whether or not this type of cell can be integrated with cached satellite backhaul like Chiha et al. (2020)'s solution and whether the cost could be more effective than using macro-cell.

This solution also is unsuitable for villages that have no good source of electricity, indicated by the absence of the PLN's electricity grid in their areas. That is because the cached GEO-satellite network needs around 34,200 kWh per year for powering the satellite terminal, MEC infrastructure, air cooling, etc (Chiha et al., 2020). This huge amount of electrical power might be difficult to fulfil by solar panels, conventional electricity generator or traditional hydropower.

Furthermore, the ACPU calculated in this solution would also need to tweak its tower cost to take into account the Indonesian unserved villages situated in the rainforests, slopes or valleys. The tower counted in Chiha et al. (2020)'s study is the 10-metre tower, while in those situations, the tower height should be higher.

To conclude, this solution is feasible in Indonesia only if supported with public subsidy and in areas where PLN's grid is presented. Moreover, the area should have at least 1050 users with a density of 14 people/sq km.

Unmanned Aerial Vehicle

Several vendors have used this technology. Some of them are Google (Loon) and Insitek (Helion). Insitek is an Indonesian start-up established by some graduates from Bandung Institute of Technology (Kominfo, 2016a). However, Helion unit has not yet been commercially deployed until now, though its pilot project has been successfully conducted in 2016 (Kominfo, 2016b). Meanwhile, in January 2021, Loon wound down as a company. It failed to get costs low enough to make it sustainable (BBC News, 2021). Loon uses autonomously flying balloon as the UAV (Osprey, 2020).

UAV technology, manifested by Helion, seems promising in providing coverage to remote and rural areas in Indonesia. It uses a helium-filled balloon that operates at an altitude of 25-50 metre so that it does not clash with Indonesian air transportation regulations (Kominfo, 2016a). Based on its pilot test using Wi-Fi frequency, Helion can provide service up to four km^2 (Kominfo, 2016b).

Nevertheless, the current UAV types available in Indonesia are different from the UAV type discussed in the previous chapter (Section B.1.3). Rotary-wing UAV is not yet available commercially in Indonesia. Meanwhile, the feasibility analysis of the available UAV types (Loon and Helion) has not been found in the reviewed literature. It is assumed that UAV proposed by the literature (Chiaraviglio et al., 2019; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Ilcev and Singh, 2004; Zhang et al., 2019) can be fabricated when needed.

The UAV network proposed by Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) requires regular maintenance for solar panel cleaning, updating SW and site inspection. Therefore, to minimise the cost, any measure that minimises the need to visit the location for maintenance would be needed.

Nevertheless, the implementation of UAV for mobile services provision collides with some of the existing Indonesian regulation. Although the Indonesian government has allocated a particular mobile band 900 MHz for the implementation of the High Altitude Platform Station (HAPS) (Kominfo, 2018), according to GR No. 52 of 2000 regarding Telecommunication Operation and GR No. 53 of 2000 regarding Radio Spectrum and Satellite Orbit Usages, it can only be operated by telecommunication operator with license. There are requirements that UAV vendors cannot meet to get the license. The alternative, in which UAV vendors cooperate with the existing MNOs to be able to use the MNO's frequency or to have MNOs renting some frequencies on behalf of the UAV vendors (Yuniarti and Hamjen, 2017), is not permitted by the government. GR No. 53 of 2000 states that radio station frequencies can not be traded or transferred to another party unless there is approval from the Minister. And yet, until now, the Minister of Kominfo has not permitted spectrum sharing, nor trading (Pratomo, 2020). Therefore, the only option to implement UAV in Indonesia is by MNO owning the UAVs.

To summarise, the UAV solution can apply to Indonesia only if either the UAV is owned by the MNO or the existing regulations regarding spectrum sharing are amended. Despite the uncertainty of the actual realisation of the UAV products proposed by Chiaraviglio et al. (2019) and Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017), it is assumed that this solution can be realised accordingly.

VillageCell

VillageCell can be used to provide coverage in a group of villages that prefer intra or inter nearby village communication than to outside world connection (Anand et al., 2012). This condition can be known by surveying the villages, mainly the topographically difficult, remote, and very low profitability ones. However, it would not provide equal connectivity and information accessibility over the country since VillageCell emphasises on intra network communication.

As the existing Indonesian regulation (Law No. 36 of 1999) allows only MNOs to use the mobile radio spectrum, not individuals or community, this solution might be able to be used only by the government (BAKTI) to provide coverage in rural areas by cooperating with an MNO—BAKTI pays the MNO for establishing and running the network. Requesting MNOs to provide coverage themselves would not be viable as they would not profit from most of the voice call traffic in a VillageCell network. Meanwhile, if regulations allow for CCN, CCN would not be suitable to deliver VillageCell. Since the idea of VillageCell is the provision of free local communication services, the network would give little to no profit to CCN.

VillageCell, just like other networks, requires regular maintenance. Therefore, to minimise the cost, any measure that minimises the need to visit the location for maintenance would be helpful.

In 2013, an ICT expert asked for governmental permission to deploy a community-based VillageCell network using OpenBTS, but the government rejected it (Pitoyo, 2013). The network was proposed to use 900/1800 MHz to offer free mobile SMS and voice call services intra network. The cost for deploying a network is only around 12-15 million rupiahs, which is much lower compared to the conventional MNO's site that requires 1-3 billion rupiahs (Pitoyo, 2013). More than a five km radius could be served by this network (Panji, 2013). He has requested permission to get a block of numbers and radiofrequency to establish the community-led VillageCell network, but it was refused. That was because the existing regulations only allow legal entities with an operational license to deploy and operate any mobile network to ensure the QoS (Pitoyo, 2013).

Hence, VillageCell is feasible in Indonesia only if BAKTI deploys it and only if it prefers to communicate locally. It also requires measures that minimise the need to visit the location for maintenance.

Solar power source

The use of solar radiation for powering the mobile network infrastructure is allowed in Indonesia. The latest regulations governing the use of solar power source are the Minister of Energy and Mineral Resources Regulation (PermenESDM) Number 49 of 2018 concerning the use of the Rooftop PLTS system by PLN consumers, which is renewed by PermenESDM Number 12, 13 and 16 of 2019. The regulation describes that for installing the solar panels less than 500 kVA in one site where PLN's grid does not yet exist, the installer only needs to report the construction and installation of the solar power plant to the Minister of Energy and Mineral Resources without having to request any operational permit. 500 kVA equals around 400-500 kilo Watts. So, for example, solar panels installation for powering a femtocell site (3 panels of 85 watts per panel = 255 watts (Rey-Moreno et al., 2011)) does not need ministerial permission.

The availability of solar panel vendors also is quite good with a comparable price. The price of solar power plant per Watt peak in Indonesia is around US$1 (CNN Indonesia, 2020), similar with the solar panel cost mentioned in Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) 0.8 euro. The cost-analysis in the literature that showed solar power economically feasibly can also apply to Indonesia. Therefore, solar power can be economically feasible as an alternative to PLN's grid, especially where PLN's grid is not available.

As a country located on the equator, getting solar energy throughout the year would not be a problem in Indonesia. On average, Indonesia gets 6-8 hours of sunlight per day, whereas the ideal duration of sunlight per day for solar panel electricity generation is 4-5 hours per day (Janaloka, 2015). The World Bank report (Suri et al., 2017) showed that Indonesia has solar power potential 2.58-7.77 kWh/m^2/day, higher than the potential in European countries (Suri et al., 2006).

Battery performance prediction model

There is no regulatory constraint for implementing this solution in Indonesia. As long as this solution is readily available to purchase at a reasonable price, site developers (MNO, SRO, community, or BAKTI) can use this system whenever they need it. It is assumed that the battery performance prediction model as designed by Fan et al. (2016) can be realised when needed.

Store-and-Forward network

As Store-and-Forward network or MDTN employs free Wi-Fi services, this solution can be realised by BAKTI without involving any MNO. BAKTI is the non-profit agency under Kominfo responsible for managing USF (Permenkominfo Number 10 of 2018). MNOs might not be interested in deploying this solution because they will not get any revenue from it. Making MDTN employ cellular services instead of Wi-Fi services is also technically unviable. One of the obstacles may be regarding the charges and billing. To employ cellular services, the MDTN app also needs to calculate the charges and billing, which is not yet accommodated in the Palazzi et al. (2011)'s solution and seems impossible to do in a delay-tolerant network (DTN).

MDTN also relies on the existing routine transportation trip from the village to the city centre (Palazzi et al., 2011). The public transportation mentioned by Palazzi et al. (2011) is a bus, where an MDTN server can be placed inside the bus. The city centre is assumed to be where a free Wi-Fi access point can be found, and the bus can stay connected for a while.

Store-and-Forward network, just like other networks, requires regular check and maintenance. Since the network devices will eventually come to the city centre during their trip, the network owner does not need to travel to the village to maintain or repair the network. However, as the devices will be placed in a public location, the public vehicle, local authority's support is needed to ensure the devices' safety.

However, finding an existing free Wi-Fi access point along the public/routine transportation route that BAKTI can use to deploy this solution might be difficult. If it is not available, BAKTI must either request an adjustment on the route or establish a new free Wi-Fi access point along the existing route. The former is only possible if the existing free Wi-Fi access point is located nearby the existing public/routine transportation route. To do the latter, BAKTI needs to cooperate with an internet service provider (ISP). The same ISP can also be employed to maintain the MDTN devices mounted in the vehicles.

Based on the existing regulation in Indonesia, this solution is technically feasible only if it is deployed by BAKTI and in an area that has a routine transportation trip with vehicles that can carry an MDTN server. Nevertheless, it requires local authority's support to protect the network. There are no regulatory constraints on this solution's implementation as it uses Wi-Fi frequency. However, this app is not yet available in Indonesia. Since the prototype has been realised (Palazzi et al., 2011), it is assumed that this app can be commercially available in Indonesia if needed.

Ambient Network

The ambient network is suitable for multinode network. Thus it can be useful when combined with VillageCell. The algorithm may help to optimise the route for communication between users within the VillageCell and also the route to reach the network gateway, making the network more robust from congestion.

However, by looking at the solution's maturity at this point, this solution is considered not applicable for Indonesia. The algorithm is not commercially available yet. In the paper, Grampín et al. (2007) mentioned some drawbacks of the system that had not yet been solved, meaning the system was still under development. The network management policies must also be site-specific (there is a routing algorithm in the system that specifically addresses particular nodes for certain conditions), thus challenging to be generalised into some off-the-shelf products.

4.2.2 Organisation solutions

Community Cellular Network

Community Cellular Network (CCN) requires quite a lot of modification in the existing regulation in Indonesia. Like the Philippines (Barela et al., 2016), mobile network spectrum bands in Indonesia are also allocated to MNOs for nationwide operation. This term is set in each MNO's spectrum licenses. Therefore, if a CCN will be established using the unused mobile spectrum of the existing MNOs, permission both from the MNO and the telecommunication regulator should be acquired. Whereas, according to GR Number 53 of 2000, the spectrum can only be used by its license holder. The recently released regulation, GR Number 46 of 2021, allows spectrum sharing but only for technology after 4G (i.e., 5G and so forth). Hence, to accommodate CCN, the existing spectrum regulation needs to be amended to accommodate spectrum sharing or trading. Also, a new regulation specifying when and how MNOs can or must permit the use of their spectrum for CCN needs to be created. Therefore, it might take a long time for this solution can be implemented legally.

The existing regulations do not allow for the community-led network. Based on Telecommunication Law No. 36 of 1999 and Permenkominfo No. 1 of 2010, a license from the Minister of Kominfo is needed for deploying and operating any mobile network and only legal entities chosen through a selection mechanism are eligible for the license. Hence, an individual or group cannot initiate a mobile network deployment.

No spectrum permission needed if the CCN employs unlicensed bands like Wi-Fi. Nonetheless, it means this CCN can only serve smartphones, not feature phones (only 2G-capable phones). Whereas a large portion of Indonesian mobile user still uses feature phones. IMCI's survey in 2017 showed that 58,62% of Indonesian mobile users still use feature phones (Agung, 2018). Moreover, data of one of the big MNO in Indonesia Indosat showed that in 2019 20% of its total users use feature phones (Kurniawan, 2020). It is believed that these feature phone users largely live in rural areas.

On the other hand, this solution emphasises the local ownership of the network, while the network architecture is not specified and can be anything. Hence, it needs to be coupled with or may also support the other measures.

In 2013, an ICT expert asked for governmental permission to deploy a CCN network, but the government rejected it (Pitoyo, 2013). The network was proposed to use 900/1800 MHz to offer free mobile SMS and voice call services intra network. He has requested permission to get a block of numbers and radiofrequency to establish the community-led network, but it was refused. Until now, no CCN has been allowed to establish.

To summarise, CCN is not feasible in Indonesia. The existing regulations do not allow the community to own, establish and operate a cellular network. To allow it, a non-legal entity (such as a local community) needs to be eligible for operating network, and spectrum sharing for essential cellular network services has to be accommodated in the regulation. However, allowing it might not happen soon since the newly released regulation, GR Number 46 of 2021, does not allow this, although the government had known the need for CCN since 2013.

Small Rural Operator

Indonesia is currently has a similar kind of operator. BAKTI is an agency under Kominfo responsible for deploying and operating mobile networks in many rural areas using USF by cooperating with MNOs (according to Permenkominfo Number 3 of 2018). For years, BAKTI has been establishing thousands of mobile network sites in rural areas (BAKTI, n.d.) by providing necessary mobile infrastructures, including the tower, backhaul network, power and radio transceivers. At the same time, an MNO handles the service and site operation, and the local government provides the land (Jatmiko, 2020; Yunus, 2018). To do so, BAKTI and an MNO made a revenue-sharing agreement (Yunus, 2018). BAKTI's infrastructures are also opened for other MNOs (Jatmiko, 2020). Therefore, SRO is a feasible solution for Indonesia, but it requires USF.

Mobile Virtual Network Operator

Currently, MVNO is not listed as one of the telecommunication operator types in Indonesia. According to GR No. 52 of 2000 and Telecommunication Law No. 36 of 1999, mobile services and numberings are only eligible for the MNOs that owned the mobile network infrastructure. Therefore, to allow this solution, the existing regulations need to be adjusted to legalise MVNOs and allow numbering sharing.

On top of that, the way this scheme relies on collaboration between MNOs and MVNOs may require government intervention in the form of a regulation that specifies when and how MNOs should consider collaborations with MVNOs. The MNOs as the hosting operator that owns the network are preponderant. Since there is a risk of revenue loss for opening their established network to other operators, they may be reluctant to collaborate without government intercession. However, allowing MVNOs to operate in rural areas might raise innovations from Indonesian non-telecom organisations for increasing rural network's service usage. MNOs will want to cooperate if they see the new services provide a win-win for them and MVNOs. By letting the collaborations arranged business-to-business on a market-led basis, its negative impact on declining the MNOs' ARPU can be prevented.

However, MVNO with no network infrastructure will have nothing to do with network expansion to the unserved areas. MVNO can be helpful after the network is established and only if there are market segment in the area.

To conclude, this solution can be feasible with the amendment of the existing telecommunication regulation. To avoid the disruption that negatively affects the existing industry, the government should let MVNO establish naturally, induced by market demands. Moreover, even if MVNO exists, MVNO cannot be the only organisation solution in the solution arrangement.

Central and local authority's support

Cruz and Touchard (2018) suggested that the government, both central and local, avoid an overly strict set of rules, complex and lengthy permit process, rent-seeking behaviour and arbitrary charges for site approvals that limit the ability for MNOs to build new sites. The recently released regulation, GR Number 46 of 2021 and Permenkominfo Number 5 of 2021 (Article 20), specify that local governments and local enterprises are allowed to establish telecommunication passive network infrastructure, such as towers, fibre ducts, poles, etc. The regulations oblige any passive infrastructure providers, including local authorities, to allow MNOs to rent the infrastructure in a non-discriminative manner and with reasonable, transparent and cost-based tariffs. The tariffs also formulated by considering the social impact of the infrastructure usage (GR Number 46 of 2021 Article 22). Moreover, they mention that central and local governments should provide telecommunication supporting facilities, such as land, building, right of way, public area access and passive telecommunication infrastructure with a reasonable and transparent price. Permenkominfo Number 5 of 2021 also specifies that telecommunication operator, including MNOs, may ask Kominfo to mediate when there is a dispute or problem in the process of deploying and operating their network (Article 43). With this regulation, the central and local authority's support can be realised according to Cruz and Touchard's recommendation. However, the central and local authority are only supporting actors and need other organisations to deploy the network.

4.2.3 Regulatory solutions

Coverage-obligated spectrum license

The coverage-obligated spectrum licenses have been introduced by the Indonesian government when renewing spectrums due in 2020. Five MNOs' licenses of spectrum 800 MHz, 900 MHz and 1800 MHz were renewed, in which a list of villages is included in each license to be covered by the MNO's network. The villages on the list are based on the government assessment regarding the unserved or underserved villages in Indonesia. Three thousand four hundred thirty-five unserved/underserved villages are distributed among the five MNOs covered at least by 2022.

Cruz and Touchard (2018) suggested five considerations for implementing coverage obligation in the spectrum license: 1) it only be applied to the low-frequency spectrum (< 1GHz), 2) it is realistic and compliable in terms of targets and timelines, 3) the license price or related tax takes into account the compliance cost, 4) It prevents infrastructure duplication in the low revenue areas, and 5) It allows infrastructure sharing to facilitate compliance. Regarding the first consideration, although the obligation is stated in the license of spectrum 800 MHz, 900 MHz and 1800 MHz, all these spectrum bands are in one license, and the obligation does not specify which spectrum to be used. Then, MNO can choose which band will be employed for fulfilling their obligations. MNOs can use the coverage bands (800 MHz and 900 MHz) if they want, except Tri, since it does not have any coverage band.

Whether or not an obligation is realistic and compliable depends on the MNO. Usually, before a license is released, Kominfo informs the draft to the respective MNO to get its acknowledgement and agreement. If

Table 4.4: Number of villages to be covered by MNOs in their spectrum licenses renewed in 2020

MNO	#Villages to cover by year	
	2021	2022
A	70	378
B	1197	1500
C	18	52
D	50	645
E	88	861

that is the case for these new spectrum licenses, these obligations are realistic for the MNOs. Nevertheless, by looking at the number of villages to be covered by 2022, only two years after the obligation is set, there are MNOs with hundreds or even thousand of villages to cover. One can argue that the number is quite large and may be unrealistic.

By realising the limited revenue potential in those villages, the licenses explicitly mention that each village is meant to be served by only one MNO. Adjustment on the list of villages can be made in case more than one MNO services present or are going to present in a village on the list. It shows that the license prevents infrastructure duplication. Moreover, the existing regulation (Permenkominfo Number 5 of 2021) about telecommunication operation allows coverage obligation compliance using infrastructure sharing.

Regarding the third consideration of the license tariff, these licenses have the same tariff as the licenses without coverage obligation (GR Number 80 of 2015). They also did not accommodate any tax reduction pertaining to the imposed coverage obligation.

To summarise, Indonesia currently has implemented coverage obligation in some of the mobile spectrum licenses, but the coverage-obligated spectrum licenses are not entirely the same as Cruz and Touchard (2018)'s suggestion. It means this solution is feasible. However, to follow Cruz and Touchard, the existing regulations regarding spectrum license pricing needs to be amended.

Spectrum management

Cruz and Touchard (2018), McDowell and Lee (2003), Sridhar and Prasad (2011), and Touchard (2017) proposed for the government to make as much as possible spectrum available for mobile services, particularly the coverage bands; set a low but effective spectrum price, particularly the coverage bands; provide a clear spectrum roadmap for MNOs or publicly; allow spectrum trading and spectrum sharing; release spectrum is technology-neutral, and release spectrum through auction or beauty contest with long duration and assurance of renewal. This scheme can have a positive impact on rural coverage enhancement in Indonesia. The scheme allows cost reductions for MNOs to deploy the network in general and minimise the uncertainties for them to invest. In Indonesia, all spectrum bands used for the existing cellular networks have already been technologically neutral (as stated on the operational licenses), released through auction or beauty contest and have a long duration (10-20 years) (according to GR Number 46 of 2021). Making as much as possible spectrum available for mobile services, particularly the coverage bands, has also been understood and carried out recently by refarming 700MHz bands (Clinten, 2020).

Cruz and Touchard (2018) specifically mentioned that the price for spectrum that beneficial for rural coverage should be lower than those that are not. In other words, the price of the coverage bands or the spectrums imposed by coverage obligation should be formulated differently from the 'normal' spectrum as network expansion to rural areas is the government's objective. Currently, the Indonesian government defines all spectrum price equally, based on GR Number 80 of 2015, without considering the rural deployment cost. Moreover, the explanation of Article 9 of GR Number 80 of 2015 states that one of the tariff components—I, the basic price index of radio frequency band according to radio propagation characteristics (Rupiah/MHz)—is set higher for the lower spectrum.

Other aspects that Indonesia does not yet apply are regarding the provision of spectrum roadmap and secondary spectrum market. So far, the Indonesian government has never provided any spectrum roadmap informing when certain spectrum blocks will be available. Meanwhile, creating a secondary market for spectrum license may require a change in frequency regulation. To decide upon the terms and conditions when and how spectrum can be traded should be consulted with relevant stakeholders, hence may take a long time. Spectrum trading or spectrum sharing is also the key enabler for other solutions, like CCN and VillageCell, where the unused MNOs' mobile frequencies are needed for deploying access network in rural areas, and UAV where UAV vendors establish a business agreement to use MNOs spectrum. Via GR Number 46 of 2021 (Article 50), the government allows for spectrum sharing but only for the new technology (the technology that does not exist in Indonesia before 2020) and between the telecommunication operators.

To conclude, the spectrum management scheme described in B.3.2 is not yet entirely implemented in Indonesia. Part of the solution, such as coverage bands availability, long duration of the license, and neutral technology, has been realised. Another part regarding spectrum roadmap is feasible since it has no regulatory constraint. Meanwhile, the existing regulation does not accommodate the part regarding spectrum pricing, spectrum sharing and trading. The relevant regulations need to be amended to accommodate them.

A taxation policy that foster investments in rural areas

Touchard (2017) argued that eliminating sectoral taxes, such as import taxes on telecommunication network equipment and imposing taxes on profits instead of revenues, can positively affect the mobile network market and encourage reinvestment in mobile network infrastructure. Until this date, no regulation exempts telecommunication network equipment, particularly those used for rural connectivity, from import taxes in Indonesia. The sectoral taxes applied for MNOs, such as telecommunication Operation Rights Fees (BHP) and USF, are calculated based on MNOs' gross revenues. Telecommunication BHP is 0.5% of the gross revenue, while USF is 1.25%, according to Permenkominfo Number 5 of 2021. Hence, this solution is constrained by the existing regulations.

Moreover, Touchard (2017) explained that if MNOs deploy the network in rural areas, reducing sectoral taxes proportional to the rural investment will encourage reinvestment in rural areas. As rural connectivity is also the Indonesian government's objective, imposing low taxes can foster the country's economic development that will offset the country's income reduction in the long term (Cruz and Touchard, 2018). Therefore, this solution should be applied when MNOs take charge of rural network investment.

Infrastructure sharing

Infrastructure sharing, including passive and active, is allowed by the existing regulation in Indonesia. Permenkominfo Number 5 of 2021 (Section 7) mentioned that the sharing needs to be set under an agreement between the involved MNOs and reported to Kominfo. Therefore, this solution is feasible and has been implemented in Indonesia.

Universal Service Fund

Indonesian mobile sector established USF in 2005 via GR Number 28 of 2005. Since then, all network operators have been obliged to pay a certain percentage of their annual gross revenue annually for implementing the universal service program (Sugondo, 2013). The most recent regulation regarding the obligation to pay USF is the Telecommunication Law Number 36 of 1999 and GR Number 80 of 2015, obliging all network operators to pay 1.25% of their gross revenue from telecommunication business as USF.

Indonesian USF is administered by BAKTI. An agency under Kominfo officiated by Permenkominfo Number 3 of 2018 and Permenkominfo Number 10 of 2018. It is guided by Permenkominfo Number 10 of 2018, which is legally flexible and technology and service neutral in managing USF.

Permenkominfo Number 10 of 2018 describes that the telecommunication universal service programs can be arranged in many ways. They can be proposed by the departments in Kominfo, other ministry or institution, local governments, telecommunication operators and/or local communities (Art. 5). It also obliges the program to be arranged in synergy with the relevant stakeholders and efficient, innovative and sustainable. Moreover, Article 4 of the regulation allows the universal service program to be funded by sources other than USF. The current program of BAKTI regarding mobile coverage delivery targets on 7904 villages and subdistricts unserved by 4G, to be served by 4G by 2022 (Jamaludin, 2020). The program was started in April 2021 (BAKTI, 2021).

By considering those conditions, USF, as suggested by Arakpogun et al. (2017), mostly has been implemented in Indonesia. As described in B.3.5, Universal Service Fund (USF) is suggested to be administered by an autonomous authority run by skilful personnel that is free from political interference; guided by a clear-defined legal and regulatory framework that is flexible, technology and service neutral; equipped with clearly specified and measurable objectives (in consultation with stakeholders), including the coverage and service delivery targets; transparent in reporting the financial flows; able to work with other funding sources (e.g. Development Banks); efficient and innovative, with a focus on the sustainability of the proposed solutions; negotiable for MNOs to choose between paying the funds or investing directly in the USF-targeted areas; spent effectively and timely. However, Indonesian USF is not administered by an autonomous authority, and MNOs cannot choose between paying the funds or directly investing in the USF-targeted areas.

Public subsidy on rural network development

Public subsidy on rural network development in Indonesia is done via the universal service program performed by BAKTI. Before 2020, in deploying a cellular site in a targeted area, BAKTI subsidised an MNO in the form of tower provision, backhaul link cost and power cost ("Proyek 4 ribu BTS untuk "Merdeka Sinyal" tak bisa hanya andalkan dana USO", 2019). The sites established from this cooperation called 'BTS USO'. The land for the site is provided by the local government free of charge, while the network components and maintenance are handled by the MNOs ("Proyek 4 ribu BTS untuk "Merdeka Sinyal" tak bisa hanya andalkan dana USO", 2019). However, the initiatives are from BAKTI, not from MNOs, according to local governments' requests ("BAKTI gandeng 19 Pemda untuk lahan "BTS BAKTI Sinyal"", 2018). Therefore, this solution is feasible, has been implemented and only for the network that MNOs deploy.

Relaxing the QoS standard for rural networks

This solution is not yet accommodated in the existing regulation in Indonesia. QoS for the cellular network is regulated in Permenkominfo Number 16 of 2013. Regarding the network performance, this regulation obliges each MNO to have service problem report $\leq$5% of their total number of users, dropped call $\leq$5%, success calls $\geq$90% and SMS delivered within 3 minutes $\geq$90%. No regulation exempts or relaxes these QoS standards for rural networks. This solution will also be more suitable if MNOs deploy the mobile network in rural areas. Therefore, this solution will be only feasible if the existing regulation regarding QoS for the cellular network is adjusted. Moreover, following Touchard (2017) that argued the relaxation of the QoS standard for rural networks could promote the sustainability of the established network, this solution should be applied to the rural network that MNOs deploy.

Information management system platform about network coverage

Kominfo has provided an information management system platform about network coverage in gisppi.kominfo.go.id. In the platform, Kominfo provides the coverage map, cellular site distribution, fibre optic line map, administrative border map, etc. However, the information is not publicly available and can be accessed using an authorisation key. According to Ditdal, the relevant stakeholders, such as Kominfo's internal departments, MNOs, and other ministries, have been given their key to access the platform. Therefore, this solution is feasible and has been implemented.

Direct public investment on the critical enabling public infrastructure

Touchard (2017) explained that directly investing in the essential national infrastructure that is supportive for mobile network development, such as electricity grid, high capacity fibre backbone network, and road access, can enhance the network penetration to rural areas. In 2015-2019, BAKTI deployed a massive fibre optic backbone network in rural areas using USF in 'Palapa Ring' program (BAKTI, 2018). Moreover, road infrastructure has been one of the main focus of the ruling president of Indonesia. Since 2015 more than 6000 km of the national road, 1852 km of highway road and 494 bridges have been constructed (Gewati, 2019). On the other hand, public investment in the electricity grid in rural areas also has been accelerated since Omnibus Law Number 11 of 2020. PLN's program 'Tol Listrik' (re: Electricity Highway) consists of 35 GW electricity generator and 46000 km of the electricity transmission system in Sumatera island, Borneo and Sulawesi (Muhammad, 2021). Therefore, this solution is feasible and has been implemented.

4.3 Summary of the applicability of the identified solutions to Indonesia

The applicability of each solution has been analysed in Section 4.2. Table 4.5 summarised them in terms of their applicability and the requirements if they are currently not applicable. The applicability can be either 'feasible', 'not feasible', 'future' or 'implemented'. They are defined as follows:

- **feasible**: it has no regulatory constraint and can be implemented when needed if the requirements fulfilled
- **not feasible**: it cannot be implemented
- **implemented**: it has been implemented accordingly
- **future**: it can be implemented in the future only after the regulatory requirements fulfilled

Based on that information, all solutions identified in the literature apply to Indonesia, except for Ambient Network. Among the applicable solutions, six solutions might only be applicable in the future since there are regulatory constraints for some or the entire aspects of the solution. And combining the Table 4.5 and Table 3.5, Table 4.6 is made to show which technology solutions applicable to Indonesia are suitable for what problem's cause and what their requirements are.

Some new findings are identified regarding the Organisation solutions. It is important to note that some of the Organisation solutions identified in the literature require another Organisation solution that is able to deploy the network. For example, MVNO in rural areas is an organisation that will not build the network in the area but use the established network. That is why it is called a 'virtual network operator'. Likewise, the central and local authority who only provide supporting facilities. Meanwhile, CCN and SRO can actually establish the network themselves. Another type of organisation that is not explicitly discussed in the literature but can also deploy the network, the conventional but most important one, is the MNO. No literature explicitly suggested MNO as the solution for the mobile coverage problem in rural areas. However, many solutions, such as UAV, cached GEO-satellite backhaul, infrastructure sharing regulatory, coverage obligated spectrum license and relaxing the QoS standard for rural network development imply the role of MNOs as the network deployer. Therefore, MNOs will also be considered as an Organisation solution for the next stage.

Furthermore, by looking at the analysis in Section 4.2, mainly the solution 'A taxation policy that foster investments in rural areas' and 'Relaxing the QoS standard for rural networks', there are suggestions from the literature that can be applied when using MNOs as the Organisation solution. Cruz and Touchard (2018) and Touchard (2017) suggested implementing sectoral taxes reduction and QoS relaxation according to the solutions 'A taxation policy that foster investments in rural areas' and 'Relaxing the QoS standard for rural networks', respectively, when MNO is chosen as the Organisation solution, to enhance the effectivity of the MNOs' network deployment. Therefore, these suggestions are included as the requirements for solution 'MNO' and listed in Table 4.5, but the applicability is 'implemented' because they are not compulsory for MNO Organisation solution.

Table 4.5: Summary of the applicability identified solutions to Indonesia

No	Solution name	Applicability	Requirement
Technology			
1	TUCAN3G	Feasible	The area has less than 1000 inhabitants; Public subsidy, if it is implemented by an MNO in an area with less than 400 inhabitants; Measure to protect the free bands backhaul link from interference; Measure to minimise the need to visit the location for maintenance.
2	Cached GEO-satellite backhaul	Feasible	Financial subsidy from the government; PLN's grid is presented in the area; The area has at least 1050 users with density 14 person/sq km; Measure to minimise the need to visit the location for maintenance.
3	Unmanned Aerial Vehicle (UAV)	Feasible	UAV is owned by the MNO, or the existing regulations regarding spectrum sharing is amended; Measure to minimise the need to visit the location for maintenance.
4	VillageCell	Feasible	VillageCell is deployed by BAKTI in villages that prefer local communications (within the village and the neighbouring villages); Measure to minimise the need to visit the location for maintenance.
5	Solar power source	Feasible	-
6	Battery performance prediction model	Feasible	-
7	Store-and-Forward network	Feasible	The network is deployed by BAKTI; There is a routine transportation trip with vehicles that can carry an MDTN server from and to the village to the city center; Local authority's support to protect the network.
8	Ambient Network	Not feasible	-
Organisation			
9	Community Cellular Network (CCN)	Future	Amendment on the regulations regarding spectrum, numbering and eligible entity for operating network.
10	Small Rural Operator (SRO)	Implemented	USF
11	MVNO in rural areas	Future	Amendment of the existing telecommunication regulation; Government lets MVNO to establish naturally induced by market demands; Other organisation to deploy the network.
12	Central and local authority's support	Implemented	Other organisation to deploy the network
13	MNO	Implemented	QoS relaxation on rural network; Sectoral tax reduction proportional to the rural network investments.
Regulatory			
14	Coverage obligated spectrum license	Implemented (partly), Future (partly)	Amendment of the existing regulations regarding spectrum license pricing.
15	Spectrum management	Implemented (partly), Future (partly)	Amendment of the existing regulations regarding spectrum pricing, spectrum sharing and trading; Spectrum roadmap provision.
16	A taxation policy that foster investments in rural areas	Future	Amendment on the regulations about telecommunication sector taxes and import taxes
17	Infrastructure sharing regulatory	Implemented	-
18	Universal Service Fund (USF)	Implemented	-
19	Public subsidy on rural network development	Implemented	-
20	Relaxing the QoS standard for rural networks	Future	Amendment on the regulations about cellular network QoS
21	Information management system platform about network coverage	Implemented	-
22	Direct public investment on critical enabling national infrastructure	Implemented	-

Table 4.6: Applicable technology solutions to Indonesia for each key factor

Key factor	Solution name	Applicability	Requirements
Low Density Profitability	Battery performance prediction model with MIML	Feasible	-
	Cached GEO-satellite backhaul	Feasible	Financial subsidy from the government; PLN's grid is presented in the area; The area has at least 1050 users with density 14 person/sq km; Measure to minimise the need to visit the location for maintenance.
	Store-and-Forward network	Feasible	The network is deployed by BAKTI; There is routine transportation trip with vehicles that can carry an MDTN server from and to the village to the city center; Local authority's support to protect the network.
	TUCAN3G	Feasible	The area has less than 1000 inhabitants; Public subsidy, if it is implemented by an MNO in an area with less than 400 inhabitants; Measure to protect the free bands backhaul link from interference; Measure to minimise the need to visit the location for maintenance
	UAV	Feasible	UAV is owned by the MNO, or the existing regulations regarding spectrum sharing is amended; Measure to minimise the need to visit the location for maintenance.
	VillageCell	Feasible	VillageCell is deployed by BAKTI in villages that prefer local communications (within the village and the neighbouring villages); Measure to minimise the need to visit the location for maintenance.
Electricity	Battery performance prediction model with MIML	Feasible	-
	Solar power source	Feasible	-
	TUCAN3G	Feasible	The area has less than 1000 inhabitants; Public subsidy, if it is implemented by an MNO in an area with less than 400 inhabitants; Measure to protect the free bands backhaul link from interference; Measure to minimise the need to visit the location for maintenance.
	UAV	Feasible	UAV is owned by the MNO, or the existing regulations regarding spectrum sharing is amended; Measure to minimise the need to visit the location for maintenance.
Road Access	Cached GEO-satellite backhaul	Feasible	Financial subsidy from the government; PLN's grid is presented in the area; The area has at least 1050 users with density 14 person/sq km; Measure to minimise the need to visit the location for maintenance.
	UAV	Feasible	UAV is owned by the MNO, or the existing regulations regarding spectrum sharing is amended; Measure to minimise the need to visit the location for maintenance.
	VillageCell	Feasible	VillageCell is deployed by BAKTI in villages that prefer local communications (within the village and the neighbouring villages); Measure to minimise the need to visit the location for maintenance.
Topography	Cached GEO-satellite backhaul	Feasible	Financial subsidy from the government; PLN's grid is presented in the area; The area has at least 1050 users with density 14 person/sq km
	TUCAN3G	Feasible	The area has less than 1000 inhabitants; Public subsidy, if it is implemented by an MNO in an area with less than 400 inhabitants; Measure to protect the free bands backhaul link from interference; Measure to minimise the need to visit the location for maintenance
	UAV	Feasible	UAV is owned by the MNO, or the existing regulations regarding spectrum sharing is amended; Measure to minimise the need to visit the location for maintenance.
	VillageCell	Feasible	VillageCell is deployed by BAKTI in villages that prefer local communications (within the village and the neighbouring villages); Measure to minimise the need to visit the location for maintenance.
Local Support	TUCAN3G	Feasible	The area has less than 1000 inhabitants; Public subsidy, if it is implemented by an MNO in an area with less than 400 inhabitants; Measure to protect the free bands backhaul link from interference; Measure to minimise the need to visit the location for maintenance

4.4 Solution arrangements

In arranging the solution for the exemplary cases, at least three types of solution need to be included in each arrangement: technology, organisation and regulatory. *Technology* is the group of solutions regarding the technical aspects of the network deployment, i.e., the access technology, backhaul technology, power technology and passive infrastructure type. These solutions may only be executed by a specific actor and/or require the involvements of certain actors. Type *Organisation* pinpoints the required and suitable actor(s) to roll out the technological solutions. Furthermore, as also described in Section 4.2, there are regulation adjustments or new regulations compulsory for implementing a particular solution by a certain actor(s). Therefore, the third type *Regulatory* completes the arrangement ensuring comprehensive solution arrangements.

Figure 4.1 illustrates the steps for arranging solutions for each village. First, some technological solutions will be selected based on the coverage problem causes in the village. Technological solutions are selected first and become the foundation for constructing the solution arrangements because the local situations constrain only the technology solutions. Having selected the suitable technological solutions that fit the village's situation, the subsequent organisation and regulatory solutions will be more implementable. On the other hand, adjusting organisation and regulation based on technology is easier than designing a new technology based on the established regulation and organisation. Second, the technological solutions will be further filtered by looking at their local requirements. The technological solutions with local requirements that the village can fulfil will be selected. Third, the remaining technological solutions are arranged and combined into one set of technological solutions option. One set of technological solutions option will consist of at least one access technology, one backhaul technology and one power technology. After that, based on the selected technology solutions, the organisation solutions are picked. Lastly, regulatory solutions are selected to ensure the technology and organisation solutions implementable and achieve optimal results. The process for each village will be explained in the following subsections.

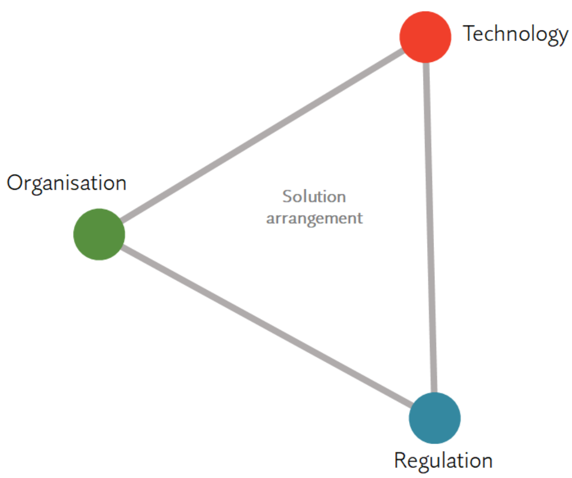

Figure 4.6: Framework for arranging the solution options

4.4.1 Unipa village

As seen in Table 4.2, the cause of the mobile coverage problem in Unipa seems to be the low population density and the topography. Unipa has been served by PLN's grid, has relatively good road accessibility. Hence they must not be the cause of the mobile coverage problem in Unipa. Any solution that only addresses the electricity problem and road accessibility should not be chosen as the solution. Referring to Table 4.6, possible technology solutions for low population density and topography are battery performance prediction model,

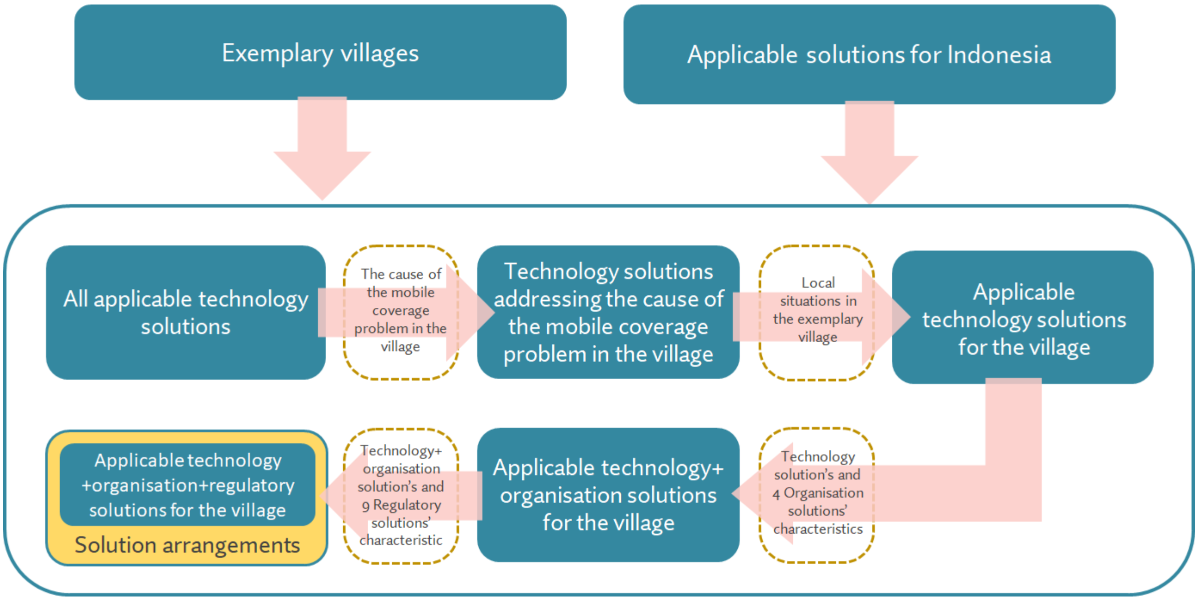

Figure 4.7: The flow for arranging solutions

cached GEO-satellite backhaul, Store-and-Forward network, TUCAN3G, UAV and VillageCell.

The Store-and-Forward solution does not fit because there is no public transportation with a vehicle that can carry the MDTN server from the village to the nearest internet access point, assumed to be in the municipality centre or the nearest 4G sites. The village also has less than 1000 inhabitants and much lower WTP, which make it unfeasible to use cached GEOsat backhaul Chiha et al. (2020). Satellite backhaul might not be cost-effective and preferred because there is a fibre optic line passing the village. Meanwhile, the village has been served well by PLN's electricity grid. Thus solar power is not necessary for Unipa. The applicable technology solutions for Unipo village are UAV, VillageCell, TUCAN3G and Battery performance prediction model. Based on that, we arrange some sets of the technology solutions as follows:

Opt-1 TUCAN3G + battery performance prediction model

Opt-2 UAV + battery performance prediction model

Opt-3 VillageCell + battery performance prediction model

The Opt-1 adopts TUCAN3G solution. Here, femtocells, which are part of TUCAN3G, are used as radio access technology after considering the low population Unipa village has. However, Unipa village does not have to employ solar power, pull a chain of wireless point-to-point links, or use a high tower as it already has an electricity grid, optical line cable, and highlands, respectively. The availability of the electricity grid and fibre optic may further reduce the deployment cost of the network in Unipa village than what TUCAN3G suggested in Prieto Egido et al. (2020). The unlicensed backhaul actually can be included in Opt-1 to extend the network from Unipa village to its surrounding nine unserved villages. Extending the network to the surrounding unserved villages can potentially make the deployment and operational cost more efficient and allow more sustainability of the established network (due to more users). The battery performance prediction model is also included to minimise network failure due to battery faults.

The Opt-2 mainly employs Chiaraviglio et al. (2019)'s solution. The difference is in the use of an electricity grid instead of solar power. The use of an electricity grid may increase the operational cost than what was stated in (Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017), but it would have a lower initial capital cost for it does not need solar panels. Opt-2 also uses a battery performance prediction model to minimise the revenue loss due to battery faults.

The last set of technological means is Opt-3 which mainly about VillageCell. Due to its low population, OpenBTS is considered to be more suitable for the village. VillageCell emphasises small-scale and local communication. VillageCell can enable free voice call and SMS communication intra Unipa village and its surrounding unserved villages. Nine neighbouring villages of Unipa village are all unserved. The battery performance prediction model is included in Opt-3 to increase the network's uptime and minimise the need for maintenance. Figure 4.8 summarised the process for arranging technological solutions for Unipa village.

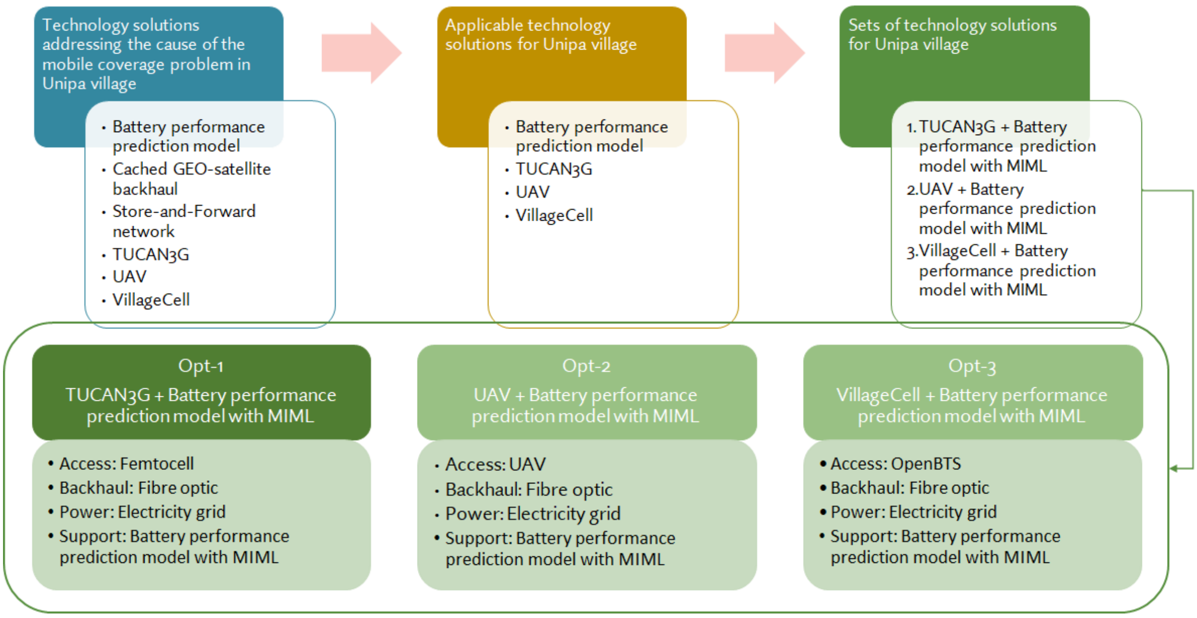

Figure 4.8: Technology solution arrangements for Unipa village

The Opt-1 employs TUCAN3G and the battery performance prediction model. The requirements for implementing these solutions are (see Table 4.5) "Measure to protect the free-band backhaul link from interference; Measure to minimise the need to visit the location for maintenance.". It means they do not specify which organisation to deploy them. However, the requirements imply the need for local authority's support.

By looking at the available Organisation solutions in Table 4.5, MNO and SRO are considered to be the most feasible. MNO and SRO both are implemented in Indonesia and can deploy the network by themselves, while the central & local authority and MVNO cannot. On the other hand, CCN is not selected as it is not yet accommodated due to regulatory constraints.

Due to the similar requirements for UAV, the same organisation solutions are required for Opt-2. Based on that, we arrange some sets of the technology+organisation solutions for Opt-1 and Opt-2 as follows:

- MNO + central and local authority
- SRO (BAKTI) + central and local authority

Opt-3 employs VillageCell and battery performance prediction model. For VillageCell, the requirements are 'VillageCell is deployed by BAKTI in villages that prefer local communications (within the village and the neighbouring villages); Measure to minimise the need to visit the location for maintenance.' Therefore, SRO + central and local authority is the only option for Opt-3. In delivering VillageCell, BAKTI can cooperate with an MNO to provide the spectrum.

So far, the technology+organisation solutions for Unipa are:

- TUCAN3G + battery performance prediction model & MNO + central and local authority
- TUCAN3G + battery performance prediction model & SRO + central and local authority
- UAV + battery performance prediction model & MNO + central and local authority
- UAV + battery performance prediction model & SRO + central and local authority
- VillageCell + battery performance prediction model & SRO + central and local authority

When MNO is used as the organisation solution, Cruz and Touchard (2018) suggested giving a QoS relaxation on the MNO's rural network and sectoral tax reduction proportional to the rural network investments for the MNO. They require solutions 'Relaxing the QoS standard for rural networks' and 'A taxation policy that foster investments in rural areas'. When SRO is used, it requires USF as the regulatory solution. While if the central and local authority is used, no regulatory solution is required. Table 4.7 summarises the solution options previously mentioned.

Table 4.7: Solution options for Unipa village

Option	Technology	Organisation	Regulatory
1	TUCAN3G + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
2	UAV + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
3	TUCAN3G + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
4	UAV + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
5	VillageCell + battery performance prediction model	SRO (BAKTI) + central and local authority	USF

4.4.2 Tampang Muda village

By looking at Table 4.2, the potential cause of the mobile coverage problem in Tampang Muda are the population density, the electricity grid availability and the road accessibility. Tampang Muda topography is flat. Hence it must be not the cause of the problem in Tampang Muda. Referring to Table 4.6, the possible technology solutions for population density, the electricity grid availability and the road accessibility are Store and Forward network, UAV, VillageCell, Cached GEO-satellite backhaul, TUCAN3G, battery performance prediction model and a solar power source.

Tampang Muda village is not suitable for using either TUCAN3G or a Cached GEO-satellite backhaul network. It has more than 1000 inhabitants, which means it does not meet TUCAN3G's requirement. Meanwhile, changing the access technology to microcell might make the site financially unfeasible, as femtocell is the key to make TUCAN3G cost-effective (Prieto Egido et al., 2020). On the other hand, the absence of an electricity grid hinders the suitability of the Cached GEO-satellite backhaul network in the village. As this solution requires high power (Chiha et al., 2020), unless PLN's electricity grid serves Tampang Muda, this solution will not be viable. Therefore, the applicable technology solutions for Tampang Muda village are Store and Forward network, UAV, VillageCell, battery performance prediction model and a solar power source. Based on that, we arrange some sets of the technology means as follows:

Opt-1 Store & Forward + solar power source + battery performance prediction model

Opt-2 UAV + solar power source + battery performance prediction model

Opt-3 VillageCell + solar power source + battery performance prediction model

The Opt-1, using Store & Forward network, is considered viable and cost-effective. There is a routine daily motor-boat trip from Tampang Muda to Kota Agung pier (Putranto, 2016; Zulhalim, 2021). Kota Agung pier area is served by three MNOs, and a fibre optic line (Ditdal PPI, 2020b, 2020d). It shows that finding or establishing a Wi-Fi internet access point reachable by the docked boat would be accessible in the pier area. The MDTN server stored in the boat can be powered by solar panels placed on the boat. Moreover, since the sea is the primary way to reach the village, putting the network access point in the parked boat is reasonable.

Opt-2 employs Chiaraviglio et al. (2019) idea of UAV. Here, an unlicensed wireless band is proposed for backhauling because a direct point-to-point link from Tampang Muda village to a 4G site in Kuta Kakhang village (around 14 km from Tampang Muda) (Ditdal PPI, 2020d) can be made crossing over the sea (see Figure 4.9), and the existing 4G site is located very close to the sea. Hence the Wi-Fi interference is considered negligible. Another possible wireless unlicensed backhaul link from Tampang Muda can be made to an existing 4G site in Putih Doh village (around 31 km from Tampang Muda) (Ditdal PPI, 2020d) also by crossing over the sea (see Figure 4.10). Despite the very long distance, this link is considered feasible as the longest link in TUCAN3G is 49.9 km (Rey-Moreno et al., 2011).

Opt-3 mainly suggests the use of VillageCell by Anand et al. (2012). The VillageCell can also include Tampang Muda's neighbouring villages still unserved, i.e., Tampang Tua, Way Asahan and Martanda, to enable free voice call and SMS communication intra these villages. Assuming that the residents in the village prefer local communication, the traffic for external communication would be small. Hence, a satellite link is considered the easiest option to accommodate voice call services to the outside world.

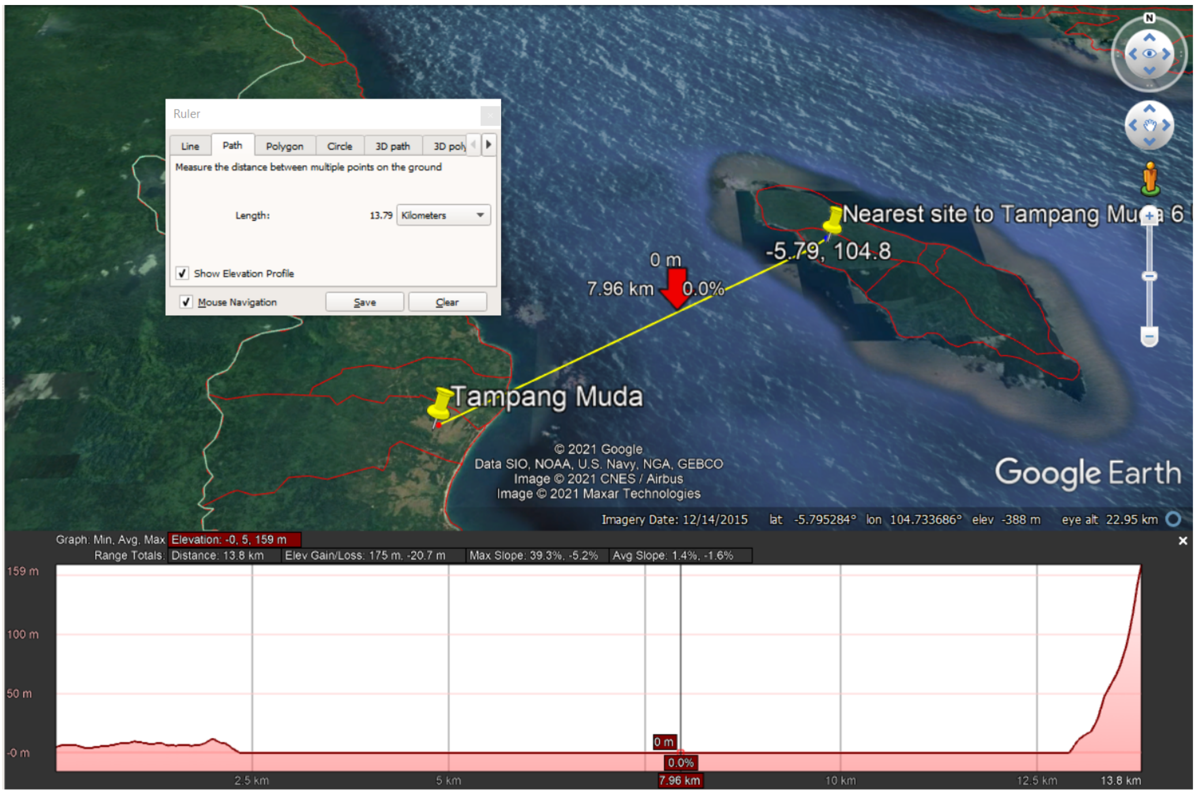

Figure 4.9: Possible wireless backhaul link from Tampang Muda village to the nearest cellular site in Kuta Kakhang village

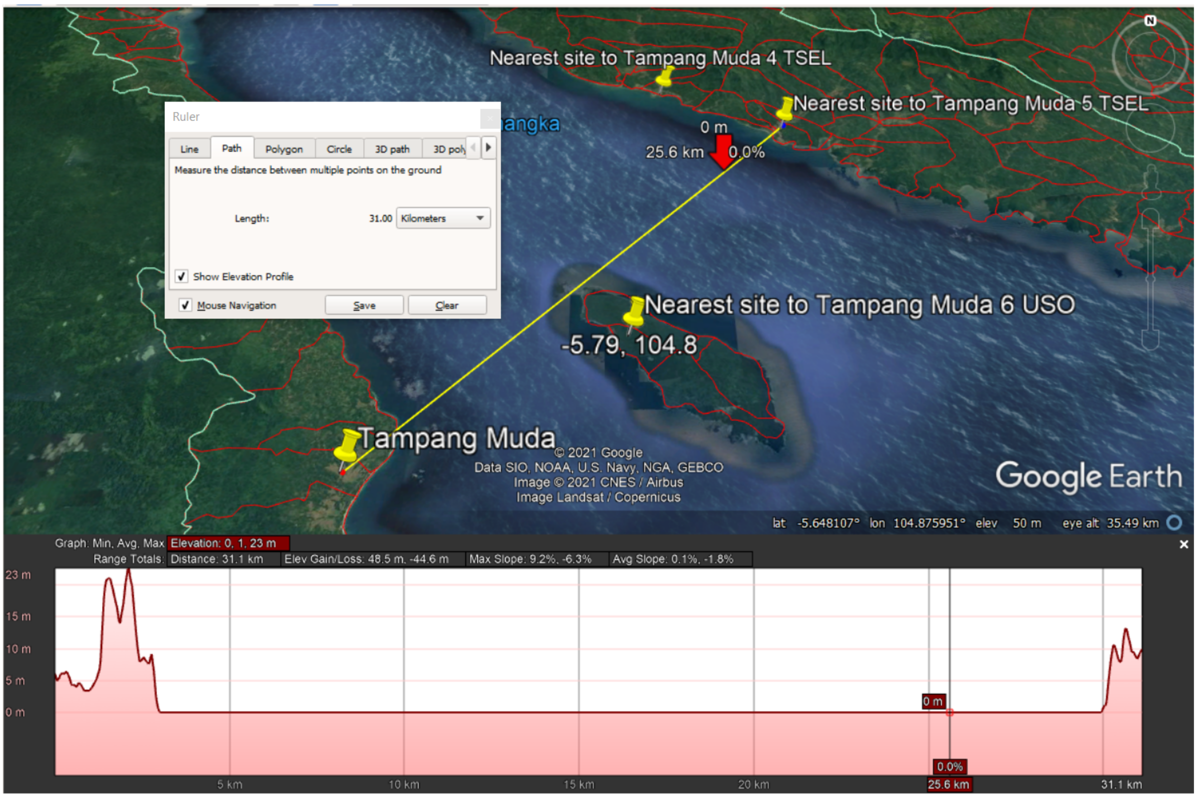

Figure 4.10: Possible wireless backhaul link from Tampang Muda village to the nearest cellular site in Putih Doh village

A battery performance predictor is included in all technology options to enhance network availability. Also, since the village has not yet served by the electricity grid, solar power is compulsory for each technology solution as the power component. Figure 4.11 summarised the process for arranging technological solutions for Tampang Muda village.

Referring to Table 4.5, Opt-1 requires the network to be deployed by BAKTI and local authority's support to protect the devices. Therefore, for Opt-1 SRO (BAKTI) + central and local authority support is needed as the Organisation solutions.

Also, by referring to Table 4.5, Opt-2 does not specify which organisation to deploy it. MNO and SRO are considered to be the most feasible. MNO and SRO both are implemented in Indonesia and can deploy the network by themselves, while the central & local authority and MVNO cannot. On the other hand, CCN is not selected as it is not yet accommodated due to regulatory constraints. Opt-2 requires 'Measure to minimise the need to visit the location for maintenance', which can be helped by adding Central and Local Authority as one of the Organisation solutions.

Opt-3 employs VillageCell and battery performance prediction model. Their requirements are 'VillageCell is deployed by BAKTI in villages that prefer local communications (within the village and the neighbouring villages); Measure to minimise the need to visit the location for maintenance'. Therefore, SRO + central and local authority is the only option for Opt-3. In delivering VillageCell, BAKTI can cooperate with an MNO to provide the spectrum.

So far, the technology+organisation solutions for Tampang Muda are:

- Store and Forward + solar power source + battery performance prediction model & SRO (BAKTI) +

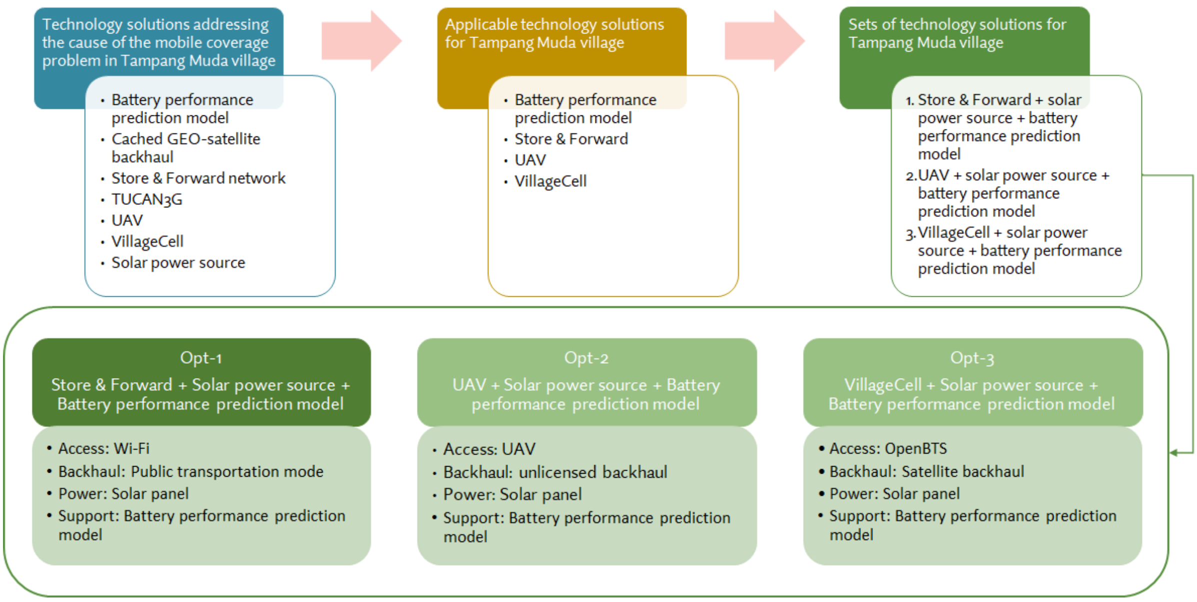

Figure 4.11: Technology solutions arrangement for Tampang Muda village

central and local authority

- UAV + solar power source + battery performance prediction model & MNO + central and local authority
- UAV + solar power source + battery performance prediction model & SRO + central and local authority
- VillageCell + solar power source + battery performance prediction model & SRO + central and local authority

When MNO is used as the organisation solution, Cruz and Touchard (2018) suggested giving a QoS relaxation on the MNO's rural network and sectoral tax reduction proportional to the rural network investments for the MNO. They require solutions 'Relaxing the QoS standard for rural networks' and 'A taxation policy that foster investments in rural areas'. When SRO is used, it requires USF as the regulatory solution. While if the central and local authority is used, no regulatory solution is required. Table 4.7 summarises the solution options previously mentioned.

Table 4.8: Solution options for Tampang Muda village

Option	Technology	Organisation	Regulatory
1	Store & Forward + solar power source + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
2	UAV + solar power source + battery performance prediction model + unlicensed backhaul	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
3	VillageCell + solar power source + battery prediction model	SRO (BAKTI) + central and local authority	USF
4	UAV + solar power + battery performance prediction model	SRO (BAKTI) + central and local authority	USF

4.4.3 Terusan village

By referring to Table 4.2, the cause of the mobile coverage problem in Terusan village is likely to be the low population density, road accessibility and topography. PLN's grid has served Terusan village. Therefore, any solutions that only address the electricity problem, such as solar power source, will not be suitable. Hence, according to Table 4.6, the possible technology solutions for population density, road accessibility and topography are battery performance prediction model, cached GEO-satellite backhaul, Store-and-Forward network, TUCAN3G, UAV and VillageCell.

By comparing the Terusan village's situation and the technology solutions' requirements in Table 4.5, Terusan village cannot use cached GEO-satellite backhaul and Store-and-Forward network solutions. It has no public transportation or any routine transportation that can carry an MDTN server as it can only be accessed via river water with a small canoe. It also has only 371 inhabitants, much less than what is required for the Cached GEO-satellite backhaul network.

The remaining technology means for Terusan village are battery performance prediction model, TUCAN3G, UAV and VillageCell. Based on that, we arrange some sets of the technology means as follows:

Opt-1 TUCAN3G + battery performance prediction model

Opt-2 UAV + battery performance prediction model

Opt-3 VillageCell + battery performance prediction model

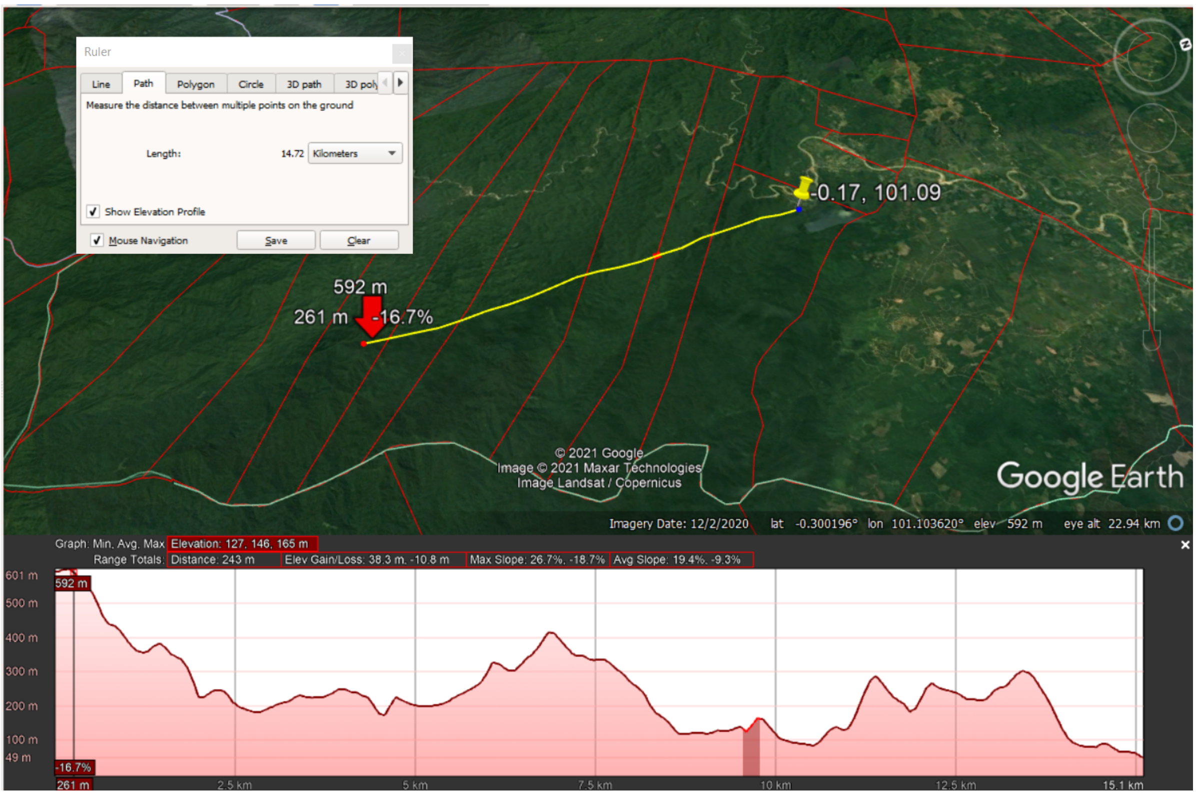

Figure 4.12: The elevation profile from Terusan village to the nearest 4G site

Opt-1 adopts TUCAN3G as proposed by Martínez-Fernández et al. (2016), Rey-Moreno et al. (2011), and Simó-Reigadas et al. (2019). This solution is considered possible as currently there is a 4G site around

15 km from Terusan village, located in Tanjung Belit village. The average point-to-point Wi-Fi link used in TUCAN3G was around 25 km (Rey-Moreno et al., 2011). Hence, establishing a wireless link between the existing 4G site to Terusan village is feasible. On the other hand, the village has highlands that can be used to mount the backhaul site. The elevation profile from Terusan village to the nearest 4G site can be seen in Figure 4.12. Since the village is served with PLN's electricity grid, the site can be powered by the grid instead of solar power. A battery performance prediction model is added to enhance the site uptime.

Licensed backhaul, WiMAX, is chosen to be used in Opt-1 instead of Wi-Fi. That is because there are already mobile services in the villages between Terusan village and the nearest 4G site (Aur Kuning, Gajah Betalut, Tanjung Beringin, Batu Sanggan, Muaro Bio and Tanjung Belit villages). Furthermore, the existing 4G site is located on low land. Thus, using Wi-Fi bands for backhaul would potentially create interference on the existing telecommunication services.

The Opt-2 mainly employs Chiaraviglio et al. (2019)'s solution. Like Unipa village, the electricity grid is used as the power source instead of solar power. The use of an electricity grid may increase the operational cost than what was stated in (Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017), but it would have a lower initial capital cost for it does not need solar panels. Opt-2 also uses a battery performance prediction model to minimise the revenue loss due to battery faults. The licensed band is proposed to be used here as the backhaul link for the same reason as Opt-1. The link would connect the UAV in Terusan village and the nearest 4G site.

The last set of technological means for Terusan village is Opt-3 which is mainly about VillageCell. It uses a similar configuration with Unipa village, except for its backhaul technology. Since Terusan village has no fibre optic line, the only option for accommodating VoIP call from/to outside the village is satellite. It is important to note that VillageCell can only be efficient if Terusan village prefers internal communication than external. Opt-3 may also be the least preferred as the VillageCell might only include three villages (Terusan, Subayang Jaya and Aur Kuning) as the other neighbouring villages have been served relatively well. Figure 4.13 summarised the process for arranging technological solutions for Terusan village.

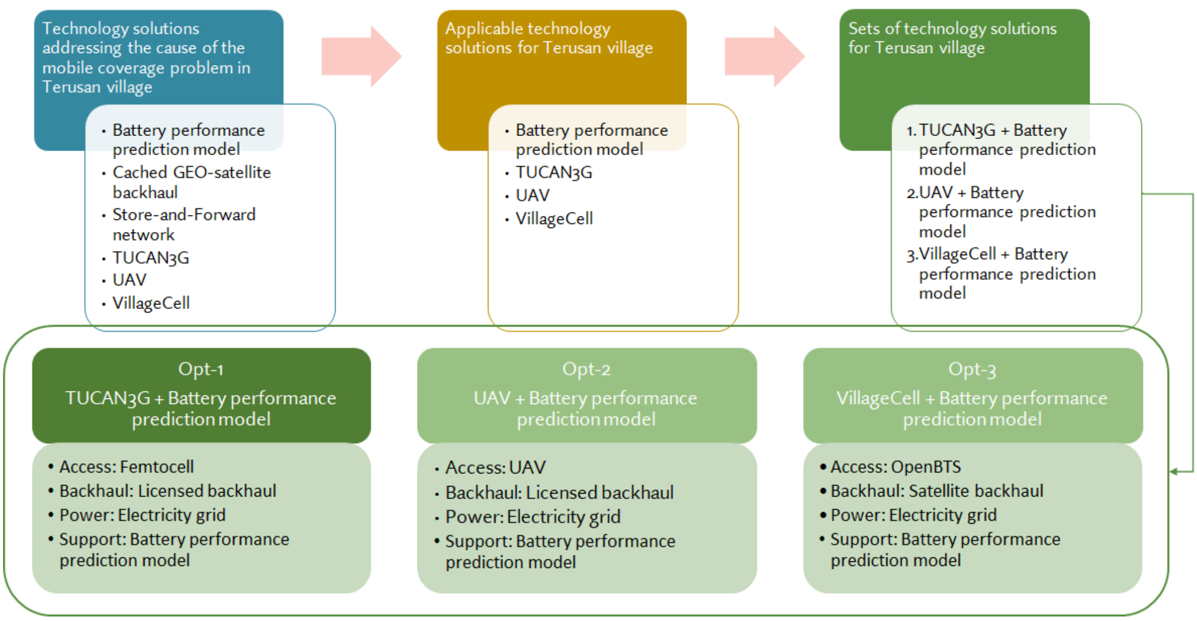

Figure 4.13: Technology solutions arrangement for Terusan village

Due to the similar technology solutions, the arrangements of Organisation and Regulatory solutions for Terusan village is similar as for Unipa village. Table 4.9 summarises the solution options previously mentioned.

The only difference is in the Organisation and Regulatory solution for Opt-1. As seen in Table 4.5, TUCAN3G requires public subsidy if an MNO implements it in an area with less than 400 inhabitants. Martínez-Fernández et al. (2016) suggested the subsidy to be allocated for establishing the backhaul tower. Since Terusan village has only 371 population, BAKTI and USF are needed if an MNO deploys Opt-1. In such a case, BAKTI can finance using USF and own the tower.

Table 4.9: Solution options for Terusan village

Option	Technology	Organisation	Regulatory
1	TUCAN3G + battery performance prediction model	MNO + central and local authority + SRO (BAKTI)	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas + USF
2	UAV + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
3	TUCAN3G + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
4	UAV + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
5	VillageCell + battery performance prediction model	SRO (BAKTI) + central and local authority	USF

4.5 Conclusion

This chapter answers the sub-research question 3: *"Which solutions available in the literature can apply to Indonesia?"*. The selection of the solutions is made by considering the national situation in Indonesia and the local situation of the unserved villages. The national situation includes the existing regulatory framework and the government's strategic plan.

Three exemplary villages are selected to examine the local situation. The key factors identified in Chapter 2 that are related to the area's condition and whose data are available are used as the criteria to select the exemplary villages, i.e., 1) the electricity grid availability, 2) the population density, 3) the accessibility by four-wheeled vehicles and 4) the topography. The selected villages are Unipa village in Papua, Tampang Muda village in Lampung and Terusan village in Riau. All of them have low population density (less than 90 people per km^2). Unipa village has an electricity grid and good road accessibility and is located on highlands. Tampang Muda village has no electricity grid, is inaccessible via road and located on flat land. Terusan village has an electricity grid, is inaccessible via road and is located on highlands with forest. Despite the lack of supporting data, these three villages are meant to represent the majority of unserved villages in Indonesia.

By evaluating each identified solution found in Chapter 3 to the Indonesian existing regulatory framework and government's strategic plan, all solutions, except Ambient Network, are found to be applicable. Some have been implemented, some are feasible, and some can only be implemented in the future. They are listed in Table 4.5.

Some options of solutions are arranged for each exemplary villages based on the applicable solutions. The arrangements consider the village's conditions and the requirements of each applicable solution. Table 4.10 summarise the solution arrangements. These arrangements will be evaluated by stakeholders' in the next chapter.

Table 4.10: Solution options for exemplary villages

Option	Technology	Organisation	Regulatory
Unipa village			
1	TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
2	UAV (UAV access & fibre optic backhaul) + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
3	TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
4	UAV (UAV access & fibre optic backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
5	VillageCell (OpenBTS access & fibre optic backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
Tampang Muda village			
1	Store & Forward (Wi-Fi access & transportation vehicle backhaul) + solar power source + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
2	UAV (UAV access & unlicensed backhaul access) + solar power source + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
3	VillageCell (OpenBTS access & satellite backhaul) + solar power source + battery prediction model	SRO (BAKTI) + central and local authority	USF
4	UAV (UAV access & unlicensed backhaul access) + solar power + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
Terusan village			
1	TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	MNO + central and local authority + SRO (BAKTI)	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas + USF
2	UAV (UAV access & licensed backhaul) + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
3	TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
4	UAV (UAV access & licensed backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
5	VillageCell (OpenBTS access & satellite backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF

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Chapter 5

Proposed Solutions

We consider a solution adequate if it accommodates the actors' perceptions and is implementable by the policymakers. Mobile telecommunication is a complex socio-technical system (Ubacht, 2020) that involves society, institutional government, technology and business. Hence, the perception of policymakers and MNOs is important. If the stakeholders disagree with the solution, implementing it will be difficult (if not impossible). Furthermore, correct governmental decisions about each policy area can lead to an enabling environment and commercially sustainable investment for operators, hence improving the coverage (Touchard, 2017).

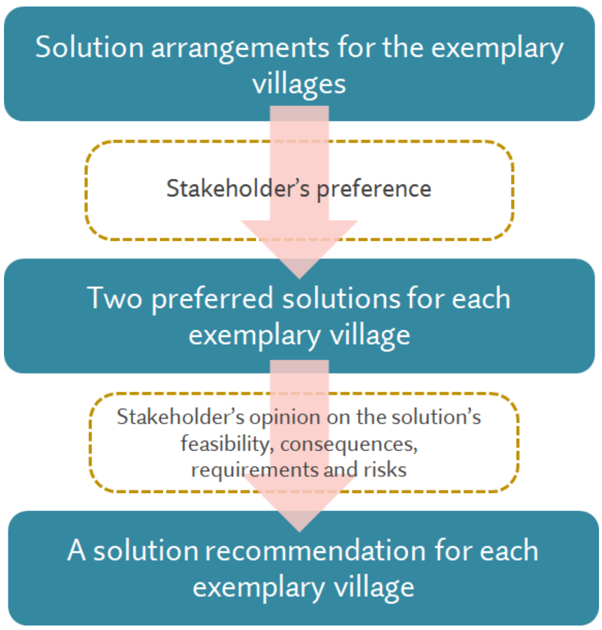

Figure 5.1: The flow of Chapter 5

This chapter aims to present a step before the main deliverable of this research. The purpose of this chapter is to fill the knowledge gap 4 and answer the sub research question 4: "What are the possible solutions to advance the mobile coverage in Indonesian rural areas that take actors perceptions into account?" by conducting interviews with relevant stakeholders. The interviews are used to evaluate the preliminary list of solutions defined in the Chapter 4, particularly Table 4.10, and to ensure that the proposed solution for each village complies with the actors' perceptions. The relevant actors will be requested to provide opinions and preference regarding the preliminary list of solutions. The requested opinions would include their vision about the feasibility to implement the solution, the negative impacts of the solutions, what is required to make the solution achieve its objective and the risks they foresee pertaining to the solutions. As the output of this chapter, each exemplary village will be given a recommendation to help solve its mobile coverage problem. Achieving this outcome will lead to answering the main research question done in the next concluding chapter.

In Appendix D, the overview of interview questions and the list of interviewees are provided. In the following section, Section 5.1, the ranked solutions for each exemplary villages based on the interviewees' preference will be presented. Two preferred solutions will be selected for each village. For each village, a discussion regarding the feasibility, negative impacts, requirements and risks of the preferred solutions will be conducted based on the interviewees' opinions in Section 5.2. Lastly, the final recommendation of solution for each exemplary village will be presented in Section 5.3. The research flow for this chapter is illustrated in Figure 5.1.

5.1 Selection of solutions based on actors' preferences

Based on the conducted interviews, the preference of interviewees towards the solution arrangements for each exemplary villages is derived and presented in Table 5.1. By calculating the sum of the ranks given by all interviewees for each option, the overall ranks are elicited. The option that has a bigger sum will have a lower overall rank.

Table 5.1: Interviewees' preference towards the solution arrangements for each village

Option	Rank								Total	Overall Rank
	Interviewee 1	Interviewee 2	Interviewee 3	Interviewee 4	Interviewee 5	Interviewee 6	Interviewee 7	Interviewee 8		
Unipa village										
1	2	1	3	2	2	2	4	2	19	2
2	4	4	4	4	5	5	5	5	38	4
3	1	2	1	1	1	1	1	1	12	1
4	3	5	2	5	4	4	2	4	33	3
5	5	3	5	3	3	3	3	3	33	3
Tampang Muda village										
1	1	4	4	4	4	4	4	4	30	4
2	2	3	1	2	2	3	3	3	21	2
3	4	1	3	1	1	1	1	2	17	1
4	3	2	2	3	3	2	2	1	22	3
Terusan village										
1	1	2	1	1	1	2	4	3	16	1
2	3	5	2	4	4	5	5	5	35	4
3	2	1	3	2	2	1	1	2	17	2
4	4	4	4	5	5	4	2	4	36	5
5	5	3	5	3	3	3	3	1	31	3

Option 3 and 1 are the two most preferable options for Unipa village. The difference between the second most preferable and the third is considerable. It shows that the preference of all actors is actually concentrated between these two options, Option 3 and 1. Meanwhile, for Tampang Muda village, the difference between all options are limited. The difference between the three most preferable options (Option 3, 2 and 4) is not significant, whereas most interviewees took Option 4 as the least preferable option. Lastly, for Terusan village, similar to Unipa village, Option 1 and 3 are the two most preferable with a significant difference with the third rank. Therefore, selecting the top 2 options for each village is considered adequate. The solution arrangements selected for each village are summarised in Table 5.2.

In the following section, actors' opinions regarding the selected solution arrangements in Table 5.2 will be discussed. The opinions are derived from the interviews.

Table 5.2: Preferred solutions for the exemplary villages

Option	Technology	Organisation	Regulatory
Unipa village			
3	TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
1	TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
Tampang Muda village			
3	VillageCell (OpenBTS access & satellite backhaul) + solar power source + battery prediction model	SRO (BAKTI) + central and local authority	USF
2	UAV (UAV access & unlicensed backhaul) + solar power source + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas
Terusan village			
1	TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	MNO + central and local authority + BAKTI	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas + USF
3	TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF

5.2 Actors' opinions on the preferred solutions

Table 5.3 summarised the actors' opinion on the preferred solutions for the three villages. Appendix D provides a more detail interviewees' opinions. In the following subsections, their opinions regarding the technology solutions, organisation solutions and regulatory solution(s) of the preferred solutions for each village will be explained. For the sake of clarity, we defined the feasibility, negative impacts, requirements and risks as follows. ***Feasibility*** describes whether or not a solution is implementable and sensible based on the interviewee's point of view. ***Negative impacts*** refer to any direct adverse effect that will *certainly* occur when the solution is implemented. ***Requirements*** list all prerequisites that have to be fulfilled to make the solution implementable. Meanwhile, ***risks*** are possible adverse effects that may or may not happen, depending on certain factors that factors that are beyond this research project.

Table 5.3: Actors' opinions on the feasibility, consequences, requirements and risks of the selected solutions for the exemplary villages

Option	Solution type	Feasibility	Consequences	Requirements	Risks
Unipa					
3	Technology	• femtocells are technologically ready, available in the market and do not clash with the existing law and regulation • a similar system for battery performance prediction model is available in the market and has been used in some sites • using the existing fibre optic is economically feasible	-	• further assessment on the village's capacity need and growth potential • a termination point of fibre optic line near the location of the site	• CAPEX and OPEX for using femtocells in rural outdoor areas are unpredictable • if the location of the fibre optic line is not exactly on the settlement areas and there is mountain between the fibre optic line and the areas, using the fibre optic could be difficult (if not unfeasible)
	Organisation	• the village is among BAKTI's responsibility • BAKTI may not be fully an SRO as described in the solution due to its position as a government agency with many other responsibilities • involving the central and local authority as the organisation solution is accommodated by existing regulations	• BAKTI would have a higher workload to manage and own more assets, need more technically skillful personnel and have a higher asset ownership risks	• cooperation between BAKTI and an MNO to provide the service	-
	Regulatory	• Using USF for this village is allowed and accommodated in the existing regulation	-	-	-
1	Technology	• femtocells are technologically ready, available in the market and do not clash with the existing law and regulation • a similar system for battery performance prediction model is available in the market and has been used in some sites • using the existing fibre optic is economically feasible	-	• further assessment on the village's capacity need and growth potential • a termination point of fibre optic line near the location of the site	• CAPEX and OPEX for using femtocells in rural outdoor areas are unpredictable • if the location of the fibre optic line is not exactly on the settlement areas and there is mountain between the fibre optic line and the areas, using the fibre optic could be difficult (if not unfeasible)
	Organisation	• having an MNO to deploy the network for Unipa village with Option 1 is heavily influenced by the distance between the nearest MNO's network termination and the village	• higher cost for deploying the site than if the site is deployed by BAKTI	• this village needs to be included in the MNO's coverage obligation	• the service price to users could be much higher than if the site is deployed by BAKTI

Table 5.3: Actors' opinions on the feasibility, consequences, requirements and risks of the selected solutions for the exemplary villages

Option	Solution type	Feasibility	Consequences	Requirements	Risks
	Regulatory	• different type of location (urban, rural and remote) might require different type of service that do not necessarily have the same quality • reducing taxes to foster investments in rural areas is perceived sensible, but any policy that would negatively affect the national income would face opposition in the process of manifesting it into regulation	• poor quality of service in many rural areas and the regulator cannot guard it • more explicit QoS gap between urban and rural areas	• QoS relaxation should be done only after assessing the actual condition of the site and applied only to the necessary sites • amendments on the QoS regulations and taxes regulations • change in the existing's government income-orientation • combining the taxation policy with coverage obligation and appropriate punitive mechanism on the coverage obligation • the criteria that clarify which site eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality • a careful tax reduction formulation	• the reduction of tax might not promote rural network development by MNOs as expected, especially if the tax is reduced first, before the MNO cover the rural areas
Terusan					
1	Technology	• femtocells are technologically ready, available in the market and do not clash with the existing law and regulation • a similar system for battery performance prediction model is available in the market and has been used in some sites • LOS link between Terusan village and the nearest site cannot be made	-	• further assessment on the village's capacity need and growth potential • a field survey to examine whether wireless terrestrial backhaul can still be feasible	• CAPEX and OPEX for using femtocells in rural outdoor areas are unpredictable • Commercially unsustainable if the relay nodes could only be placed in unpopulated areas
	Organisation	• having an MNO to deploy the network for Unipa village with Option 1 is heavily influenced by the distance between the nearest MNO's network termination and the village • BAKTI has never provide subsidy to the network owned by MNO	• higher cost for deploying the site than if the site is deployed by BAKTI	• this village needs to be included in the MNO's coverage obligation • a new policy or work guide that permitting BAKTI for providing subsidy in the areas in need	• the service price to users could be much higher than if the site is deployed by BAKTI
	Regulatory	• different type of location (urban, rural and remote) might require different type of service that do not necessarily have the same quality • reducing taxes to foster investments in rural areas is perceived sensible, but any policy that would negatively affect the national income would face opposition in the process of manifesting it into regulation • USF has never been used to subsidise network owned by an MNO	• poor quality of service in many rural areas and the regulator cannot guard it • more explicit QoS gap between urban and rural areas	• QoS relaxation should be done only after assessing the actual condition of the site and applied only to the necessary sites • amendments on the QoS regulations and taxes regulations • change in the existing's government income-orientation • combining the taxation policy with coverage obligation and appropriate punitive mechanism on the coverage obligation • the criteria that clarify which site eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality • a careful tax reduction formulation • adjustment in the regulation to allow subsidy for MNOs network in areas in need	• the reduction of tax might not promote rural network development by MNOs as expected, especially if the tax is reduced first, before the MNO cover the rural areas

Table 5.3: Actors' opinions on the feasibility, consequences, requirements and risks of the selected solutions for the exemplary villages

Option	Solution type	Feasibility	Consequences	Requirements	Risks
3	Technology	• femtocells are technologically ready, available in the market and do not clash with the existing law and regulation • a similar system for battery performance prediction model is available in the market and has been used in some sites • LOS link between Terusan village and the nearest site cannot be made	-	• further assessment on the village's capacity need and growth potential • a field survey to examine whether wireless terrestrial back-haul can still be feasible	• CAPEX and OPEX for using femtocells in rural outdoor areas are unpredictable • commercially unsustainable if the relay nodes could only be placed in unpopulated areas
	Organisation	• Terusan village is not categorised as an eligible scope of work for BAKTI, but having BAKTI to cover Terusan village is sensible after looking at the village's situation	• BAKTI would have a higher workload to manage and own more assets, need more technically skillful personnel and have a higher asset ownership risks	• a clear definition of 'area in need' • cooperation between BAKTI and an MNO to provide the service	-
	Regulatory	• Terusan village currently is not eligible for USF, but having USF to cover Terusan village is sensible after looking at the village's situation	-	• adjustment in the regulation to allow the use of USF in areas in need	-
Tampang Muda					
3	Technology	• VillageCell is technologically ready and available in the market • VillageCell clashes with the existing law and regulation • a similar system for battery performance prediction model is available in the market and has been used in some sites • there are existing sites powered by solar panel in the existing MNOs' network	• the network would not be able to interconnect with the existing mobile network, could only offer a limited mobile service to users, i.e., voice call, and could not be commercialised • an inequality of the telecommunication service provided to this village and the rest of the country • frequent change of the SIM cards for those who often go outside the village • unsatisfying delayed communication to outside village using VoIP • a higher initial CAPEX for solar power system	• amendment on the regulation regarding numbering blocks, telecommunication operation and/or spectrum trading • MNO's involvement in deploying the network and providing the GSM spectrum • a new block of spectrum that is allowed for VillageCell • reliability of the solar power source in Tampang Muda village • upskilling the power engineers and more research on the usability of solar power for Indonesian mobile network in rural areas • agreement from Tampang Muda village for VillageCell type of service	• illegal usage charge or commercialisation to users • this solution might spark residents' resentment if they perceive that the service is impractical and unequal • longer network time to repair due to the use of solar panel
	Organisation	• Terusan village is not categorised as an eligible scope of work for BAKTI, but having BAKTI to cover Terusan village is sensible after looking at the village's situation	• BAKTI would have a higher workload to manage and own more assets, need more technically skillful personnel and have a higher asset ownership risks	• a clear definition of 'area in need' • cooperation between BAKTI and an MNO to provide the service	-

Table 5.3: Actors' opinions on the feasibility, consequences, requirements and risks of the selected solutions for the exemplary villages

Option	Solution type	Feasibility	Consequences	Requirements	Risks
	Regulatory	• Terusan village currently is not eligible for USF	-	-	-
2	Technology	• the UAV-based network technology is not commercially available • using UAV would be difficult considering Indonesian weather and vandalism in rural areas • if the UAV is owned and operated not by the MNO, it would clash with the existing regulation (national security, spectrum and airspace) • UAV base station is not yet internationally standardised • especially in the village with centered settlement areas, the use of UAV could reduce the CAPEX • unlicensed band for backhaul is allowed by regulation and has been used in some existing sites • LOS link between Tampang Muda village and the nearest existing site can be made • a similar system for battery performance prediction model is available in the market and has been used in some sites • there are existing sites powered by solar panel in their network	• high CAPEX and OPEX for UAV • complex operation of UAV • upskilling the existing network engineers • lower service quality due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link, instead of wireline • no regulatory guard on the unlicensed band's interference • a higher initial CAPEX for solar power system	• UAV technology as described in this solution should be manufactured and commercially available • weather-proof UAV considering Indonesian climate • an assessment to see whether this solution is more cost-efficient than the conventional large cell solution • adjustment in the existing regulation to allow UAV-based network • coordination with border countries regarding the use of UAV • reliability of the solar power source in Tampang Muda village • upskilling the power engineers and more research on the usability of solar power for Indonesian mobile network in rural areas	• a short network lifetime due to vandalism, extreme weather, too complex operation of UAV and the potential growth of ISPs using unlicensed bands • the use of UAV tethered balloon could disturb the local activity in the surrounding areas • if the UAV is operated by a company affiliated with foreign countries, it could threaten Indonesian national security • lower quality of service due to the interference in the backhaul link • interference to the existing Wi-Fi network in the village • longer network time to repair due to the use of solar panel
	Organisation	• having an MNO to deploy the network for Unipa village with Option 1 is heavily influenced by the distance between the nearest MNO's network termination and the village	• higher cost for deploying the site than if the site is deployed by BAKTI	• this village needs to be included in the MNO's coverage obligation	• the service price to users could be much higher than if the site is deployed by BAKTI
	Regulatory	• different type of location (urban, rural and remote) might require different type of service that do not necessarily have the same quality • reducing taxes to foster investments in rural areas is perceived sensible, but any policy that would negatively affect the national income would face opposition in the process of manifesting it into regulation	• poor quality of service in many rural areas and the regulator cannot guard it • more explicit QoS gap between urban and rural areas	• QoS relaxation should be done only after assessing the actual condition of the site and applied only to the necessary sites. • amendments on the QoS regulations and taxes regulations • change in the existing's government income-orientation • combining the taxation policy with coverage obligation and appropriate punitive mechanism on the coverage obligation • the criteria that clarify which site eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality • a careful tax reduction formulation	• the reduction of tax might not promote rural network development by MNOs as expected, especially if the tax is reduced first, before the MNO cover the rural areas

5.2.1 Unipa village

Option 3

Technology solutions All interviewees agree that the access technology proposed by TUCAN3G, femtocell, is technologically ready, available in the market and does not clash with the existing law and regulation, thus feasible. They acknowledged that femtocells had been used by MNOs, although currently for a different purpose (indoor access technology). Interviewee 3 even argued that femtocell might be beneficial for the 5G deployment in the future. Considering femtocells' characteristics, Interviewee 4 and 5 admitted that femtocells could significantly reduce the deployment cost and simplify the network rollout process. Interviewee 5 believed that femtocell would be feasible only if the assessment result shows that it can cover the capacity need in the village, considering the Indonesian government's target is to provide 4G service, not 2G or 3G. Answering this doubt, Interviewee 8 explained that the femtocell's capacity depends on the backhaul capacity. With the available fibre optic line in Unipa village, backhaul capacity should not be a problem.

However, further assessment of the village's capacity need and growth potential is required to use femtocell as an access technology. Interviewee 6 argued that femtocell technology might be less efficient for a village with a very sparsely distributed population, like Unipa. It has been mentioned that Unipa's population density is 1.5 people/km2, which means one cluster of residents can be very far apart. While according to the TUCAN3G specification, femtocell's maximum coverage is only around 2 km (Prieto Egido et al., 2020). Thus, when the settlement areas are too far apart and cannot be covered by one location of the femtocell node, a new or more femtocell node location needs to be established, and the additional cost might be higher than having one large cell. Interviewee 7 and 8 also argued that the femtocells available in Indonesia currently have a very small coverage, that might be less than 500 m, different from the one mentioned in the article (Prieto Egido et al., 2020). Hence, network dimensioning that pays attention specifically to the capacity need and its growth potential (whether or not femtocell would be sufficient) and surveying the actual condition of the village is required.

Moreover, some steps are required to use the existing fibre optic line as the backhaul. A termination point near the site's location needs to be built before the line can be used. Interviewee 8 explained that if there is no termination point in the village, to use the fibre optic line, a new line needs to be pulled from the nearest termination point that might be far from Unipa village. However, BAKTI, who has partial ownership of the fibre optic line in Unipa village, said that it is feasible.

The interviewees foresaw some risks pertaining to this technology solutions. Since femtocell has never been used in rural areas outdoor, the CAPEX and OPEX is unpredictable. Moreover, Unipa, due to its mountainous topography, might not be able to be served by the fibre optic line it has now. If the location of the fibre optic line is not precisely on the settlement areas, and there is a mountain between the fibre optic line and the areas, even if they are in the same village, extending the fibre optic network with another fibre optic line or wireless backhaul can be impossible or very expensive.

Interviewees 4, 7 and 8 gave comments specifically for the feasibility of the battery performance prediction model. Interviewees 4 and 7 mentioned that the feasibility of this technology depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. Meanwhile, Interviewee 8 explained that the battery performance prediction system had been used in the existing network. Although it is not exactly the same as the proposed solution, the one that is available and used today is sufficient to inform the battery performance and predict when the batteries need to change. Therefore, this technology solution is implementable.

Organisation solutions All interviewees agree that having BAKTI acting as an SRO to deploy the solution for this village is feasible. SRO provides all network infrastructure needed in rural areas, including the power system, transmitter equipment, backhaul link, tower and land so that MNOs can directly use them to provide mobile services. Unipa village is categorised among underdeveloped areas according to Presidential Regulation Number 63 of 2020; thus, it is among BAKTI's responsibility. It means BAKTI is allowed to provide mobile network coverage in this village using its public funds. Moreover, the deployment of the network by BAKTI can be more feasible since BAKTI can request the local authority or other governmental institutions to lend their lands for free. If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. Using the existing fibre optic also feasible since it is a Palapa Ring network; BAKTI can use it without an extra cost and has the privilege to request for termination point to the network operator. Interviewee 6 also explained that according to the existing regulation (GR Number 46 of 2021), BAKTI could let more than one MNO provide service in its established site, as long as they do not share spectrum. Adding to that, Interviewee 7 conveyed that transmitting different operators' signals under one transmitter (RRU) is possible without sharing spectrum by using a specific type of transmitter. However, BAKTI may not be fully an SRO as described in the solution. Due to its position as a government agency with many other responsibilities, being an SRO who rent out its networks to operators would be too complicated for BAKTI.

The deployment of a rural network under the SRO scheme by BAKTI has some negative impacts. Interviewee 4 argued that as an SRO, BAKTI's workload would be higher since it will have more assets to manage and more public fund required (also to buy the active infrastructure). It will need more technically skilful personnel and have higher asset ownership risks due to the ownership of active infrastructure that is developed quickly and quickly out-of-date.

Moreover, BAKTI needs to cooperate with an MNO to provide the service. Interviewee 7 believed that BAKTI and MNO should have a service level agreement. Otherwise, the service has to be operated by the MNO itself because MNO needs to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected.

Involving the central and local authority as the organisation solution is feasible. All interviewees from Kominfo explained that it had been accommodated in GR Number 46 of 2021 in which it enhances the relevant authorities' support and mitigates any network deployment issues caused by governments.

Regulatory solutions The use of USF as the regulatory solution for this option is feasible and sufficient to allow the option. It has been allowed and accommodated in the existing regulation that BAKTI can use USF for providing mobile network service in underdeveloped areas. The interviewees gave no additional comment regarding the regulatory constraints of the other technology and organisation solutions.

Option 1

Technology solutions Option 3 and 1 have the same technology solutions. Thus the actors' opinions regarding the technology solutions for Option 1 are the same as Option 3.

Organisation solutions Option 1 proposes MNO as the network deployer for Unipa village. Although most interviewees did not see it as unfeasible, they expressed some limitations of this solution compared to Option 3 (which proposes BAKTI as the network deployer). Interviewee 5 explained that if it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. Consequently, the cost for deploying the site would be higher in this solution because the MNO has an additional expense for the land acquisition. Subsequently, the service price to users can be much higher than if BAKTI deploys the site.

Interviewee 3 and 5 explained that this organisation solution also requires either MNO's willingness or inclusion of this village in the coverage obligation. Nonetheless, by looking at the meagre number of potential users, Interviewee 5 doubted that MNOs would be highly unlikely to be interested in covering this village voluntarily. Therefore, if Option 1 is used, coverage obligation should be taken as a regulatory solution.

Moreover, the feasibility of having an MNO to deploy the network for Unipa village with Option 1 is also heavily influenced by the distance between the nearest MNO's network termination and the village. The nearer it is from the Palapa Ring Timur's fibre optic line, the more feasible the solution will be since the cost for connecting the Palapa Ring Timur's line and the MNO's network will be lower.

Regulatory solutions Most interviewees from Kominfo thought that relaxing the QoS standard for rural networks is plausible and feasible. They acknowledged that different locations (urban, rural and remote) might require different types of service that do not necessarily have the same quality. For example, regarding latency of the internet services, urban areas require low latency connection due to their daily activity (the presence of IoT, etc.) and mobility. Meanwhile, rural may be okay with the medium latency. They also realised that rural areas could be tough to access. Thus the QoS standard should consider this situation.

However, Interviewee 3 argued that differing the QoS standard is feasible but should be done only after assessing the site's actual condition and only applied to the necessary sites. There are mainly two types of QoS in the existing regulation: 1. regarding availability, 2. regarding capacity. For example, if Unipa village turns out to be servable by fibre optic backhaul, then differing the QoS standard regarding capacity will not be suitable for Unipa. Also, if there is already a solution regarding availability, such as the battery performance prediction model and the support from the local community to ensure the site availability, differing the QoS standard regarding availability will not be effective.

Interviewees mentioned some negative impacts of implementing the QoS relaxation. If the area is excluded from the QoS standard due to implementing this regulatory solution, the users in that area may experience poor quality of service, and the regulator cannot guard it. Subsequently, a more explicit QoS gap between urban and rural areas will occur.

Different opinions appeared regarding the taxation policy's feasibility that fosters investments in rural areas, which proposes a sectoral tax reduction for MNOs that deploy rural networks. Some interviewees saw that this regulatory solution is sensible and feasible but requires regulation amendment. Interviewee 6 believed that the tax reduction is considered feasible due to a suitable formulation of the coverage obligation Kominfo has released recently and the punitive mechanism design for the non-conformities of the coverage obligation that is almost done. Interviewee 3 explained that the sectoral taxes reduction could be applied on the telecommunication BHP, USO, regional taxes (IMB, PAD, etc.) or other taxes as long as it is formulable and easily calculable, and accommodated in the regulation. Only if it is accompanied by rural network deployment by MNOs and the government can assure it will this tax reduction policy be considered feasible. Interviewee 5 added that tax reduction would be more effective if applied on the spectrum BHP, not USF. That is because USF actually will be returned to the telecommunication operator since the network deployers are the existing telecommunication operators financed by USF. Meanwhile, other interviewees argued that sectoral taxes reduction is not feasible when looking at the existing government's orientation. Reducing taxes would directly reduce the national income. Therefore, any policy that would negatively affect the national income would face opposition in the process of manifesting it into regulation.

Interviewee 6 foresaw that there is a risk that the reduction of tax does not promote rural network development by MNOs as expected, especially if the tax is reduced first, before the MNO cover the rural areas. This risk can be mitigated by implementing the coverage obligation with an appropriate punitive mechanism.

Interviewees mentioned some requirements for realising this regulatory solution. All interviewees agree that regulatory solutions require amendments to the existing regulation about cellular network QoS and relevant taxes. To allow QoS relaxation, the criteria that clarify which site eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality is needed, according to Interviewee 3.

Some interviewees identified some requirements for implementing the taxation policy that foster investments in rural areas. Interviewee 3 suggested that if it wants to be accommodated in the telecommunication BHP, the regulation about telecommunication BHP could be amended to include 'rural investments' or 'rural site's deficit' as one of its reduction factors. Nonetheless, this policy requires a careful tax reduction formulation, regardless of which tax it is objected to (import tax, BHP, etc.).

Another requirement mentioned by some interviewees is regarding mental revolution. They said that to allow an amendment on the taxation regulation, the government and lawmakers should consider telecommunication development as an alternative' profit' other than cash income. After that, if the tax will be reduced, particularly of the spectrum BHP, USF and/or the telecommunication BHP, a major change in the existing business process is required. Currently, BAKTI is perceived as the main actor responsible for the rural network deployment and is subjected to a particular target related to telecommunication service provision to rural areas in Indonesia. If the tax reduction is implemented, the burden for rural network development should not be on BAKTI anymore, BAKTI should be demanded less, and MNO should be demanded more build the network in rural areas. Considering that BAKTI has already been responsible for covering thousands of villages in Indonesia by 2022, at least until this target is accomplished, tax reduction could not be applied. That is because BAKTI needs public funds to finance this target, and the public funds provided to BAKTI depends on the country income Kominfo generates (the sectoral tax). On top of that, it also requires an excellent new business process to ensure that the tax reduction benefits rural network development, i.e., the tax savings are used by MNOs to expand their network more in rural areas. The business process includes, for example, a mechanism to value the MNOs rural investment for calculating their tax reduction amount, an audit mechanism by an independent auditor to ensure that Kominfo reduces the tax for MNOs according to the law, and so on.

5.2.2 Terusan village

Option 1

Technology solutions The technology solution in Option 1 for Terusan village is similar to the Technology solution in Option 1 for Unipa village. The only difference is in the type of backhaul it uses; it uses fibre optic in Unipa village, while in Terusan, it uses licensed backhaul. Therefore, the interviewees' opinion regarding the technology solution aspects except for the backhaul is the same.

Interviewee 8 expressed concern regarding the use of wireless terrestrial backhaul for this option. The use of terrestrial wireless backhaul for this solution might be not feasible since the LOS link from Terusan village to the nearest existing site in Tanjung Belit village cannot be made. According to the contour map, some mountains are between the villages; thus, some relay nodes should be established. If there are no potential users in the location of the relay nodes, covering the Terusan village would not be feasible for MNO since the CAPEX and OPEX spent for the relay nodes are not going to generate revenues in addition to a very low number of potential users in Terusan village itself. Moreover, establishing a site on a location where no one nearby is operationally difficult as no residents can be requested to help maintain the site, and the site would be difficult to access. Interviewee 8 explained that when the relay nodes that only have power and backhaul systems get a network problem, it would be difficult to remotely analysed due to no base station's NMS for that site. Usually, network engineers require data from three NMS to analyse the network problem: NMS of power system, NMS of backhaul system and NMS of radio base station system. Since there are no users around the relay nodes, installing the radio base station system on the relay nodes is wasteful. In such a case, using satellite backhaul might be more efficient. However, five villages currently have no cellular site established between Terusan village and the nearest existing site in Tanjung Belit village. If the relay nodes could take advantage of the potential users in those five villages, using licensed backhaul can be effective. Therefore, a field survey is needed to examine whether wireless terrestrial backhaul can still be feasible.

Organisation solutions Most interviewees prefer Option 1 more than Option 3 for Terusan village because Terusan village is not included in the underdeveloped areas either according to Presidential Regulation Number 131 of 2016 or Presidential Regulation Number 63 of 2020. They mentioned that BAKTI could not cover all areas not included in the underdeveloped areas according to the existing regulation and business process. Therefore, most interviewees saw that MNO is a more feasible organisation solution for this option. Also, considering the terms mentioned above, having BAKTI as a supporting organisation to provide subsidy would not be feasible without adjusting the existing regulation.

Interviewees concerns regarding the use of MNO as the organisation solution in Option 1 of Unipa village also apply here. They admitted that this organisation solution has a consequence the cost for deploying the site would be higher in this solution because the MNO has an additional expense for the land acquisition. Subsequently, the service price to users could be much higher than if BAKTI deploys the site. However, Interviewee 2 argued that since this solution promises commercial sustainability, MNOs should be taken as the first option for network deployer to minimise the government's intervention in the industry. Only if MNOs refuse with reasonable reasons BAKTI could take the lead. Interviewees 3 and 5 explained that coverage obligation is required to support this organisation solution and balance the MNOs' commercial orientation. That is supported by Interviewee 7 and 8, who argued that MNOs, in general, will never voluntarily cover the unprofitable or risky areas.

Regulatory solutions The regulatory solutions in Option 1 for Terusan village are relaxing the QoS standard for rural networks, a taxation policy that foster investments in rural areas and USF. The interviewees' opinion regarding the first two regulatory solutions are the same as explained in Option 1 Unipa village. Regarding the use of USF for providing subsidy to support MNO, Interviewee 5 stated that BAKTI has never provided a subsidy to the network owned by MNO until now. He added that USF is bound to Presidential Regulation Number 131 of 2016. Therefore, supporting Option 1 with USF would be feasible only if a new policy or work guide permitting BAKTI for providing subsidy in the areas in need is created.

Option 3

Technology solutions Option 3 and 1 have the same technology solutions. Thus the actors' opinions regarding the technology solutions for Option 3 are the same as Option 1.

Organisation solutions Option 3 for Terusan village proposes BAKTI as the network deployer. Since Terusan village is not categorised as an eligible scope of work for BAKTI, this option is less preferred by most of the interviewees. Interviewee 5 explained that actually BAKTI could cover this area too if, based on assessment, this area is categorised as an area in need. However, this definition is not yet created, and BAKTI currently could only work in underdeveloped areas. Some interviewees also thought that having BAKTI to cover Terusan village is sensible after looking at the village's situation. In order to do that, a clear definition of 'area in need' needs to be formulated.

Interviewees conveyed the same concerns regarding BAKTI as an SRO in Option 3 of Terusan village and Option 3 of Unipa village. Having BAKTI as the leading organisation might lead to a lower service cost for end-users. Working as an SRO would also give BAKTI a higher workload and risks to manage more assets.

Regulatory solutions The use of USF as the regulatory solution for this option would be feasible only if there is a regulation permitting BAKTI to work in areas outside the ones mentioned in Presidential Regulation Number 131 of 2016.

5.2.3 Tampang Muda village

Option 3

Technology solutions All interviewees agree that the technology for VillageCell is commercially available and ready to use. However, they also admit that VillageCell is not feasible without MNO's involvement in deploying the network and providing the GSM spectrum. Some interviewees argued that amending the spectrum regulation to allow spectrum sharing for the VillageCell to be developed without involving an MNO would be opposed by the incumbent MNO(s) since it may affect the MNO's business case. It would also result in a chaotic operation of the spectrum and more complexity for the regulator to monitor the spectrum usage since the existing mobile spectrum is allocated nationally to all MNOs, not divided between zones. According to Interviewee 1, changing the licensing model from nationwide to region or zone-wide currently is not considered by the Indonesian mobile sector and government. Interviewee 4 believed that to comply with the existing spectrum regulation, VillageCell is possible only if it is delivered by BAKTI, employing MNO to operate the VillageCell. But, according to Interviewee 8, the use of open sources system, such as OpenBTS, might pose a security threat to the MNO's system. Therefore, MNOs cannot deliver VillageCell using their spectrum. Nevertheless, Interviewee 5 mentioned that there is a plan to allocate part of the 700 MHz spectrum for this kind of purpose in the future.

All interviewees admitted that the use of VillageCell would have some negative impacts. The network would not interconnect with the existing mobile network and could only offer a limited mobile service to users, i.e., voice call and SMS service. It would create an inequality in the telecommunication service provided to this village and the rest of the country. The network also could not be commercialised. A special SIM card (and number) only for the VillageCell network would be created and used. At least the village residents need two SIM cards: one for VillageCell and one for the regular cellular network outside the village. If they do not have dual-SIM phones, then changing the SIM cards would be frequently needed for those who often go outside the village. Moreover, satellite as the backhaul for the VillageCell's VoIP service can result in unsatisfying delayed communication. Some interviewees predicted that any village users would not prefer this option.

Despite those challenges in the feasibility of the VillageCell, if the option is really needed, some requirements would have to be met. First, it needs the residents' consent and acknowledgement regarding the VillageCell service capability, according to Interviewee 3. Only if the residents value and will use more local communications than external communication, the VillageCell shall be implemented. Next, it requires an amendment to the regulation regarding numbering blocks, telecommunication operation and/or spectrum trading. It also would require cooperation between BAKTI and MNO to operate the network. Interviewee 7 particularly reminded that for VillageCell, when another party uses an MNO's spectrum, the MNO's brand should not be used. Otherwise, the MNO has to operate the network themselves to guard its brand image. If others manage it and fail to meet their QoS standard, the MNO's image would be affected.

The use of VillageCell poses some risks. According to Interviewee 2 and 5, since the network would be operated either by the MNO employed by BAKTI, or ISP that provides the internet service or the local community itself, there is a risk that either of them set a usage charge to users without BAKTI's knowing. It could deteriorate the objective of the network and make the solution ineffective. Moreover, Interviewee 6 conveyed that the local population are very sensitive to the equality of the telecommunication service in their area. If they perceive that the service is impractical and unequal, this solution might spark residents' resentment. He argued that often no service is better than the 'ugly' service.

Seeing the challenges of the VillageCell, some interviewees suggested alternatives. Interviewee 1 and 8 suggested providing a Wi-Fi access point instead of the VillageCell to avoid the regulatory constraints. Interviewee 5 suggested using MNO's private network, which according to Interviewee 8, would lead to a considerable expensive price for users. Meanwhile, interviewee 6 and 7 suggested the conventional large cell + satellite backhaul, which might not be commercially sustainable. Interviewee 7 explained that coverage obligation is required to make any MNO agree to cover this village regardless of any technology it uses.

Solar power can be a feasible solution in Tampang Muda, which has no PLN's electricity grid. Interviewee 8 said that there are existing sites powered by solar panel in their network. Thus solar power is technically feasible. However, Interviewee 7 and 8 agreed that the feasibility of using solar panel depends on the reliability of the solar power source in Tampang Muda village. If the sunlight is predicted to be unreliable for a long time, then the site would need a bigger power capacity to prevent downtime. Interviewee 7 believed that using solar power would always result in a higher initial CAPEX. It would also require upskilling the power engineers and more research on the usability of solar power for Indonesian mobile network in rural areas. He added that if the cost to accommodate this is too high, it would be better to use a fuel electricity generator than solar power.

The use of solar panel might result in a long time to repair. According to Interviewee 7, the solar panel is not commonly used as the power source for a mobile network in Indonesia. As a result, MNOs are not yet familiar with the system. When it is disrupted or got an issue, it might take a longer time to repair it because the engineer is less capable of handling solar power and the solar power engineers are not many in Indonesia yet. Also, since the performance of solar power relies on the weather, it becomes less predictable. Unscheduled maintenance usually leads to a longer time to repair than having the maintenance scheduled. A fossil-fueled electricity generator is considered more effective by Interviewee 7 since it is more reliable than solar power, and the MNO can predict when to visit the site for refuelling.

The feasibility of the battery performance prediction model used in this option is the same as mentioned in the previous village. Interviewee 8 explained that the battery performance prediction system had been used in the existing network, although it is not exactly the same as the proposed solution. Therefore, this technology solution is feasible.

Organisation solutions BAKTI currently is bound to work only in the underdeveloped areas, according to Presidential Regulation Number 131 of 2016. Tampang Muda village is not included among the underdeveloped areas according to that regulation. Therefore, interviewees argued that a regulatory adjustment is needed to allow BAKTI to cover Tampang Muda village. Interviewee 5 explained that BAKTI could cover this village using USF since it is allowed to do so by Permenkominfo Number 10/2018, considering the village is an area in need. However, it requires a new regulation for defining the 'area in need'.

Regulatory solutions Just as BAKTI's scope of work is bound by Presidential Regulation Number 131 of 2016, the use of USF for this village is currently not directly feasible. Interviewees argued that a new regulation for defining the 'area in need' is required to allow it.

Option 2

Technology solutions All interviewees doubted the feasibility of UAV as the access technology for a mobile network in rural areas for various reasons. Interviewee 2, 4, 7 mentioned that it is not feasible due to the unavailability of the vendor for this technology, the manufactured product and the commercial use as a cellular site. Interviewee 5 added that even if it is commercially available, this technology needs to be massively used in another country before deciding to use it to ensure effectiveness. Interviewee 3 said using UAV would be difficult considering Indonesian weather and vandalism in rural areas. If the UAV is owned and operated not by the MNO (like Google Loon used to be), this solution would also not be feasible due to the existing spectrum regulation. Interviewee 1 added that UAV would be difficult to apply considering the national security threat and the existing air transportation regulations. Moreover, according to Interviewee 8, the use of UAV seems to be unfeasible considering its operational challenges. Interviewee 6 and 8 believed that UAV seems inconvenient as a long term solution.

Interviewee 6 explained that the possibility for using UAV as a base station, as proposed in this solution, is still discussed by standardisation and regulatory bodies like 3GPP and ITU under the name of HIBS (HAPS for IMT Base Stations). The international mobile telecommunication association is finding suitable bands for HIBS and is estimated to be decided by 2023. Hence, Indonesia would not allow UAV solution (as a base station) until the standard for HIBS is released in 2023.

Interviewees also identified some possible negative impacts of the use of UAV. All interviewees estimated that both the CAPEX and OPEX for this technology could be high, and the network operation would be extremely complex. Moreover, Interviewee 7 explained that since this network model is significantly different from the existing mobile network technology, the knowledge and skill set of the existing operators' network personnel would be insufficient to handle the sites. The personnel would need an additional qualification to maintain and operate this solution. Interviewee 6 added that the Ministry of Transportation obliges anyone who operates drones to have a pilot certificate. Therefore, the network engineer would need a pilot certification, which is not among the expected qualifications of a network engineer today. Interviewee 7 also argued that the UAV-based network's service quality could be low due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link instead of wireline.

To allow this solution, there were requirements identified by the interviewees. First, UAV technology as described in this solution should be manufactured and commercially available. The UAV should be weatherproof, considering the Indonesian climate. Second, based on Interviewee 6's opinion, the manufactured UAV should be assessed to see whether this solution is more cost-efficient than the conventional large cell solution. Third, the clarification on the compliance of the UAV model network to Indonesian regulations needs to be ensured. Interviewee 5 explained that before deciding to use UAV, coordination with border countries regarding the use of UAV needs to be down, and there should be ample UAV rotary-wing technology implementation in another country.

Some risks of UAV-based network were also indicated. Interviewee 3 and 4 believed that a UAV-based network could have a short life because the infrastructures are more prone to damages due to vandalism, extreme weather and too complex operation (the autonomous scheduled trajectories, scheduled charging, etc.). The use of a UAV tethered balloon could pose a risk of disturbing the local activity in the surrounding areas, according to Interviewee 6. If the UAV is installed in the residential neighbourhood, the cable may put the residents in danger unless protected adequately. He added that if the UAV is operated by a company affiliated with foreign countries like Loon is affiliated with the US' Google; it poses a risk to Indonesian national security.

Interviewee 8 believed that, especially in the village with centred settlement areas, the use of UAV could reduce the CAPEX since it does not require tower erection and big antennas installation, which would address the accessibility challenges in rural areas. However, due to more aspects of the network operation that are prone to a network problem, such as the drone's issue, the power issue, and so on, technicians from the

MNO's central office might need to visit the site more often, which lower the effectivity of this solution.

There are different opinions between the interviewees regarding the feasibility of using the unlicensed band, such as Wi-Fi 2.4 GHz and 5.8 GHz, for backhaul. Interviewee 2 saw it as unfeasible, while the others saw it as feasible as long as its implementation complies with the existing regulation. Interviewee 2 explained that the use of the unlicensed band is considered unfeasible because, based on surveys in some unserved villages in the past, many villages that are not yet served by cellular network services have been served by an internet service established by the local communities who use Wi-Fi bands for establishing the network to provide the internet services. Many new ISPs have sprung up, especially in remote areas. Hence, if cellular backhaul link uses Wi-Fi bands, the risk of interference would be high. Meanwhile, Interviewee 4 argued that unlicensed backhaul is feasible to be used in rural areas like Tampang Muda because this free band is rarely used there, thus less risk of interference. Interviewees 1 and 6 also saw that using an unlicensed band for backhaul is allowed as long as it is according to the law (Permenkominfo Number 1 of 2019), which obliges the transmit power be less than 4 watts and bandwidth is less than 20 MHz. Interviewee 6 explained that an unlicensed backhaul link had been implemented in many existing mobile network sites. Moreover, by looking at the spatial position of the village and the nearest sites, Interviewee 8 argued that the use of terrestrial wireless unlicensed backhaul for this village is considered feasible since the LOS link from the village to the nearest existing site (either in Kuta Kakhang or Putih Doh village) can be made.

The interviewees agreed that there is a risk of interference due to unlicensed bands to its mobile network and the existing small local ISP's networks. It could result in a low QoS due to a lack of regulatory guard on the unlicensed bands. Moreover, Interviewee 2 argued that the network using the unlicensed band might not last long considering the potential growth of ISP using unlicensed bands. As a requirement, Interviewee 8 mentioned that backhaul capacity in the nearest existing site for serving the Tampang Muda's site should be available.

The interviewees' opinions regarding using solar power and battery performance prediction model are the same as in Option 3.

Organisation solutions The interviewees' opinion regarding the organisation and regulatory solutions of Option 2 for Tampang Muda is mostly the same as their opinion for Option 1 of Terusan village. Tampang Muda village is not included in the underdeveloped areas either according to Presidential Regulation Number 131 of 2016 or Presidential Regulation Number 63 of 2020. They mentioned that BAKTI could not cover all areas not included in the underdeveloped areas according to the existing regulation and business process. Therefore, most interviewees saw that MNO is a more feasible organisation solution for this option than BAKTI (SRO).

Interviewees concerns regarding the use of MNO as the organisation solution in Option 1 of Unipa village and Option 2 for Tampang Muda also apply here. They admitted that this organisation solution has a consequence the cost for deploying the site would be higher in this solution because the MNO has an additional expense for the land acquisition. Subsequently, the service price to users could be much higher than if BAKTI deploys the site. However, Interviewee 2 argued that since this solution promises commercial sustainability, MNOs should be taken as the first option for network deployer to minimise the government's intervention in the industry. Only if MNOs refuse with reasonable reasons BAKTI could take the lead. Interviewees 3 and 5 explained that coverage obligation is required to support this organisation solution and balance the MNOs' commercial orientation. That is supported by Interviewee 7 and 8, who argued that MNOs, in general, will never voluntarily cover the unprofitable or risky areas.

Regulatory solutions The regulatory solutions in Option 2 for Tampang Muda village are relaxing the QoS standard for rural networks and a taxation policy that foster investments in rural areas. The interviewees' opinion regarding the regulatory solutions are the same as explained in Option 1 Unipa village.

Seeing the challenges of all available Options for Tampang Muda village and the village's condition, some interviewees suggested the conventional large cell + satellite backhaul as the technology solutions and BAKTI as the organisation solution. The large cell + satellite backhaul model is a typical network model in Indonesian rural areas. Thus, both MNOs and Kominfo saw that it is feasible. However, they acknowledged that it might indeed be not commercially sustainable. Interviewee 7 explained that coverage obligation is required to make any MNO agree to cover this village regardless of any technology it uses. Meanwhile, Interviewee 2, 5, 6 and 8 argued that this village should be under BAKTI and USF responsibility so that commercial sustainability does not matter.

5.3 Recommendation for the exemplary village's mobile coverage problem

Table 5.3 enlists the two most preferable solutions by the stakeholders and their opinions regarding each solution's feasibility, negative impacts, requirements and risks. Based on those combined opinions, each solution's feasibility, negative impacts, requirements and risks will be evaluated and categorised into High, Medium and Low. High, Medium and Low are defined as in Table 5.4. According to the table, each selected option for each exemplary village is evaluated as in Table 5.5.

A solution among the two most preferred options listed in Table 5.5 that has the highest feasibility and the lowest negative impacts, requirements and risks are considered the most suitable solution for the village. As seen from the table, Option 3 would be the suitable solution for Unipa village as its feasibility is higher, and its negative impacts, requirements and risks are lower than Option 1. Option 3 for Unipa village uses TUCAN3G (femtocell access & fibre optic backhaul) as the technology solution, SRO (BAKTI) and central and local authority as the organisation solution and USF as the regulatory solution. For the same reason, Option 3 also would be the most suitable solution for Terusan village. Option 3 for Terusan village uses TUCAN3G (femtocell access & licensed backhaul) as the technology solution, SRO (BAKTI) and central and local authority as the organisation solution and USF as the regulatory solution. Meanwhile, for Tampang Muda village, Option 3 that uses VillageCell, is selected.

Both Option 3 for Unipa village and Option 3 for Terusan village has medium-to-high feasibility and medium-to-low negative impacts, requirements and risks. Therefore the implementability of the solution is considered high. On the other hand, Option 3 for Tampang Muda village has high negative impacts, high requirements and high risks regarding the technology solutions. Therefore, considering the stakeholders' opinion, this solution's implementability is low. Comparing to this solution, many stakeholders saw that using a large cell + satellite backhaul model would be preferable.

Table 5.4: Categorisation of the feasibility, negative impacts, requirements and risks of the solution

Level	Technology	Organisation	Regulatory
Feasibility			
High	is commercially available, has been implemented in Indonesia, does not clash with the existing regulation and technically implementable	does not clash with the existing regulation and has no uncertain factor	allowed by the existing regulation and business process
Medium	is commercially available but technically unimplementable or clash with the existing regulation	need a feasible adjustment on the existing regulation	requires a feasible change in the existing regulation
Low	is commercially not available and clash with the existing regulation	need an unfeasible adjustment on the existing regulation	requires a nearly unfeasible change in the existing regulation
Negative Impacts			
High	unsatisfying network service, high deployment cost and complicated operation	high deployment cost and complicated operation	worse telecommunication sector condition than if without the solution
Medium	unsatisfying network service, high deployment cost or complicated operation	high deployment cost or complicated operation	service quality gap
Low	no identified consequence	no identified consequence	no identified consequence
Requirements			
High	adjustment on the existing regulation, field study, adjustment on the existing industry (such as major adding new skill for the existing network engineers)	an unfeasible adjustment on the existing business process and policy	an unfeasible adjustment on the existing system and regulation
Medium	field study and adjustment on the existing regulation or adjustment on the existing industry (such as major adding new skill for the existing network engineers)	a feasible adjustment on the existing business process and policy	a feasible adjustment on the existing system and regulation
Low	next steps that can be performed directly, such as field study and the network planning	next steps that can be performed directly, such as cooperating with other organisation, adjusting the coverage obligation	no identified requirements
Risks			
High	the risks that can worsen the condition (such as residents' resentment and disturbance to locals)	the risks that can worsen the condition (such as residents' resentment and disturbance to locals)	the risks that can worsen the condition (such as residents' resentment and disturbance to locals)
Medium	the risks that could make the solution ineffective (such as unpredictable cost and/or technical obstacle)	the risks that could make the solution ineffective (such as unpredictable cost and/or technical obstacle)	the risks that could make the solution ineffective (such as unpredictable cost and/or technical obstacle)
Low	no identified risk or the risk that is acceptable	no identified risk or the risk that is acceptable	no identified risk or the risk that is acceptable

Table 5.5: The preferred solutions' feasibility, consequences, requirements and risks evaluation

Village	Option				Feasibility			Consequences			Requirements			Risks		
	No.	Technology	Organisation	Regulatory	Tech	Org	Reg	Tech	Org	Reg	Tech	Org	Reg	Tech	Org	Reg
Unipa	3	TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF	High	High	High	Low	Medium	Low	Low	Low	Low	Medium	Low	Low
Unipa	1	TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas	High	Medium	Low	Low	Medium	Medium	Low	Low	High	Medium	Low	Medium
Tampang Muda	3	VillageCell (OpenBTS access & satellite backhaul) + solar power source + battery prediction model	SRO (BAKTI) + central and local authority	USF	Medium	Medium	Medium	High	Medium	Low	High	Medium	Low	High	Low	Low
Tampang Muda	2	UAV (UAV access & unlicensed backhaul) + solar power source + battery performance prediction model + unlicensed backhaul	MNO + central and local authority	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas	Low	Medium	Low	High	Medium	Medium	High	Low	High	High	Low	Medium
Terusan	1	TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	MNO + central and local authority + BAKTI	Relaxing the QoS standard for rural networks + a taxation policy that foster investments in rural areas + USF	Medium	Medium	Low	Low	Medium	Medium	Low	Medium	High	Medium	Low	Medium
Terusan	3	TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF	Medium	Medium	Medium	Low	Medium	Low	Low	Medium	Medium	Medium	Low	Low

5.4 Conclusion

This chapter answers the sub-research question 4: *"What are the possible solutions to advance the mobile coverage in Indonesian rural areas that take actors perceptions into account?"*. By conducting interviews with relevant actors, their opinions regarding the feasibility, negative impacts, requirements and risks of the preliminary solutions derived in Chapter 4 Table 4.10 are gathered, and the two most preferred options are selected for each exemplary village.

After that, the actors' opinions regarding the preferred options are analysed, resulting in one most suitable solution for each village. The actors' opinions show the level of feasibility, negative impacts, requirements and risks of the options. The option with the highest feasibility and lowest negative impacts, requirements and risks indicates the highest implementability, thus is selected as the suitable solution for the village. According to this analysis, solution recommendation for each village is as Table 5.7, 5.6 and 5.8. In each table, the solution arrangement composed of technological, organisational and regulatory solutions is described at the top, followed by the information regarding the feasibility, negative impacts, requirements and risks of the solution arrangement below it. This information is derived from the actors' opinion showing that the solution recommendation takes actors perceptions into account. The information is important to consider before implementing the solution arrangement.

Solutions for both Unipa village and Terusan village have a high implementability due to their medium-to-high feasibility and medium-to-low negative impacts, requirements and risks. On the other hand, Option 3 for Tampang Muda village has high negative impacts, high requirements and high risks regarding the technology solutions. Therefore, considering the stakeholders' opinion, the implementability of the solution for Tampang Muda village is low. Comparing to this solution, many stakeholders argued that using a large cell + satellite backhaul model would be preferable.

Table 5.6: Solution for Tampang Muda village

<table>
<tr><th colspan="3">Solution for Tampang Muda village</th></tr>
<tr><th>Technology</th><th>Organisation</th><th>Regulatory</th></tr>
<tr><td>VillageCell (OpenBTS access & satellite backhaul) + solar power source + battery prediction model</td><td>SRO (BAKTI) + central and local authority</td><td>USF</td></tr>
<tr><td colspan="3">Feasibility</td></tr>
<tr><td colspan="3">Technology - Medium
• VillageCell is technologically ready and available in the market
• VillageCell clashes with the existing law and regulation
• a similar system for battery performance prediction model is available in the market and has been used in some sites
• there are existing sites powered by solar panel in their network
Organisation - Medium
• Tampang Muda village is not categorised as an eligible scope of work for BAKTI, but having BAKTI to cover Tampang Muda village is sensible after looking at the village's situation
Regulatory - Medium
• Tampang Muda village currently is not eligible for USF, but having USF to cover Tampang Muda village is sensible after looking at the village's situation</td></tr>
<tr><td colspan="3">Negative Impacts</td></tr>
<tr><td colspan="3">Technology - High
• the network would not be able to interconnect with the existing mobile network, could only offer a limited mobile service to users, i.e., voice call, and could not be commercialised
• an inequality of the telecommunication service provided to this village and the rest of the country
• frequent change of the SIM cards for those who often go outside the village
• unsatisfying delayed communication to outside village using VoIP
• a higher initial CAPEX for solar power system
Organisation - Medium
• BAKTI would have a higher workload to manage and own more assets, need more technically skillful personnel and have a higher asset ownership risks
Regulatory - Low</td></tr>
<tr><td colspan="3">Requirements</td></tr>
<tr><td colspan="3">Technology - High
• amendment on the regulation regarding numbering blocks, telecommunication operation and/or spectrum trading
• MNO's involvement in deploying the network and providing the GSM spectrum
• a new block of spectrum that is allowed for VillageCell
• reliability of the solar power source in Tampang Muda village
• upskilling the power engineers and more research on the usability of solar power for Indonesian mobile network in rural areas
• agreement from Tampang Muda village for VillageCell type of service
Organisation - Medium
• a clear definition of 'area in need'
• cooperation between BAKTI and an MNO to provide the service
Regulatory - Low</td></tr>
<tr><td colspan="3">Risks</td></tr>
<tr><td colspan="3">Technology - High
• illegal usage charge or commercialisation to users
• this solution might spark residents' resentment if they perceive that the service is impractical and unequal
• longer network time to repair due to the use of solar panel
Organisation - Low
Regulatory - Low</td></tr>
</table>

Table 5.7: Solution for Unipa village

Solution for Unipa village		
Technology	Organisation	Regulatory
TUCAN3G (femtocell access & fibre optic backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF

Feasibility

Technology - High
- femtocells are technologically ready, available in the market and do not clash with the existing law and regulation
- a similar system for battery performance prediction model is available in the market and has been used in some sites
- using the existing fibre optic is economically feasible

Organisation - High
- the village is among BAKTI's responsibility
- BAKTI may not be fully an SRO as described in the solution due to its position as a government agency with many other responsibilities
- involving the central and local authority as the organisation solution is accommodated by existing regulations

Regulatory - High
- using USF for this village is allowed and accommodated in the existing regulation

Negative Impacts

Technology - Low

Organisation - Medium
- BAKTI would have a higher workload to manage and own more assets, need more technically skillful personnel and have a higher asset ownership risks

Regulatory - Low

Requirements

Technology - Low
- further assessment on the village's capacity need and growth potential
- a termination point of fibre optic line near the location of the site

Organisation - Low
- cooperation between BAKTI and an MNO to provide the service

Regulatory - Low

Risks

Technology - Medium
- CAPEX and OPEX for using femtocells in rural outdoor areas are unpredictable
- if the location of the fibre optic line is not exactly on the settlement areas and there is mountain between the fibre optic line and the areas, using the fibre optic could be difficult (if not unfeasible)

Organisation - Low

Regulatory - Low

Table 5.8: Solution for Terusan village

Solution for Terusan village		
Technology	Organisation	Regulatory
TUCAN3G (femtocell access & licensed backhaul) + battery performance prediction model	SRO (BAKTI) + central and local authority	USF
Feasibility		
Technology - Medium • femtocells are technologically ready, available in the market and do not clash with the existing law and regulation • a similar system for battery performance prediction model is available in the market and has been used in some sites • LOS link between Terusan village and the nearest site cannot be made Organisation - Medium • Terusan village is not categorised as an eligible scope of work for BAKTI, but having BAKTI to cover Terusan village is sensible after looking at the village's situation Regulatory - Medium • Terusan village currently is not eligible for USF, but having USF to cover Terusan village is sensible after looking at the village's situation		
Negative Impacts		
Technology - Low Organisation - Medium • BAKTI would have a higher workload to manage and own more assets, need more technically skillful personnel and have a higher asset ownership risks Regulatory - Low		
Requirements		
Technology - Low • further assessment on the village's capacity need and growth potential • a field survey to examine whether wireless terrestrial backhaul can still be feasible Organisation - Medium • a clear definition of 'area in need' • cooperation between BAKTI and an MNO to provide the service Regulatory - Medium • adjustment in the regulation to allow the use of USF in areas in need		
Risks		
Technology - Medium • CAPEX and OPEX for using femtocells in rural outdoor areas are unpredictable • commercially unsustainable if the relay nodes could only be placed in unpopulated areas Organisation - Low Regulatory - Low		

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Chapter 6

Conclusion

This chapter is devoted to providing answers to the research questions and reflecting on the execution of the research. First, it revisits the sub-research questions in Section 6.1, which then followed by the conclusion that answers the main research question in Section 6.2. Afterwards, it presents the scientific and societal contribution in Section 6.3. The limitations and future research recommendations are discussed in Section 6.4. Reflection follows in the Section 6.5. Last, we conclude this chapter by providing recommendations regarding this study's outcomes in Section 6.6.

6.1 Revisiting the sub research questions

The study was triggered by the mobile coverage condition in rural areas in developing countries. While many previous studies found out that mobile telecommunication services play a more crucial role in promoting economic and human development in developing countries than in the developed ones, and acts as the primary means of communication that rules down the wired communication, billions of people were still not covered by mobile telecommunication service in 2017. The vast majority of them live in the rural areas in developing countries. Many studies identified that the lack of mobile telecommunication coverage in rural areas in developing countries is a complex socio-technical issue that involves society, institutional government, technology and business.

Drawing upon these situations, research focused on identifying possible solutions to advance mobile coverage to rural areas emerged. Indonesia was taken as the case study to allow a comprehensive analysis of the actual situation of the rural areas and the socio-technical complexity of the mobile telecommunication sector. Moreover, the main research question was formulated as 'How can the Indonesian Ministry of Communication and Informatics advance the mobile coverage in Indonesian rural areas?'. It was disassembled into four sub research questions.

SRQ1: Why do mobile coverage problems occur in Indonesian rural areas?

Identifying the cause of the mobile coverage problem is the first step of this research. A systematic literature study was performed to address this question. It resulted in seven key factors causing the mobile coverage problems in Indonesian rural areas: 1) Low population density; 2) Lack of electricity grid; 3) Low road accessibility; 4) Difficult topography; 5) Lack of local support; 6) Low MNOs' financial capacity, and 7) Ineffective coverage compliance policy. Key factors 1-5 represents the area's condition. It means an area's mobile network coverage is affected by its population density, topography, electricity readiness, road accessibility and local support.

SRQ2: What are the possible solutions to solve the mobile coverage problem in rural areas and their charac-

teristics?

In parallel, exhaustive literature research was done to enlist possible solutions for the rural coverage problem. Twenty-one different possible solutions were identified. They are classified into three types: technology, organisation and regulatory. Technological solutions address the problem using specific network architectures, technology and equipment. Organisational solutions address the problem by introducing a new actor or involving certain actors. Meanwhile, regulatory solutions are mainly about governmental interventions in the form of new/modified regulations and/or policies. Table 3.2, 3.3 and 3.4 summarise the technology, organisation and regulatory solutions, respectively, including the key factors they address and their requirements and challenges as their characteristics.

SRQ3: Which solutions available in the literature can apply to Indonesia?

Various solutions suggested in the literature are either derived from studies on certain countries (case studies) or based on a model which might not apply to Indonesia. Therefore, the applicability of the 21 solutions to Indonesia was examined using relevant regulation documents of Indonesia, news article, websites and reports. Table 4.5 enlist the result of the examination. Of all the applicable solutions, one is not feasible (Ambient Network). Furthermore, one organisational solution is added (MNO) as many solutions, such as UAV, cached GEO-satellite backhaul, infrastructure sharing regulatory, coverage obligated spectrum license and relaxing the QoS standard for rural network development imply the role of MNOs as the network deployer. As a result, seven technology solutions, five organisational solutions and nine regulatory solutions were found applicable for Indonesia.

However, as the result of SRQ1 (Chapter 2) showed that the area's condition affects its mobile communication coverage, and the result of SRQ2 (Chapter 3) revealed that there are local requirements for implementing some solutions, assessing the actual condition of the unserved villages became crucial. Hence, we selected three real unserved villages in Indonesia as exemplary cases: Unipa village, Tampang Muda village and Terusan village. Unipa village has an electricity grid and good road accessibility and is located on highlands. Tampang Muda village has no electricity grid, is inaccessible via road and located on flat land. Terusan village has an electricity grid, is inaccessible via road and is located on highlands with forest. The villages' condition were assessed through desk study involving journalistic articles, governmental websites and government's data. By juxtaposing the villages' situations and the applicable solutions, we arranged some solution options as in Table 4.10.

SRQ4: What are the possible solutions to advance the mobile coverage in Indonesian rural areas that take actors perceptions into account?

To enhance the implementability of the proposed solutions, we conducted interviews with eight actors; six from Kominfo and two from MNOs. The six interviewees from Kominfo represent four different but interdependent departments relevant with the mobile network deployment in rural areas. Each actor expressed their preference and opinion regarding the solution options arranged in Table 4.10. Their opinion includes the feasibility, negative impacts, requirements and risks they foresee about each solution option. Based on these insights, a solution each for Unipa, Tampang Muda and Terusan village was formulated in Table 5.7, Table 5.6 and Table 5.8, respectively.

6.2 Answering the main research question

Answering the four sub research questions led to answering the main research question. The main research question is *How can the Indonesian Ministry of Communication and Informatics advance the mobile coverage in Indonesian rural areas?*. Since the SRQ4 has successfully offered the possible solutions to advance the mobile coverage in Indonesian rural areas, we conclude that Kominfo can use the overall approach that we took in this study as a *Decision Support Scheme* to identify the possible solution for the problem, hence advancing the mobile coverage in Indonesian rural areas.

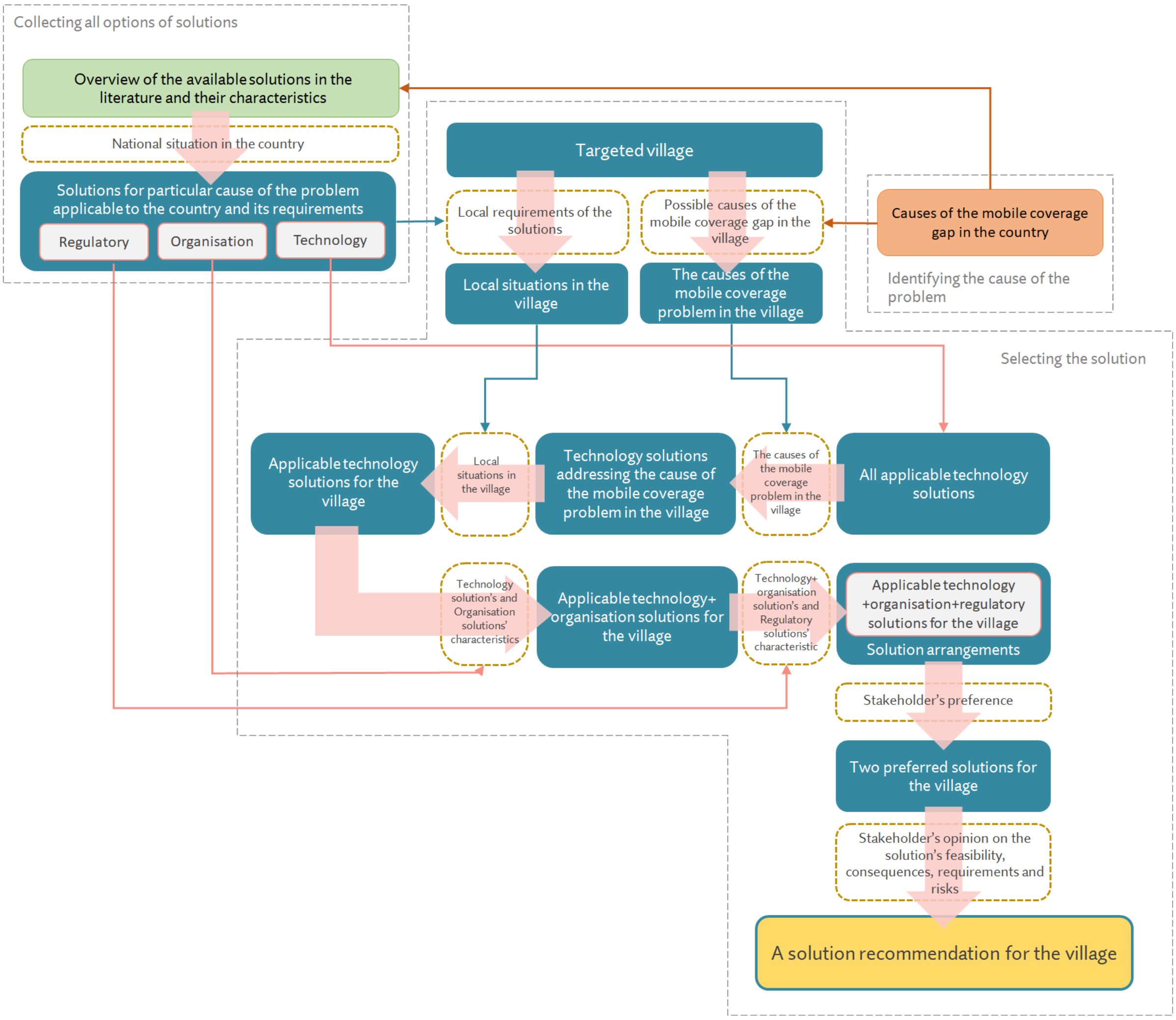

Figure 6.1: The Decision Support Scheme that Kominfo can use for finding the solution of mobile coverage problem in rural areas

The Decision Support Scheme is illustrated in Figure 6.1. It is derived from the research flow diagrams in Chapter 2-5. Starting with juxtaposing the possible causes of the problem as listed in Figure 2.4, the available and applicable solutions as listed in Table 3.2, 3.3 and 3.4, and the target village's condition, Kominfo can identify the solution options that consist of technology, organisation and regulatory solutions. Afterwards, Kominfo evaluates them with stakeholders' perspectives. An elaboration on the recommended practical use of the Decision Support Scheme is provided in Section 6.6. It is important to note that Kominfo needs to involve some actors for implementing the Decision Support Scheme, such as:

- consultant, to provide the overview of the available solutions in the literature and their characteristics;
- MNO, to provide opinions regarding the solution's feasibility; and

- network technology vendor, to clarify the feasibility, cost and benefit of innovative solutions that are not yet available on the market.

We expect that the Decision Support Scheme is future-proof for Kominfo; it can be used to find the solution for the rural coverage problem in Indonesia in the future by updating the list of regulatory, technology and organisation solutions. For now, we consider the available and applicable solutions as listed in Table 3.2, 3.3 and 3.4 up-to-date. Thus Kominfo can directly use them to support their effort to advance mobile coverage in rural areas. Those tables fill the green rectangle part of the scheme. However, an innovation in the mobile network technology, regulatory and organisation may be fast-developed. Therefore, if the effort to advance the mobile coverage in Indonesian rural areas will be held in the next two years or more, we suggested that a literature review for inventorying the available solutions be re-conducted. Meanwhile, we expect that the causes of the mobile coverage gap in the country (the orange rectangle part) as found in Chapter 2 Figure 2.4 would still be applicable in the future.

6.3 Contribution

6.3.1 Scientific contribution

By conducting this study, we claim that we have provided the following scientific contributions:

1. Comprehensive analysis of the causes of the mobile coverage problem in rural areas
   This research fulfils the first knowledge gap identified in Chapter 1. A comprehensive study about the cause of the mobile coverage problem in rural areas was lacking. None of the articles found in the literature research (more than a hundred documents) provides an analysis of the mobile coverage problem in rural areas. The cause of the mobile coverage problem was only shortly mentioned in the articles proposing solutions through the case they were studying. The articles showed that the potential cause(s) of the problem might be different between areas and countries. We hereby provide: 1) a comprehensive analysis of the mobile coverage problem causes in rural areas globally and 2) a comprehensive analysis of the mobile coverage causes in Indonesian rural areas that also confirms some of the causes mentioned in the previous studies. They are presented in Chapter 2.

2. Comprehensive guidance for finding solutions of mobile coverage problem in rural areas
   A plethora of studies for solving the mobile coverage problem in rural areas has been conducted separately. Each of them indicates a specific context to apply and requirements for its effectiveness. In Chapter 3, we presented a collection of possible solutions available in the literature for mobile coverage problems in rural areas completed with the information about their context (what cause(s) of the problem it addresses) and their requirements (local requirements, national requirements and challenges).

3. A scientific study proposing solutions for mobile coverage problem in Indonesian rural areas
   This study also fills the knowledge gap for scientific study proposing solutions for the mobile coverage problem in Indonesian rural areas. We offered solutions for the mobile coverage problem in Indonesian rural areas that are implementable rightfully to Unipa and Terusan villages. The solution may also apply to other unserved villages with the same situations as Unipa and Terusan villages.

4. A solution for mobile coverage problem in rural areas that includes stakeholders' perspective
   We also accomplished academic research to find solutions for mobile coverage problems in rural areas that incorporate stakeholders' perspectives. None of the literature we have reviewed provides solutions that consider the stakeholders perspective, while their perspectives are essential to consider as mobile telecommunication is a complex socio-technical system. The final solution proposed in this study has incorporated the stakeholders' perspectives. Furthermore, we proposed Decision Support Scheme for identifying solutions in which stakeholders' involvement takes part. This is the more practical part of the activities to be taken as presented in Figure 6.1.

6.3.2 Societal contribution

This study also contributes to society as follows:

1. This research outcome is beneficial for any country seeking solutions for mobile coverage problems in rural areas. Table 3.2, 3.3 and 3.4 may provide guidance for any country to initiate their own process of developing the solution for mobile coverage problem in rural areas.

2. The final result of this study, a set of solutions in Table 5.7, 5.6 and 5.8, can be directly usable for the Ministry of Communication and Informatics as a starting point to cover Unipa, Tampang Muda and Terusan village, and in developing policy or regulations for mobile coverage expansion to its rural areas. The solution can also be used for other villages with the same characteristics as Unipa, Tampang Muda and Terusan. Despite the the lack of supporting data, we expect that these three villages represent the majority of unserved villages in Indonesia.

3. The Decision Support Scheme (Figure 6.1) can be used by any country and government as step-by-step guidance to find solutions for mobile coverage problem in its rural areas.

6.4 Limitations and future research recommendation

6.4.1 Limitations

Despite extensive discussion in this research, it possesses several limitations and assumptions that have to be made explicit:

- The research uses some data of past years, while situation changes can be significant even just in a year. The research was conducted in 2021, but it used:

    a) CovData which represents mobile coverage status of Q2 2020 (Ditdal PPI, 2021a)
    b) Data of population per village in 2016 (Dukcapil, 2016)
    c) Fibre optic network map in Q3 2019 (Ditdal PPI, 2020b)
    d) Site distribution map in Q3 2019 (Ditdal PPI, 2020d)
    e) MNO's financial reports of 2018 (Ditdal PPI, 2020a)
    f) Number of sites per province per MNO of Q4 2019 (Ditdal PPI, 2020c)
    g) Coverage obligation model as of March 2021
    h) Data of population density per province in 2019 (Badan Pusat Statistik, n.d.-e)
    i) Data of electricity readiness per province in 2018 (Badan Pusat Statistik, n.d.-c)
    j) Data of poverty rates per province in 2018 and 2020 (Badan Pusat Statistik, n.d.-a, n.d.-b, n.d.-f, 2020)
    k) Data of the solid road percentage per province in 2014 (Kementerian PUPR, 2019)

- The selection of the three exemplary villages was based on the variation between the four key factors (electricity, population density, topography and road accessibility), not the actual condition of the majority of unserved villages in Indonesia. Due to data unavailability, we did not examine how many unserved villages have no PLN's electricity grid and low population, their topography type, and how accessible their roads are.
- The final solutions proposed for a specific village may not apply to rural areas in general. The applicability depends on its area's condition. Only if the village has the same characteristics as Unipa, Tampang Muda or Terusan villages as described in Sections 4.1 and 4.4, including the surrounding contour, the solution could be applicable.

- The use of the conventional model for the rural site (large macro cell + high tower + satellite backhaul) was not found suggested in the reviewed literature, thus not included as a technology solution in this study. Instead, the conventional model was used as a comparison in the articles and was found to be relatively less cost-efficient. Then, it is assumed that the collection of solutions provided in this study is more cost-efficient and commercially sustainable than the conventional model. However, we found through the interviews that, in some cases, some stakeholders indicated their preference on the conventional model than the available options due to the certainty of the conventional model's implementability (even tough it may be less commercially sustainable or not profitable at all). Hence, the stakeholders' preference might change if the conventional model was included in the options.
- The interviews showed that some expertise for assessing the available options is required, which was demanding for the interviewees. The available solutions were found to be too complex to understand in a short time, while the interviewees only had a short time to read the material. This situation led to suboptimal interview outcome because, some of the interviewees could not comment on the solution's negative impacts, requirements and risks as they did not fully understand the solution.
- This study did not conduct any survey to the respective villages nor have on-site informants to provide the actual data of the village. Therefore, as also mentioned in the Table 5.7, 5.6 and 5.8, each proposed solution requires further assessment on the village (for the field survey, for measuring the capacity need and/or for deriving the residents' preference). Due to the same reason, this study also excludes the 'rural local support' in the identification of the solution options in Chapter 4.
- Mobile network vendor's and smaller-scale MNOs' opinion were not involved. Based on the interview results, we found out that network vendors play a crucial role in making a particular technology available, such as UAV, battery performance prediction model and MDTN. Due to the limited time, we have not interviewed any network vendors. We also only interviewed representatives from Indosat and Telkomsel. These two MNOs are 'big' in terms of its market share and operational spectrum. We have tried to interview some persons from Smartfren and Net1, but they were not willing to be interviewed and we could not find other representatives, which were beyond our power. Hence, opinions from MNOs with smaller market share and that operate only in one or two spectrum (s) were also not incorporated in this study.
- In Section 2.2, a simple correlation test using SCC and linear regression analysis is used based on data per province. It led to a correlation like 'more unserved villages can be found in a less dense province'. However, even in a province, the density varies; there are urban villages with high population density and there are rural villages. A more accurate relationship between the indicators would be derived using data with higher resolution, resulting in a more precise correlation like 'more unserved villages can be found in a less dense district'. Currently, it used provincial data, which is the first administrative division (Adm1) in Indonesia. Meanwhile, Village is the fourth administrative division (Adm4) after Municipality (Adm2) and District (Adm3). It also used SCC to show the correlation without conducting any in-depth analysis about which statistical method would be best for this use, while there are also Pearson, Kendall tau rank, Goodman and Kruskal's gamma and many more. We recommend a further quantitative analysis that involves a thorough statistical analysis to enhance the result of Chapter 2.
- As also has been mentioned in Section 4.2, only information mentioned in Appendix B, which is based on the reviewed articles, was assessed. Not all information on the solution may be mentioned in the reviewed articles since the reviewed articles might only discuss certain aspects. For example, regarding UAV, the reviewed articles (Chiaraviglio et al., 2019; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Ilcev and Singh, 2004; Zhang et al., 2019) did not mention the social aspects, such as regarding theft and personnel skills in their papers. Hence, those aspects were not included in assessing the applicability of the solution to Indonesia. A designated study is required to understand each solution that involves much more literature fully. It was beyond the scope of this research.

6.4.2 Future research recommendations

Based on the limitations of this research, we identify the following research potential in the future:

1. Identifying causes of the mobile coverage problem in Indonesian villages using quantitative and statistical analysis on the higher resolution data
   Our study shows that empirical numerical data (such as statistic results and annual report) can be used to analyse the actual cause of the mobile coverage problem in a country. Hence, an in-depth quantitative and statistical analysis of the village-level data may result in a more precise understanding of the problem's actual cause that informs the significance of each key factor to the problem. The information may allow the subsequent research to focus on solutions that address the most significant factor.

2. In-depth multi-actor analysis regarding the options of solution for each exemplary village in Table 4.7, 4.9 and 4.8 using comparative cognitive map or game theory
   The interview showed that to solve the mobile coverage problem in Indonesian rural areas, the actors are interdependent to each other, have conflicting interests, and have different perceptions. An in-depth multi-actor analysis towards the options of solution for each exemplary villages may lead to another interesting, yet win-win, solution for the exemplary village, other than the solution proposed in this study which was merely based on ranking and feasibility assessment. The multi-actor analysis may take into account the actors' resource dependency and political position as well.

3. Developing a serious game to increase awareness and collaboration between the relevant stakeholders of the mobile coverage problem in Indonesian rural areas.
   As one of this study's limitation, it found that the interview was not effective in delivering all important points of the solutions provided in the literature, including the reasons why the solutions proposed by the literature. For example, the UAV solution was also proposed to offer flexibility. Moreover, as a solution comprised of technology, organisation and regulatory, delivering a solution requires a good collaboration between relevant stakeholders, such as MNO, spectrum regulator, QoS regulator, license grantor, USF administrator and local authority. Meanwhile, the interview results showed that some actors could have different perceptions due to misunderstanding. For example, the license grantor who perceived the SRO model as impossible for BAKTI and the MNO thought unlicensed bands could not be used for backhaul. Therefore, research that examines the effectiveness of serious game to promote collaboration between stakeholders by allowing them to sit together while also increase the stakeholders' information uptake by interactively presenting it can be done as a further study.

4. Evaluation of the effectiveness of the proposed Decision Support Scheme (Figure 6.1) for finding solution of mobile coverage problem in some rural regions by conducting a field study on the respective villages and cost-benefit analysis
   Another limitation of this study is that it cannot explain to what extent the exemplary villages can represent the unserved Indonesian villages. Subsequently, the extent of the proposed solution can be considered as the solution for the mobile coverage problem in Indonesian rural areas is also questionable. Research that evaluates the applicability and effectiveness of the proposed solution to other unserved villages, that also include the financial aspect of the solution, would be beneficial to clarify the generalisability of the exemplary villages and the proposed solutions in this study.

5. Evaluation of the applicability of the Decision Support Scheme to the mobile coverage problem in rural areas in general by adopting it to other cases in another country
   We proposed Decision Support Scheme for identifying solutions to mobile coverage problem in rural areas that any actor can use in any country. Thus, we recommend further research that adopting this Decision Support Scheme to identify solutions in other countries. The research could further reduce the global mobile coverage gap between urban and rural areas.

6.5 Reflection

Beyond answering the research questions, we found some more additional insights during the research journey. We divide the reflections into four themes: the additional findings regarding the study of mobile network coverage in rural areas, the research execution, the generalisability of the outcomes and the research relevance with the EPA program.

The study of mobile network coverage in rural areas

There is an interdependency circle around the innovation of the mobile network technology for rural areas, as illustrated in Figure 6.2. Our research started with a literature study, in which many innovative solutions proposed to be used by society to improve mobile network coverage in rural areas. It implied a dependency of the researchers that develop or invent an innovation to the mobile network vendors that would produce their invention and make it available for the government and MNOs. On the other side, vendors rely on the government and MNOs to use their products and would not produce a product unless they were assured that it would be used by the government and/or MNOs. However, when we brought the innovation to the government and MNOs, they mentioned that they might use it if there is research or report that proves the solution concept is applicable in their country. It implied a dependency from a government in a country on the researchers. Meanwhile, the researcher depends on the country to 'test' the innovation. Moreover, the government and MNOs also mentioned that they might use it if there is a vendor that realises the innovation into actual and commercial products.

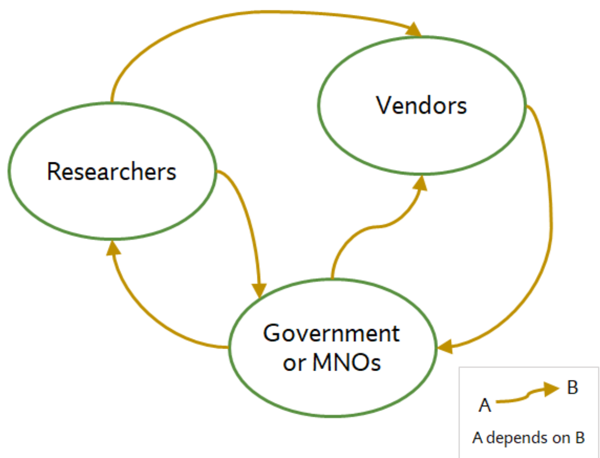

Figure 6.2: Interdependency circle around the innovation of the mobile network technology for rural areas

The causes of the mobile coverage problem can indeed be different between countries. By comparing the key factors causing the mobile coverage problem in Indonesia (in Section 2.2) and the global key factors (in Section 2.1), we found out that poverty rates factor has a little to no influence to the mobile coverage problem in Indonesia. Meanwhile, this factor, often also mentioned as local income, has been mentioned frequently in the literature as one of the possible causes of the mobile coverage problem in rural areas. In such a case, financial supplements to residents would not be beneficial to increase the mobile network penetration to rural areas in Indonesia. It gave us insight that assessing the actual cause of the country's mobile coverage problem is critical before deciding to implement any measure.

The solution created for the three exemplary villages is a patchwork. As discussed in Chapter 4, the solutions were selected also based on the village's conditions, particularly its electricity readiness, road accessibility, topography and population density. However, we foresee that the applicability of this patchwork, once proven by the field survey on the exemplary villages, can be scaled up to a more integrated solution in Indonesia. Once proven and wherever suitable, at least, BAKTI can use the technology solution to cover the unserved/underserved villages BAKTI is responsible for. For example, in the next network rollout in thousands of villages, BAKTI assesses each village's passive and infrastructure needs. If the villages have the same characteristic as Unipa, Tampang Muda or Terusan, BAKTI may use the patchwork for those villages and rollout the network accordingly.

Research execution

Composing a solution with three aspects: technology, organisation, and regulatory enhance the certainty of the solution's implementability. Performing the study made us realise that selecting the 'right' organisation and regulatory support are as important as the technology solution itself. Many promising technology solutions offered in the literature were not feasible to implement in Indonesia due to clashing with the existing regulatory framework. For example, the UAV-based network. Although the technology was supported with a thorough and detailed analysis and argued by the authors to be feasible, when it was juxtaposed with Indonesian regulation, i.e., airspace and spectrum regulation, it is difficult to be accommodated, even in the near future. Selecting the organisation to deliver the technology was also found to be crucial as it affects the regulatory supports needed.

We only involved two 'big' MNOs in the interview. Initially, we considered that to represent MNOs' perspective, at least the interviewees should come from the different size MNO: the big ones (Telkomsel, Indosat and XL) and the small ones (Smartfren and Net1). We thought that their different market segment and different spectrum might result in different opinions. However, after we conducted the interview and analysed the result, we argued that interviewing big MNOs will be more valuable and insightful for the Indonesian case. That is because, first, these MNOs are the ones that have more rural sites, so they have the more relevant background knowledge to comment on the preliminary solutions. Second, as their spectrum are the typical mobile spectrum, they are more relevant to the technology solutions discussed in this study. It would be much more helpful to discuss, for example, TUCAN3G to these MNOs, than to Net1 that only operates in 450 MHz because Net1 services cannot be used by the ordinary 3G phones. As such, Net1 might not be interested in knowing the technologies discussed in this research. Third, the big MNOs are the ones that usually BAKTI cooperates with for delivering mobile network in rural areas using USF. Hence, BAKTI depends also on these MNOs' opinion towards the solution that it will implement.

However, based on the interviews, we found some more relevant actors that were not yet included: technology vendors, the Ministry of Finance and the villages' authorities. Network technology vendors play a crucial role in making a particular technology available, such as UAV, battery performance prediction model and MDTN. For the solutions using the technology that is not yet available in Indonesia, all interviewees stated that the feasibility of those solutions depends on the network technology vendors. Therefore, having vendors interviewed could clarify the feasibility doubted by all interviewees. If the technology vendors said that a solution is impossible to produce, the solution would automatically void. The Ministry of Finance has a major influence in regulating the sectoral taxes, such as the spectrum price, telecommunication BHP and USF and national taxes, such as import tax. All the preliminary solutions, the preferred solutions and the proposed solutions have a regulatory solution related to finance, either USF or a taxation policy. Some of them require amendments to the taxation policy or USF. In such cases, according to interviewees, the Ministry of Finance's opinion is essential to see whether those regulatory solutions are feasible or not. If they say amendment on the taxation policy or USF is impossible, then the solution would be void as well. The opinions of Unipa, Tampang Muda and Terusan village's authority towards the possible technology solutions were found to be essential by the interviewees. That is because the technology solutions determine the type of services the residents would get. Only if the residents benefit and satisfy with the offered services, the technology solutions could be deployed. The local authorities represent the residents' opinions. If they say the service provided by the solution is insufficient or inconvenient, worse than not having at all, the solution would be void. The absence of these actors in the interview resulted in some missing views in selecting the proposed solutions, which might lead to the inclusion of unfeasible solutions in the list of proposed solutions.

The generalisability of the research outcomes

We argue that some of the research outcomes are generally usable, some are country-specific, and some are case-specific. Five main usable outcomes of this research were identified: 1) The comprehensive causal analysis of the mobile coverage problem in general (globally) (Figure 2.2); 2) The key factors of the mobile coverage problem in Indonesian rural areas (Figure 2.4); 3) The collection of the possible solutions available in the literature for mobile coverage problems in rural areas and their characteristics (Table 3.2, 3.3 and 3.4); 4) The Decision Support Scheme (Figure 6.1), and 5) The proposed solution for the exemplary villages (Table 5.7, 5.6 and 5.8). Outcome 1, derived from research in many countries mentioned by the reviewed papers, is expected to be applicable globally, regardless of country. Hence, we expect this diagram can be used as a starting point by any country that wants to study the mobile coverage problem in their areas. Outcome 2 is specific for Indonesia as it was derived from Indonesian empirical data. We believe that the key factor(s) of the mobile coverage problem can be different between countries, and the country's empirical data should be analysed to conclude the actual cause(s) of the mobile coverage problem in the country. Outcome 3 is expected to be usable regardless of country. It was derived by reviewing the articles that resulted from search keys that are not country-specific. Outcome 4 also is supposed to be generally applicable. Any actor or country who aims to find solutions for a mobile coverage problem in a certain area may use the Decision Support Scheme as their approach.

Last but not least, Outcome 5 is case and country-specific. The proposed solutions were selected according to the village's condition and Indonesia's situation. Therefore, we suggest the exact solution to be only proposed to other cases if the case's condition and the country's situation is the same. We expect that the many other unserved villages in Indonesia have similar conditions as our exemplary villages (Unipa, Tampang Muda and Terusan) despite the lack of our study showing the representativeness of the exemplary villages to the entire Indonesian unserved villages. Hence, we believe that the proposed solution for the exemplary villages can apply to many other unserved villages in Indonesia as well.

Relevance with EPA program

The mobile telecommunication sector is considered a complex socio-technical sector in which various actors with conflicting interests are involved in making mobile telecommunication policies. At least, there are MNOs who aim for profitability, Kominfo who aims for mobile network coverage all over the country and the government who is interested in higher country's tax income. Meanwhile, mobile telecommunication policies are inseparable from mobile telecommunication's technical aspects, such as technology and its technical operation. As seen in Chapter 3 and 5, to be able to find the solution to the mobile coverage problem in rural areas, we need to understand telecommunication technologies, such as UAV, prediction algorithm, and OpenBTS, and consider its very detailed technical aspects, such as the LOS-ness of the site to the nearest existing site and technical maintenance procedure. On the other hand, the research execution and results also showed that actors' perspectives matter in realising specific policy or regulation regarding the mobile network, mainly to find solutions for rural areas' mobile coverage problem. Moreover, we also identified interdependencies between the actors influencing their decision and eventually affecting the mobile coverage situation in rural areas. The characteristics mentioned above are the type of arena that the EPA program is dealing with.

Furthermore, mobile coverage problems in rural areas in developing countries can be considered as a *wicked problem* involving inadequate policy arrangements. It is a symptom of another problem (such as lack of electricity service and road accessibility and/or ineffective coverage obligation, and so on), has good-or-bad solutions instead of true-or-false and irreversible with no chance to learn by trial and error, has no stopping rule and ill-defined (actors perceived differently). Those characteristics match with Rittel and Webber (1973)'s definition of the *wicked problems*. This research studied mobile coverage problems in rural areas in developing countries and offers solutions that not only solve the technological aspect but also address the societal and political aspects by taking the actors' perspective into account and combining technology solutions with organisation and regulatory measures.

6.6 Recommendations

This study provided two main outcomes: the proposed solution for exemplary villages and the Decision Support Scheme for finding solutions to mobile coverage problems in rural areas. We recommend taking into account the following practical aspects of implementing those outcomes.

For implementing the proposed solution for exemplary villages

Evaluate the alignment between the type of mobile network services provided by the solution and the government's objective
During the interview, the actors from Kominfo explained that the government had set the target to provide 4G service in every village in Indonesia by 2022. On the other hand, this study did not specifically define *coverage* as '4G' coverage or the presence of 4G service, but any mobile network service. The technology solution proposed for Unipa and Terusan village was TUCAN3G, while Tampang Muda was VillageCell. By looking at the TUCAN3G technology description in Subsection 4.2.1, this technology solution might be adopted for the 4G service as well. Unfortunately, VillageCell cannot accommodate 4G service as it focuses on voice communication, not data service. Therefore, the solution proposed for Tampang Muda village cannot be used by the government to fulfil its 2022 target.

Conduct site survey to the villages
Solutions provided here were based on a desk study, which might not exactly represent the actual condition of the villages. To see whether the technology solutions are implementable, via the site-survey, the network deployer has to:

- spot the possible points for the mobile network base station
- check its actual contour type and obstacles surrounding the settlement area
- identify the actual size of potential users
- estimate the reliability of the solar power source
- request agreement from the local government and the local community regarding the service to be delivered

based on which, the type of technology can be confirmed as either feasible, effective and efficient or not. Using this information, the network deployer may also want to do a cost and benefit analysis between the proposed solution and the conventional rural network model (large cell + satellite backhaul + fossil-fueled electricity generator).

Evaluate the negative impacts, requirements and risks listed in the Table 5.7, 5.8 and 5.6
Only if the stakeholders acknowledge and agree to take those negative impacts and risks and fulfil all the requirements, the solution could be used.

For implementing the Decision Support Scheme

We claim the Decision Support Scheme in Figure 6.1 can be used by any party or actor seeking some solutions to advance mobile coverage to rural areas in any country by some slight extensions. The process is mainly divided into three stages:

1. Identifying the cause of the problem, which is the right part of the diagram.
2. Collecting all options of solutions, the left part of the diagram.
3. Selecting the solution, the middle to the bottom of the diagram, ended with the yellow rectangle.

Start with Figure 2.2 for Stage 1
The orange rectangle, which is the causes of the mobile coverage gap in the country, is derived from the Chapter 2's research flow (Figure 2.1). For Indonesia, the orange rectangle can be straightly filled by the seven key factors depicted in Figure 2.4. For other countries, as the causes of the problem may be different, the possible factors causing the mobile coverage gap globally (as in Figure 2.2) can be used as a starting point to do Stage 1 to find the actual causes of the problem in the country. Based on that, the quantitative correlation analysis using relevant indicators and the country's empirical data, as in Section 2.2, can guide to the actual causes of the mobile coverage problem in the country. Therefore, for other country's adoption, the Stage 1 (identifying the cause of the problem) should be extended as in Figure 6.3.

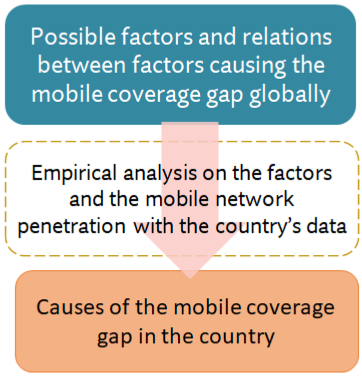

Figure 6.3: The extension on the Decision Support Scheme for Stage 1 to be applicable on other countries

Start with Table 3.2, 3.3 and 3.4 for Stage 2
The green rectangle, which is the collection of literature's available solution, has been made available through this study. Table 3.2, 3.3 and 3.4 summarised the solution options from the literature and categorised them into Technology, Regulatory and Organisation. Explanation of each solution can be found in Section 3.1. These sources can be used to start Stage 2. Nevertheless, they should be kept updated to ensure that we include all state-of-the-art solutions. We suggest to any party who implement the approach to check the literature results of the keywords we used and include the new relevant solutions, if any. It is also possible to perform a new literature study with a specific objective in mind, such as finding the solution for solving mobile coverage problems in rural areas using 4G technology or mobile broadband, etc. Next, the applicable solutions for the country can be derived by filtering them with the country's national situation, including its regulations, strategic plan, culture and other relevant aspects.

Collaboration between researchers, government, vendors and MNOs
The Decision Support Scheme requires involvement and knowledge from researchers, government, vendors and MNOs. Stage 1 and 2 are research-based, including data analytics, literature review and desk study. Therefore, this Decision Support Scheme needs researchers or consultants. On the other hand, for Stage 3, as it is field-based, it requires information from the actors that know precisely the situation of the problem, i.e., the MNOs who know the mobile communication business, the vendor who knows the technology and its possible development and the government who knows the administrative process, regulatory framework and national strategic plan.

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Appendix A

Literature Review

The literature searching was done in three moves: using the first search term in Scopus, using the second search term in Scopus and then arbitrarily in Researchgate. The list of the reviewed articles and the review results are described in the following sections.

A.1 Using the first search term in Scopus

Search term: TITLE-ABS-KEY (mobile AND coverage AND rural AND “telecom*” AND (“solution*” OR “solve*”)) AND (LIMIT-TO (LANGUAGE, ”English”)) AND (EXCLUDE (SUBJAREA, ”MEDI”) OR EXCLUDE (SUBJAREA, ”PHYS”) OR EXCLUDE (SUBJAREA, ”BIOC”) OR EXCLUDE (SUBJAREA, ”EART”) OR EXCLUDE (SUBJAREA, ”CHEM”) OR EXCLUDE (SUBJAREA, ”IMMU”) OR EXCLUDE (SUBJAREA, ”VETE”))
Number of articles resulted in: 57

No.	Year	Document Title	Authors	Included?	Reason
1	2021	A Survey on Coverage Enhancement in Cellular Networks: Challenges and Solutions for Future Deployments	Borralho R., Mohamed A., Quddus A.U., Vieira P., Tafazolli R.	No	Only provides general or summarization of all solutions.
2	2020	GNSS spoofing detection via opportunistic IRIDIUM signals	Oligeri G., Sciancalepore S., Di Pietro R.	No	Out of context. It is about a technique to combat spoofing (an act of generating and broadcasting fake navigation signals) using IRIDIUM satellite
3	2020	Bridging internet coverage gaps among nomadic pastoralists in Namibia	Chamunorwa M.B., Winschiers-Theophilus H., Zaman T.	No	The solution is specifically made for nomadic communities and found to be not suitable for common population in rural areas
4	2020	Full Coverage with 3GPP technologies on the feasibility of providing full rural cellular coverage	Jalden N., Lun J., Frenger P., Furuskar A., Venkatasubramanian S., Trojer E.	No	It discussed a technical assessment on technological solution to implement 5G in rural areas. No economic analysis regarding the profitability of the site considering the rural potential revenue level.
5	2020	A Case for Large Cells for Affordable Rural Cellular Coverage	Amuru S., Ganti R.K., Kuchi K., Milleth J.K., Ramamurthi B.	No	Out of context. It analysed a test case requirement for IMT-2020 compliant.
6	2020	Techno-economic viability of integrating satellite communication in 4G networks to bridge the broadband digital divide	Chiha A., Van der Wee M., Colle D., Verbrugge S.	Yes	Cached GEOsatellite backhaul network for increasing the affordability of satellite-based network in rural areas
7	2020	Unmanned aerial vehicles integrated HetNet for smart dense urban area	Gupta A., Gupta S.K., Rashid M., Khan A., Manjul M.	No	Out of context. This paper investigates Long Range Wide Area Network (LoRaWAN) for agriculture-based use cases.

No.	Year	Document Title	Authors	Included?	Reason
8	2020	LoRaWAN in a rural context: Use cases and opportunities for agricultural businesses	Grunwald A., Schaarschmidt M., Westerkamp C.	No	The solution is specifically made for urban environment to increase data capacity and enhance coverage (patching up coverage 'holes')
9	2020	Utilizing Connectivity Maps to Accelerate V2I Communication in Cellular Network Dead Spots	Meyer J.A.E., Puka E., Herrmann P.	No	Not addressing the problem as it studied the novel technology that predict a blank spot's border
10	2019	Minimum Cost Design of Cellular Networks in Rural Areas with UAVs, Optical Rings, Solar Panels, and Batteries	Chiaraviglio L., Amorosi L., Blefari-Melazzi N., Dell'olmo P., Lo Mastro A., Natalino C., Monti P.	Yes	UAV technology for solving rural areas problem
11	2019	Evaluating LTE coverage and quality from an unmanned aircraft system	Nekrasov M., Adarsh V., Paul U., Showalter E., Zegura E., Vigil-Hayes M., Belding E.	No	About network measurement campaign technique
12	2019	5G new radio for rural broadband: How to achieve long-range coverage on the 3.5 GHz band	Lun J., Frenger P., Furuskar A., Trojer E.	Yes	Mentions a bit about spectrum management
13	2019	Techno-economics study of spectrum sharing for mobile network operator in rural area: Study Case: Multi-Operator Core Network (MOCN) Band 1800 MHz	Hafiza L., Reza M., Mufti Adriansyah N., Denny Setiawan I.	No	About the assessment of MOCN scheme of RAN sharing for reducing MNO's expenses in rural areas, not about coverage enhancement
14	2019	Leveraging multiuser diversity for adaptive hybrid satellite-LTE downlink scheduler (H-MUDoS) in emerging 5G-satellite network	Zangar N., Hendaoui S.	No	Addressing the 4G coverage enhancement in an area where urban and rural zones are present using a combination of terrestrial and satellite network. However, it did not include economic analysis. The main solution for covering rural areas here is by utilizing satellite network, which is not a new thing. It emphasised on increasing the quality of service and capacity (cell throughput) for 4G service.
15	2019	Enabling mobile technology for healthcare service improvements	Dobaria B., Bhatt C.	No	About mobile application to support healthcare service in rural areas
16	2019	Techno-managerial Considerations for 5G Deployment in India	Jha A., Silal P., Saha D.	Yes	About UAV network planning algorithm
17	2019	Channel Measurement and Resource Allocation Scheme for Dual-Band Airborne Access Networks	Zhang R., Guo Q., Zhai D., Zhou D., Du X., Guizani M.	No	A use-case scenario-based assessment of techno-financial feasibility for 5G deployment in India
18	2019	Optimal energy management of uav-based cellular networks powered by solar panels and batteries: Formulation and solutions	Amorosi L., Chiaraviglio L., Galan-Jimenez J.	Yes	About UAV technology. It supplements Chiaraviglio, 2019 (10)
19	2018	IoRL Indoor Location Based Data Access, Indoor Location Monitoring Guiding and Interaction Applications	Ali K., Alkhatar A., Jawad N., Cosmas J.	No	The paper is not matched with the abstract. Error.
20	2018	How to Ensure Reliable Connectivity for Aerial Vehicles over Cellular Networks	Nguyen H.C., Amorim R., Wigard J., Kovacs I.Z., Sorensen T.B., Mogensen P.E.	No	UAV interference mitigation techniques. It investigated the performance of aerial radio connectivity in a typical rural area network deployment using extensive channel measurements and system simulations. Does not include economic analysis and does not address the coverage problem of rural area.
21	2018	Economical and sustainable power solution for remote cellular network sites through renewable energy	Kabir A., Kitindi E.J., Ul Abidin Jaffri Z., Rehman G., Ubaid F.B., Iqbal M.S.	Yes	About solar PV innovation

No.	Year	Document Title	Authors	Included?	Reason
22	2017	An energy and cost aware framework for cell selection and energy cooperation in rural and remote femtocell networks	Thakur R., Mishra S., Murthy C.S.R.	Yes	A technique to reduce energy consumption with femtocell. It supplements Simo-Reigadas, 2015 (31).
23	2017	Cell selection and resource allocation for sleep mode enabled femtocells with backhaul link constraint	Thakur R., Narayan Swain S., Siva Ram Murthy C.	Yes	A technique to reduce energy consumption with femtocell. It supplements Simo-Reigadas, 2015 (31).
24	2017	Telecommunications on the ring of fire	Ruiter R.	No	Describing the historical events regarding natural disaster affecting telecommunication services.
25	2016	Assessing the usage feasibility of TV White Spaces for railway communication applications	Samra M., Chen L., Roberts C., Constantinou C., Shukla A.	No	Mobile communication in railway communication domain.
26	2016	Enhancing the ad-hoc mesh networks infrastructure in rural areas: Adaptive approach	Obeidat I., Abid A.A., Natoureah H.	No	It studied the method to dimension the number of relays optimally in a decentralized mesh network in rural areas.
27	2016	Boosting service availability for base stations of cellular networks by event-driven battery profiling	Fan X., Wang F., Liu J.	Yes	Prediction model to boost battery performance in cellular base stations that may increase the rural site's profitability.
28	2016	Interoperability of electricity distribution and communication networks in large-scale outage situations	Horsmanheimo S., Maskey N., Tuomimaki L., Maki K.	No	Mobile network functionalities to improve electricity resiliency and speed up electricity outage recovery.
29	2016	Factors affecting the adoption of ICT in malnutrition monitoring. Case study: Western Uganda	Charles T.P., Yoshida C.	No	ICT app for combatting malnutrition in Uganda.
30	2016	E-Tegeko: A system that will boost citizens' participation on parliamentary regulations in Rwanda	Kabalisa R., Cyuzuzo Y., Yoshida C., Ingabire A.	No	ICT app to to boost the citizen's participation in the law making in Rwanda.
31	2015	Sharing low-cost wireless infrastructures with telecommunications operators to bring 3G services to rural communities	Simo-Reigadas J., Municio E., Morgado E., Castro E.M., Martinez A., Solorzano L.F., Prieto-Egido I.	Yes	TUCAN3G project that successfully provide network in Peruvian rural areas.
32	2015	The r-l square point process: The effect of coordinated multipoint joint transmission	Cherif I.L., Zitoune L., Veque V.	No	A modeling technique to suggest locations of femtocells in order to get the optimum coverage while mitigating interference
33	2015	Radio propagation characteristics in the large city and LTE protection from STL interference	Yoon Y., Kim J., Jung M., Chong Y.	No	Radio propagation measurement.
34	2015	LTE techno-economic assessment: The case of rural areas in Spain	Ovando C., Perez J., Moral A.	No	Techno-economic assessment on the feasibility of deploying LTE in rural areas in Spain.
35	2014	Evaluation of active position detection in Vehicular Ad Hoc Networks	Penna K., Yalavarthi V., Fu H., Zhu Y.	No	Comparison of energy consumption between different type of backhaul technologies (fibre optic, satellite and microwave link)
36	2014	Green backhauling for rural areas	Fiorani M., Tombaz S., Monti P., Casoni M., Wosinska L.	No	An investigation to optimize femtocells deployment in dense network to determine the optimum location for maximizing the number of served users and improve QoS
37	2014	Optimizing small cell deployment in arbitrary wireless networks with minimum service rate constraints	Hsieh H.-Y., Wei S.-E., Chien C.-P.	No	The technical review of a mobile multimedia broadcasting technology, DVB-NGH
38	2014	DVB-NGH: The next generation of digital broadcast services to handheld devices	Gomez-Barquero D., Douillard C., Moss P., Mignone V.	No	A review of algorithms for vehicle position identification which is important to obtain road safety for vehicles and drivers and avoid collision

No.	Year	Document Title	Authors	Included?	Reason
39	2013	Evaluation of interdependencies between mobile communication and electricity distribution networks in fault scenarios	Horsmanheimo S., Maskey N., Tuomimaki L., Kokkoniemi-Tarkkanen H., Savolainen P.	No	A review of utilizing commercial mobile networks (GSM-900 and UMTS-900) to remotely control and monitor a smart electricity grid in rural and suburban areas
40	2013	Harvesting MDT data: Radio environment maps for coverage analysis in cellular networks	Galindo-Serrano A., Sayrac B., Ben Jemaa S., Riihijarvi J., Mahonen P.	No	A review of a tool to predict a cellular network's coverage more accurately
41	2013	Next generation mobile broadcasting	Gomez-Barquero D.	No	An overview of the past, present, and future of mobile multimedia broadcasting technologies
42	2012	VillageCell: Cost effective cellular connectivity in rural areas	Anand A., Pejovic V., Johnson D.L., Belding E.M.	Yes	Proposing VillageCell as a solution for rural connectivity
43	2011	WiRE: A new rural connectivity paradigm	Dhananjay A., Tierney M., Li J., Subramanian L.	No	Same with VillageCell but without clear and sufficient elaboration.
44	2011	MDTN: Mobile delay/disruption tolerant network	Palazzi C.E., Bujari A., Bonetta S., Marfia G., Roccetti M., Amoroso A.	Yes	Delay Tolerant Networking or Store-and-Forward communication model
45	2011	WiRE: A new rural connectivity paradigm	Dhananjay A., Tierney M., Li J., Subramanian L.	No	[Duplication of entry 43] Same with Village-Cell but without clear and sufficient elaboration.
46	2010	Implementation of wide area broadcast NRTK on a communication satellite platform	Yang L., Hill C., Moore T.	No	A feasibility study for wireless broadband networks based on LTE technology in rural Victoria using Broadcast Australia (BA) TV tower sites (height >90m) and either 750MHz or 2.1GHz. This paper does not provide any new solution regarding coverage enhancement in rural areas. It concludes that using 750MHz and BATV tower sites will result in better rural coverage than 2.1GHz and common cellular tower (around 30m), which has been a common general knowledge.
47	2010	Feasibility study for LTE wireless Broadband Network in rural Victoria	Preradovic S., Zalio F., Vasic D., Marks I., Gay G.	No	A study about the implementation of positioning technology, Network-based Real-Time Kinematic (NRTK), using satellite network
48	2009	An adaptive smart antenna testbed for WiMAX radio	Khallaayoun A., Olson A., Panique M.D., Huang Y.	No	Out of context. It is about a testbed for testing an antenna and network technology.
49	2009	Requirements of a mobile procurement framework for rural South Africa	Dorflinger J., Friedland C., Merz C., De Louw R.	No	Out of context. It is about the use of mobile phone and its technology for procurement processess in rural economies
50	2008	Interoperability between WiMAX and broadband mobile space networks	Giuliano R., Luglio M., Mazzenga F.	Yes	Utilizing of WiMAX as the access network and broadband satellite network as the backhaul. No economic feasibility assessment. Has been addressed in TUCAN3G for its WiMAX access, and Chiha for its satellite backhaul.
51	2008	The mobicert mobile information community for organic primary producers: A south australian prototype	Lu N., Swatman P.	No	The use of an m-commerce app to improve information access/provision for agriculture producers in rural and regional areas
52	2007	A multi-mode MAC protocol with relay support	Otyakmaz A., Aktas I., Schinnenburg M., Pabst R.	No	The use of relay points to extend a base station coverage. No economic feasibility assessment. It does not add any useful information since it only concludes that the architecture was technically feasible.
53	2007	A wireless mesh network-based system for hotspots deployment and management	Hortelano J., Cano J.-C., Calafate C.T., Manzoni P.	No	A technique to manage Wi-Fi hotspots focusing on the captive portal component, the web component, and the user database component
54	2006	Augmenting rural supply chains with a location-enhanced mobile information system	Javid P.S., Parikh T.S.	No	An optimization of supply-chain management using mobile technology

No.	Year	Document Title	Authors	Included?	Reason
55	2004	Hybrid positioning using GPS and GSM ranging measurements	Favey E., Ammann D., Burgi C.	No	It investigated a method for estimation and characterization of traffic in cellular communication networks
56	2004	Development of stratospheric Communication Platforms (SCP) for rural applications	Ilcev St.D., Singh A.	Yes	About UAV technology. It supplements Chiaraviglio, 2019 (10)
57	2004	Characterization of rural traffic and evaluation of cellular protocols for fixed-mobile rural application	Gatwaza W.W., Afullo T.J., Sewsunker R.	No	A location positioning technique using GPS and GSM signals

A.2 Using the second search term in Scopus

Search term: TITLE-ABS-KEY (mobile AND rural AND "telecom*" AND ("govern*" OR "polic*" OR "regulat*")) AND (LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "ECON") OR LIMIT-TO (SUBJAREA, "ARTS") OR LIMIT-TO (SUBJAREA, "PSYC") OR LIMIT-TO (SUBJAREA, "MULT"))
Number of articles resulted in: 88

No.	Year	Document Title	Authors	Included?	Reason
1	2021	Mobile money adoption and response to idiosyncratic shocks: Empirics from five selected countries in sub-Saharan Africa	Koomson I., Bukari C., Villano R.A.	No	Out of context. It is a study examining the link between mobile money adoption and response to idiosyncratic shocks from the perspectives of senders and receivers using comprehensive household data across five countries
2	2021	Are telecommunications regulators correct in their beliefs that network size affects origination/termination?	Parsons S.G., Duffy-Deno K.T.	No	Out of context. It examined the relationship between the network operator size and the call off-net payments associated with the originating and the terminating minutes.
3	2021	Social Work Responses and Household-level Determinants of Coronavirus Preparedness in Rural Ethiopia	Addis Y., Abate D.	No	Out of context. This study identified the barriers toward the understanding of COVID-19 in the rural Ethiopia using statistical analysis, and telecommunnication was found to be one of the barriers.
4	2020	Using mobile phone data helps estimate community-level food insecurity: Findings from a multi-year panel study in Nepal	Liang L., Shrestha R., Ghosh S., Webb P.	No	Out of context. It studied empirical relationships between data relating to mobile phones (ownership and spending on service use), and food insecurity in rural Nepal.
5	2020	Small rural operators techno-economic analysis to bring mobile services to isolated communities: The case of Peru Amazon rainforest	Prieto-Egido I., Aragon Valladares J., Munoz O., Cordova Bernuy C., Simo-Reigadas J., Aucca-puri Quispetupa D., Bravo Fernandez A., Martinez-Fernandez A.	Yes	Small Rural Operator as a solution to enhance the mobile network penetration in rural areas
6	2020	LokaLTE: 600 MHz Community LTE Networks for Rural Areas in the Philippines	Hilario C.A.G., Claire Barela M., De Guzman M.F.D., Loquias R.T., Raro R.V.C.B., Quitayen J.J.J., Marciano J.J.S.	No	It discussed a case study in Phillipines that used a community-based LTE network in 600 MHz
7	2020	ICT Interventions in Rural Development Schemes: A Case of Rupshi Development Block, Assam	Ghosh S.K., Das A.K., Choudhury S.	No	Out of context. It discussed and analysed the use of ICT system for transforming socio-economic conditions and living standard of people in the rural areas
8	2020	Not every line is connected equally: evidence from Deyang's mobile users	Liu C., Wang L.	No	Out of context. It studied a novel conceptualization of 'access' by including both connection and service to measure the equality of access.

No.	Year	Document Title	Authors	Included?	Reason
9	2019	Towards auspicious agricultural informatization- implication of farmers' behavioral intention apropos of mobile phone use in agriculture	Mwalupaso G.E., Wang S., Xu Z., Tian X.	No	Out of context. It evaluated farmers' behavioral intention towards mobile phone use using cross-sectional data from Zambia.
10	2019	Contribution of mobile phones in expanding human capabilities in selected rural districts of Tanzania	Msoffe G.E.P., Lwoga E.T.	No	Out of context. It investigated the use of mobile phones in enhancing human capabilities and agricultural development among small-scale farmers in selected rural districts of Tanzania
11	2019	Supporting Ghanaian micro-entrepreneurships: the role of mobile technology	Asiedu E.M., Shortland S., Nawar Y.S., Jackson P.J., Baker L.	No	Out of context. The study explored the role of mobile technology and related service platforms in supporting informal micro-entrepreneurships in rural Ghana
12	2019	The adoption of network goods: Evidence from the spread of mobile phones in Rwanda	Bjorkegren D.	No	Out of context. It is about a method to estimate and simulate the adoption of a network good using transaction data from nearly the entire network of Rwandan mobile phone subscribers.
13	2019	Governing mobile Virtual Network Operators in developing countries	Son P.H., Son L.H., Jha S., Kumar R., Chatterjee J.M.	Yes	MVNO. Addressing the issue of rural site's sustainability
14	2019	Pay-As-You-Go financing: A model for viable and widespread deployment of solar home systems in rural India	Yadav P., Heynen A.P., Palit D.	No	Out of context. It studied the Pay-As-You-Go (PAYG) model as a solution to provide decentralised energy access to rural and remote communities in developing nations.
15	2019	Techno-managerial Considerations for 5G Deployment in India	Jha A., Silal P., Saha D.	No	Not as solution but has some useful info regarding the problem understanding
16	2019	E-government and the Quest for Transparent Public Service in Nigeria	Dyaji G.M., Oni S.O., Ibietan J., Joshua S.	No	Out of context. It studied a use-case scenario-based assessment of techno-financial feasibility for 5G deployment in India by taking into account growth curve-based demand forecasting of 5G services from the MNOs perspective.
17	2019	Theoretical Framework for Digital Payments in Rural India: Integrating UTAUT and Empowerment Theory	Sharma M., Sharma S.K.	No	Out of context as it is an assessment the adoption of e-government in Nigeria for a transparent public service.
18	2018	The cost, coverage and rollout implications of 5G infrastructure in Britain	Oughton E.J., Frias Z.	No	Out of context. It is an exploration of how the potential 5G rollout may take place by focusing on ubiquitous ultrafast broadband of 50 Mbps and test the impact of annual capital intensity, infrastructure sharing and reducing the end-user speed in rural areas to either 10 or 30 Mbps.
19	2018	Welfare effects of the Telecommunication Reform in Mexico	Ayala E., Chapa J., Garcia L., Hibert A.	No	A study analysing the effect of telecommunication reform done by Mexico to the consumer welfare, and income distribution. It is not included as a solution but provide some backgaround information regarding the moble coverage problem.
20	2018	Time-controlled neighborhood-driven policy-based network selection algorithm for message dissemination in hybrid vehicular networks	Oleinichenko O., Sevilmis Y., Roscher K., Jiru J.	No	This study does not provide solution for mobile coverage problem in rural areas as it is about a Hybrid Policy-based Network Selection Algorithm that uses LTE to strengthen and complement ITS-G5 under critical conditions in vehicular ad-hoc networks (VANETs).
21	2018	Smallholder farmers' knowledge of mobile telephone use: Gender perspectives and implications for agricultural market development	Owusu A.B., Yankson P.W.K., Frimpong S.	No	Out of context. It assessed the technical capacity and mobile telephone-based market information access to farmers in selected rural districts of Ghana.
22	2017	Performance of mobile phone sector in India	Mehta B.S.	No	Data of Indian mobile communication

No.	Year	Document Title	Authors	Included?	Reason
23	2017	Impediments to the implementation of universal service funds in Africa – A cross-country comparative analysis	Ogiemwonyi Arakpogun E., Wanjiru R., Whalley J.	Yes	Universal Service Funds as a solution to finance the telecommunication needs in unfavorable areas.
24	2017	The digital divide: Patterns, policy and scenarios for connecting the 'final few' in rural communities across Great Britain	Philip L., Cottrill C., Farrington J., Williams F., Ashmore F.	Yes	It mentioned the use of community-led network, satellite connection and public funding to promote broadband coverage to the 'final-few' areas
25	2017	Complementarity and substitution between physical and virtual travel for instrumental information sharing in remote rural regions: A social network approach	Matous P.	No	Out of context. It is an empirical research analysing physical and virtual contact patterns within 1270 instrumental information-sharing relationships reported by the inhabitants of the Pulau Panggung and Sumber Rejo rural subdistricts of Indonesia.
26	2017	Comparative study of short-term time series models: Use of mobile telecommunication services in CR regions	Koppelova J., Jindrova A.	No	Out of context. It is about the construction of adequate models and model analysis in the field of mobile telecommunication services, their consumption and use in various regions of the Czech Republic.
27	2017	Building foundations before technology: An operation model for digital citizen engagement in resource constrained contexts	Pade-Khene C., Thinyane H., Machiri M.	No	Out of context. It presents a case study of a digital citizen engagement project called MobiSAM (Mobile Social Accountability Monitoring), which uses mobile technology to support two-way communication between citizens and local government.
28	2017	Mobile money: Concept, ecosystem, benefits and challenges associated with mobile money	Sujata J., Perumal S., Zaman Md.A., Jha A.	No	Out of context. It is a literature review on mobile money.
29	2016	An in-depth study of the ICT ecosystem in a South African rural community: unveiling expenditure and communication patterns	Rey-Moreno C., Blignaut R., Tucker W.D., May J.	No	It assessed the affordability of access of communications in rural areas in developing countries by providing a picture of the expenditure and communication patterns of its dwellers using data from two stratified random surveys conducted in a South African rural community.
30	2016	Information need and seeking behavior of farmers in Laduba community of Kwara State, Nigeria	Akande F.T., Adewojo A.A.	No	Out of context. It is a report of a study that examined information needs and seeking behaviour of farmers in Laduba community, Kwara State, Nigeria.
31	2016	Does Migration Support Technology Diffusion in Developing Countries?	Hubler M.	No	Out of context. It studied the extent of national and international migration influence the rural technology diffusion.
32	2016	Women and Nigerian ICT policy: The inevitability of gender mainstreaming	Gapsiso N.D., Jibrin R.	No	Out of context. The chapter examines Nigeria Information Technology Policy and possible areas of encouraging gender mainstreaming in order to encourage and boost the ICT engagement for women empowerment
33	2016	Enablers and barriers of mobile banking opportunities in rural India: A strategic analysis	Behl A., Singh M., Venkatesh V.G.	No	Out of context. The paper explores the possible barriers and enablers of M-Banking in rural India and weaves them using an interpretive structural modelling (ISM).
34	2016	The making of a sustainable wireless city? Mapping public Wi-Fi access in Shanghai	Wang M., Liao F.H., Lin J., Huang L., Gu C., Wei Y.D.	No	Out of context. It is an examination of the recent development and spatial distribution of public Wi-Fi access in Shanghai, a leading business hub in China.
35	2015	Pattern of leisure-lifestyles among Indian school adolescents: Contextual influences and implications for emerging health concerns	Singh A.P., Misra G.	No	Out of context. It examines the pattern of leisure practices in a sample of school-going adolescents from rural, urban, and metro regions of North India.
36	2015	Broadband internet access and the digital divide: Federal assistance programs	Kruger L.G., Gilroy A.A.	No	Full-text was not accessible

No.	Year	Document Title	Authors	Included?	Reason
37	2015	Mobile government in African Least Developed Countries (LDCs): Proposed Implementing framework	Mtingwi J.E.	No	Out of context. It is a study about Mobile Government (M-Government) Implementing Framework in the Least Developed Countries (LDCs).
38	2015	'Two-speed' Scotland: Patterns and Implications of the Digital Divide in Contemporary Scotland	Philip L.J., Cottrill C., Farrington J.	No	The paper presents an analysis of the most recent mobile telecommunications and broadband infrastructure data published by Ofcom, the UK telecommunications regulator.
39	2015	LTE techno-economic assessment: The case of rural areas in Spain	Ovando C., Perez J., Moral A.	No	A feasibility study 30 Mbps LTE fixed service in rural areas in Spain and an assessment whether passive network sharing could make it feasible.
40	2015	Legal, Regulatory, and Risk Management Issues in the Use of Technology to Deliver Mental Health Care	Kramer G.M., Kinn J.T., Mishkind M.C.	No	It provides an assessment regarding some of the key legal, regulatory, and risk management issues in today's telemental health (TMH) environment, with specific emphasis on licensure, malpractice, credentialing and privileging, security and privacy, and emergency management.
41	2014	Entry modes and the impact of mobile microfinance at the base of the pyramid: Scenarios of "My Village Phone" in Egypt	Mohamad M., Wood-Harper T., Ramlogan R.	No	Out of context. It is a scenario analysis to explore the linkages between the entry modes and development paradigms for mobile telecoms market in general and for mobile microfinance specifically.
42	2014	New Zealand's ultra-fast broadband plan: Digital public works project for the twenty-first century or playfield of incumbent interests?	Winseck D.	No	An examination of the development of telecommunications, media and internet in New Zealand and the prospects for the government's Ultra-Fast Broadband and Rural Broadband initiatives
43	2014	Boosting capacity through small cell data offloading: A comparative performance study of LTE femtocells and Wi-Fi	Voicu A.M., Simic L., Petrova M.	No	A system-level comparative study between IEEE 802.1 Wi-Fi and LTE femtocell performance as mobile data traffic offloading techniques
44	2014	Assessing mergers and budget constraint in multiple-unit ICT Procurements - The cooperation/competition dilemma	Zahi D.	No	An analysis of a model for multiple-unit procurement combining Merger and Budget Constraint under Cournot competition to overcome the issue of business viability pertaining to high deployment cost of network infrastructure
45	2013	An analysis of the antecedents of loyalty and the moderating role of customer demographics in an emerging mobile phone industry	Qayyum A., ba Khang D., Krairit D.	No	An investigation of how various antecedents (customer satisfaction, perceived service quality, value, switching costs, trust, and corporate image) influence customer loyalty in the mobile phone industry and how customer demographic variables moderate such relationships
46	2013	Mobile communication, popular protests and citizenship in China	Liu J.	No	An examination of how spontaneous mobilization via mobile phones demonstrates how Chinese citizens have expanded the political uses of mobile phones in their struggle for freedom of information flow, social justice, and the rule of law, while seeking to build an inexpensive counter-public sphere
47	2013	TeleWeaver: An innovative telecommunication platform for marginalized communities in Africa	Dalvit L., Gumbo S., Ntshinga L., Terzoli A.	No	Out of context. A description of a holistic e-service solution offered by the TeleWeaver platform in South Africa
48	2012	Bayesian confirmatory factor analysis to design a mobile training system in rural areas	Najafabadi M.O., Mirdamadi S.M., Najafabadi A.P.	No	Out of context. A design of a mobile training system in rural areas of Iran using Bayesian Confirmatory Factor Analysis (CFA).
49	2012	Special issue on smart applications for smart cities - new approaches to innovation: Guest editors' introduction	Schaffers H., Ratti C., Komninos N.	No	Out of context. An analysis of the smart applications' role in cities and an exploration of smart applications innovation process and how it is intertwined with urban development itself.

No.	Year	Document Title	Authors	Included?	Reason
50	2012	Evaluation of access technology to speed-up Internet penetration in remote areas, case study: Community access point in Regency of Garut, West Java, Indonesia	Kurniawan A., Wartika E.	No	This article does not provide solution to promote network coverage to the unserved areas, since the case studies chosen were already have either cellular or DSL network established. It assessed the economical feasibility of the government program District Information Service Center (PLIK) to provide internet access to rural population. However, the study did not elaborate in detail about how the network infrastructure (either the cellular or DSL) was established in the area at the first place and rather focused on the promotion of internet usage in rural areas through PLIK. The techno-economic analysis also did not include the cost for establishing the cellular or DSL network.
51	2012	The challenge of universal service in 21st century portugal	Madureira R.C., Manuel De Oliveira Duarte A., Matias-Fonseca R.	No	Only about review on Portuguese's universal access, not universal service fund nor their ways to provide universal service access.
52	2012	Organization of the social sphere and typology of the residential setting: How the adoption of the mobile phone affects sociability in rural and urban locations	Fortunati L., Taipale S.	No	Out of context. It explores the role that the possession of the mobile phone plays in the organization of the relational sphere at a social level, in different geographical settings.
53	2012	Market competition and the distributional consequences of mobile phones in Canada	Thakur D.	No	Out of context. The research provides understanding of how competition based telecommunication policies function as a mediating variable in the distribution of socio-economic consequences of mobile phones using the case of Canada.
54	2012	Conclusions: A decade of innovation that matters	Fuchs R., Elder L.	No	Out of context. It is a documentation of a special time and space in the business of ICT development globally.
55	2012	Satellite based education and training in remote sensing and geo-information: An E-learning approach to meet the growing demands in India	Raju P.L.N., Gupta P.K.	No	Out of context. It is an explanation of EDUSAT, an exclusive satellit for educational purposes in India.
56	2012	Developing mobile telecommunications to narrow digital divide in developing countries? Some lessons from China	Loo B.P.Y., Ngan Y.L.	No	Not as solution but has some useful info regarding the problem understanding
57	2012	Bridging the digital divide: The Indian experience in increasing the access to telecommunications services	Mani S.	No	Lesson learn from India: coverage expansion can be encouraged by increasing competition in the mobile network industry but it did not specify the policies nor the measures. Other article like Sridhar & McDowell provide more specification.
58	2011	Reaching the hard to reach: Information technology reached rural Kaudwane in Botswana	Pheko B.C.	No	Full-text was not accessible
59	2011	A system to provide primary healthcare services to rural India more efficiently and transparently	Mukherjee C., Gupta K., Nallusamy R., Kalra S.	No	Out of context. It is an explanation of a decision support system in rural India, which can provide first level assessment of a patient by taking all the symptoms as well as vital parameters.
60	2011	A low cost connectivity solution for rural mobile telemedicine	Meethal S.P., Jyothish J.	No	Out of context. The study presents an evaluation of various type of wireless technologies and link aggregation method to establish a low cost rural mobile telemedicine projects in India.

No.	Year	Document Title	Authors	Included?	Reason
61	2011	Out of the reach of children? Young people's health-seeking practices and agency in Africa's newly-emerging therapeutic landscapes	Hampshire K.R., Porter G., Owusu S.A., Tanle A., Abane A.	No	An analysis of young people's health-seeking practices in Ghana which were turned out to be affected by the telecommunication growth.
62	2011	Access to and penetration of ICT in rural Thailand	Tengtrakul P., Peha J.M.	No	An econometric study of information and communication technology (ICT) in Thai's rural villages that may help policymakers decide where to put limited resources to promote ICT and help profit-seeking ICT companies target regions that maximize revenues.
63	2011	Towards a new policy framework for spectrum management in India	Sridhar V., Prasad R.	Yes	Spectrum policy analysis in India. It suggested spectrum regulatory framework adjustments which allows spectrum trading and sharing between MNOs. However, it did not address the coverage problem nor any cause of the problem. It also did not show any effect of the solution to the aspects of interest (coverage gap, digital divide, network sustainability, areas' profitability, compliance and so on)
64	2011	Research on docking of supply and demand of rural informationization and "internet digital divide" in urban and rural areas in China	Sun Z., Wang Y., Lu P.	No	It studied the potential ways to reduce the internet digital divide by increasing the internet usage level of rural populations. It means, it applies for areas that already have mobile network infrastructure established. It did not study ways to increase network coverage in rural areas.
65	2010	Community enpowerment strategy with agro ergonomics approach to the white cow preservation in Taro Village Bali	Sucipta N.	No	An empowerment program in Bali for indigenous communities.
66	2010	Educational gaming an effective tool for learning and social change in india	Chaudhary A.G.	No	The analysis of the correlation between the disparities in access to and quality of education and the use of new personal interactive and entertaining ICTs
67	2010	Dialing up knowledge-and harvests	Stone R.	No	News article that does not propose any solution for improving rural mobile coverage
68	2009	Breaking in	Taaffe J., Kemp I.	No	Data of Indian mobile communication
69	2009	Mobile devices and services: Bridging the digital divide in rural areas	Pimenidis E., Sideridis A.B., Antonopoulou E.	No	Not as solution but has some useful info regarding the problem understanding
70	2008	Application of the SMS platform in rural informatization	Huang X.Q., Zhu X.L.	No	An SMS-based informatisation platform for farmers in rural areas.
71	2008	Social tools and social capital: Reading mobile phone usage in rural indigenous communities	Sinanan J.	No	Out of context. It investigates the mobile phones user behaviour and the potential value of mobile phones in aiding social and financial communications of rural Victorian (Australia) indigenous communities.
72	2007	Convergence opportunities and factors influencing the use of internet and telephony by rural women in South Africa and India towards empowerment	Joseph M.K., Andrew T.N.	No	Out of context. It is an analysis of how telephony (both cellular and land line), internet and other ICTs can benefit rural women in educational, business and economic sector.
73	2007	Wireless network architecture for digital inclusion in rural environments	Grampin E., Baliosian J., Visca J., Giachino M., Vidal L.	Yes	Ambient network as a solution to minimise the need for manual operation and maintenance of the multihop network in rural areas
74	2007	2007 1st International Global Information Infrastructure Symposium, GIIS 2007 - "Closing the Digital Divide"	-	No	A conference proceedings. It only informs the topics discussed in the conference.

No.	Year	Document Title	Authors	Included?	Reason
75	2007	Broadband in India: Strategic investment opportunities	Tanguturi V.P., Harmantzis F.C.	No	The paper outlines the success factors (social, economic, and technological) that have contributed to the growth of the mobile communications industry in India and proposes strategic investment opportunities for service providers, governments, and corporate organizations in the field of broadband services.
76	2007	As broad as it's long	Taaffe J.	No	Out of context. It is a short survey that describes challenges in high-speed broadband networks investment the Australian mobile operators and governments are facing.
77	2007	Recruiting and retaining high-quality teachers in rural areas	Monk D.H.	No	Irrelevant. It is a research about rural schools and teachers.
78	2007	M-democracy: A disruptive innovation for democracy-hungry groups	Abdelaal A.M., Ali H.M.	No	Out of context. It studies the emerging mobile technologies for political participation.
79	2006	12th Americas Conference on Information Systems, AMCIS 2006, Volume 4	-	No	A conference proceedings. It only informs the topics discussed in the conference.
80	2006	Mongolia: Mobilizing communities for participation in e-government initiatives for the poor and marginalized	Ariunaa L.	No	The full article cannot be found. The article is about the Mongolian Information and Communications Technology Authority (ICTA)'s programs.
81	2005	The scramble for BOP penetration in telecommunications	Cooper R., Boye A.	No	It provides a background information regarding rural telecommunication system based on studies on India and Ghana, not a solution.
82	2005	The effects of speed enforcement with mobile radar on speed and accidents: An evaluation study on rural roads in the Dutch province Friesland	Goldenbeld C., Van Schagen I.	No	Out of context. It evaluates the effects of targeted speed enforcement on speed and road accidents.
83	2004	The Use of Telephones amongst the Poor in Africa: Some Gender Implications	Scott N., Mckemyey K., Batchelor S.J.	No	Out of context. It is an analysis of the use of telecommunications services between genders in African countries based on surveys.
84	2003	Rural health care support mechanism. Final rule	-	No	Out of context. It is about rural healthcare support mechanism.
85	2003	India's experiments in mobile licensing	McDowell S.D., Lee J.	Yes	Licensing in India, but not only about mobile/cellular license, but also wired and fixed wireless communication. Supplementing the coverage obligated spectrum license solution. Supplementing the Spectrum management solution
86	2003	China: More haste, less speed?	McClelland S.	No	Out of context. It is a discussion of issues related to the growth and economy of Chinese telecom sector.
87	2001	Infrastructure and rural development: Insights from a Grameen Bank village phone initiative in Bangladesh	Bayes A.	No	It evaluates the role of telecommunications in rural development in general and of poverty reduction in particular using Bangladesh case study.
88	1995	Reaching out to remote and rural areas: Mobile satellite services and the role of Inmarsat	Wright D.	Yes	It identifies that satellite can be used for mobile communication using Inmarsat-M (voice) and Inmarsat-C (messaging). However the usage cost would be relatively high that this scheme would need policy supports to encourage MNOs willingness to use this scheme to expand coverage to rural and remote areas.

A.3 Researchgate

No.	Year	Document Title	Authors	Included?	Reason
No	Year	Document Title	Authors	Included?	Why?

No.	Year	Document Title	Authors	Included?	Reason
1	2018	Enabling Rural Coverage Regulatory and policy recommendations to foster mobile broadband coverage in developing countries	Cruz G., Touchard G.	Yes	Enabling Rural Coverage Regulatory and policy recommendations to foster mobile broadband coverage in developing countries
2	2017	Connected Society Unlocking Rural Coverage: Enablers for commercially sustainable mobile network expansion	Touchard G.	Yes	Connected Society Unlocking Rural Coverage: Enablers for commercially sustainable mobile network expansion
3	2015	Criteria for mobile coverage obligations-Overview in Europe	Mucalo A. K., Simac G., Tekovic A.	Yes	Supplementing Cruz, 2018 which specifies how coverage obligations can be implemented/designed
4	2006	Accelerating Indian Rural Telecom Services: Policy and Regulatory Approaches	Jain R.	No	It does not specifically address the mobile network penetration in rural areas but telecommunication service in general, and more on fixed telephony access. There are reviews on Indian existing policy initiatives, such as Village Telephone, Lower Tariff Policy, Rural Telecom Funding Policies (USF and Access Deficit Charge), Centre of Indigineous Development and Internet Centre. However they are generally described and not sufficiently elaborated.

Appendix B

Elaboration of the Available Solutions

B.1 Technology solutions

B.1.1 TUCAN3G

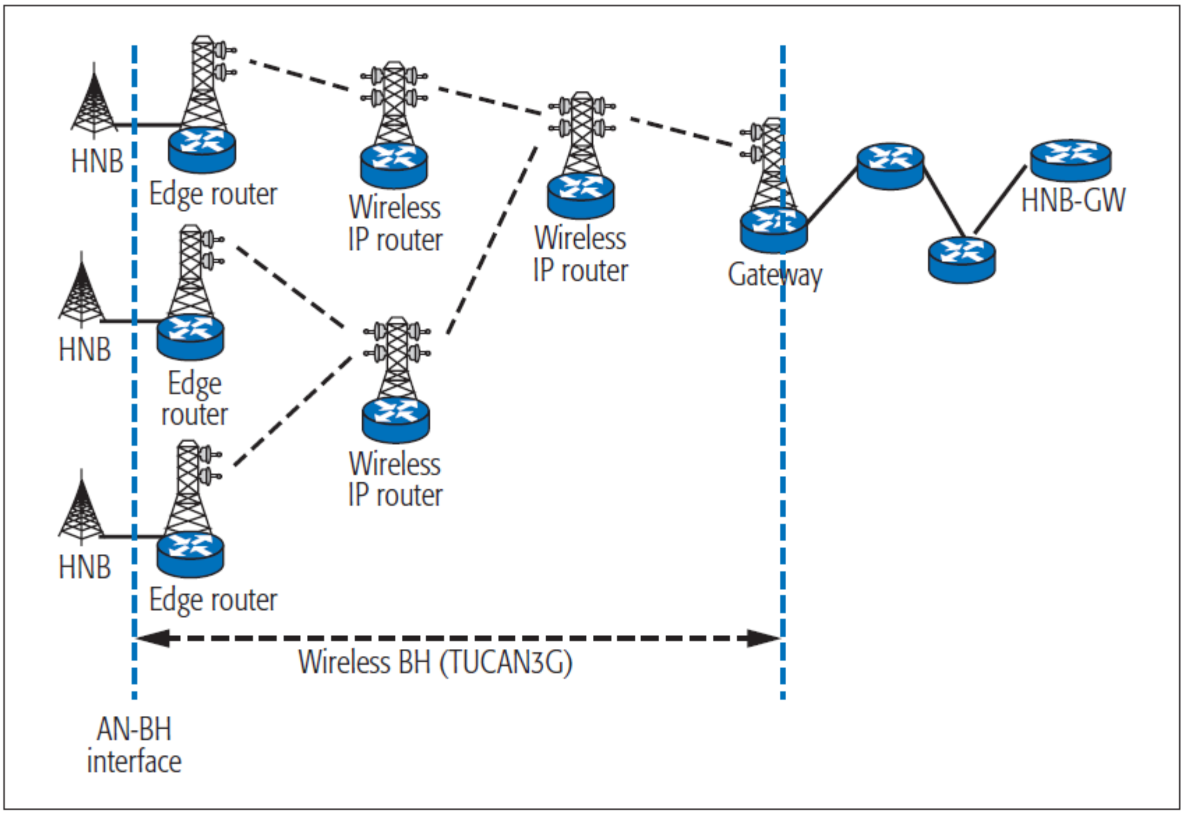

Figure B.1: Network architecture of TUCAN3G (Martínez-Fernández et al., 2016, p.39)

TUCAN3G proposed a solution for bringing 3G connectivity to isolated rural areas in developing regions using heterogeneous wireless backhauling in unlicensed bands (WiFi for Long Distances or WiLD) and WiMAX (Martínez-Fernández et al., 2016). It employs 3G femtocells for the access network (AN) and a wireless multi-hop backhaul (BH) to connect the access network with the operator's core network (Martínez-Fernández et al., 2016). One AN is placed in every settlement area. In Peruvian projects, femtocells deployed in the 800 MHz bands can cover an area up to 2 km, and since the distance between communities was 20-70 km, interference is negligible (Martínez-Fernández et al., 2016). This Peruvian network was believed to be the most extended permanent WiFi network in the world, covering an end-to-end distance of around 450 Km through sixteen hops since March 2007 (Rey-Moreno et al., 2011).

TUCAN3G suggests a shared backhaul network and the use of unlicensed bands, as seen in Figure B.1. This scheme was made to press down the CAPEX and OPEX of network expansion hence increasing the economic viability of network expansion to rural areas. However, the Peruvian pilot project also uses WiMAX in part of its backhaul chain for some reasons and shows that the deployment cost is still acceptable.

Further detail on the network dimensioning and site configuration of TUCAN3G can be found in (Martínez-Fernández et al., 2016; Rey-Moreno et al., 2011; Simó-Reigadas et al., 2019).

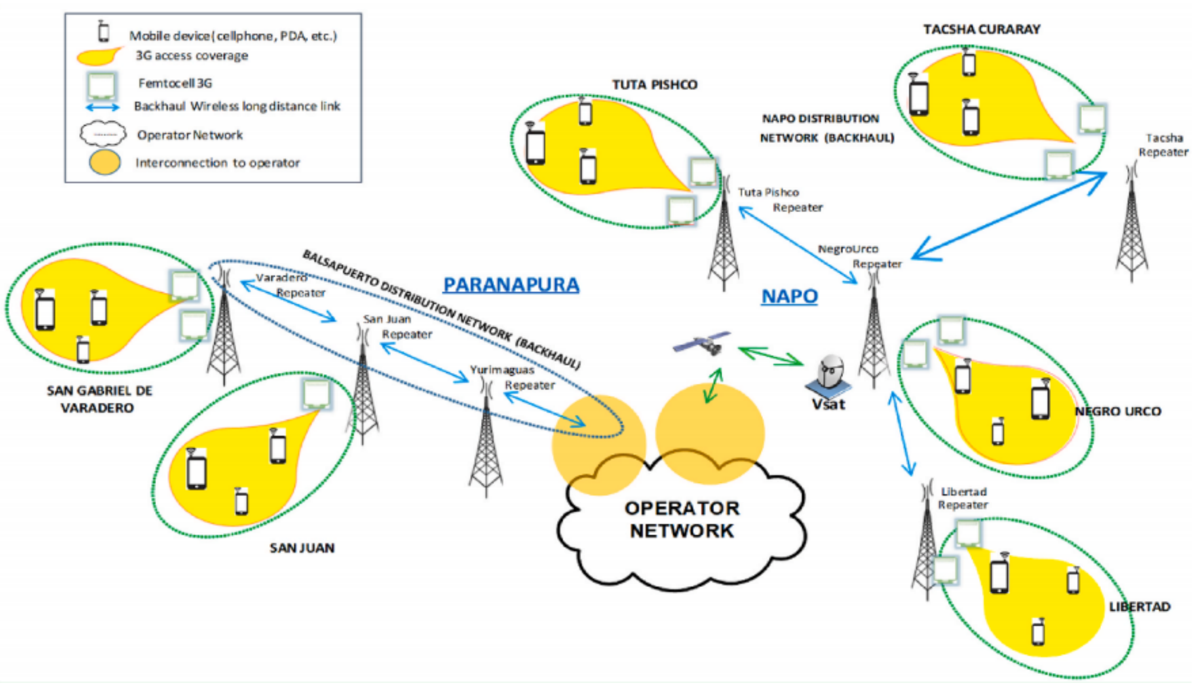

Figure B.2: TUCAN3G project in Paranapura and Napo communities (Prieto Egido et al., 2020, p.3)

TUCAN3G aims to provide an economically sustainable solution to help to cover the isolated communities with (3G) mobile service. Two pilot projects used the TUCAN3G solution in two communities of the Paranapura river and four communities of the Napo River, both in the Peruvian Amazon rainforest (Figure B.2). These projects were deployed to connect the rural healthcare facility in each community to Iquitos Hospital. The communities' locations are scattered and far from the city centre or any area with a good telecommunication network coverage. The target communities in the Peruvian Amazon Rainforest are also located in challenging topography type, i.e., rainforest and highlands. The rainforest is characterized by very high trees and extreme weather conditions (Rey-Moreno et al., 2011). Satellite backhaul network is commonly known as the easiest backhaul type for these kinds of situation. However, deployment costs for using satellite would be considerably high and make the solution not commercially sustainable. Therefore, a low-cost chain of terrestrial backhaul consisting of long-distance point-to-point WiFi or WiMAX free band links in the range of 20–55 km each is used to bring the service to these communities. The use of free bands allows reducing the operational cost significantly. The end-to-end distance from Iquitos Hospital to the farthest community is approximately 450 km (Figure B.3) (Simó-Reigadas et al., 2019).

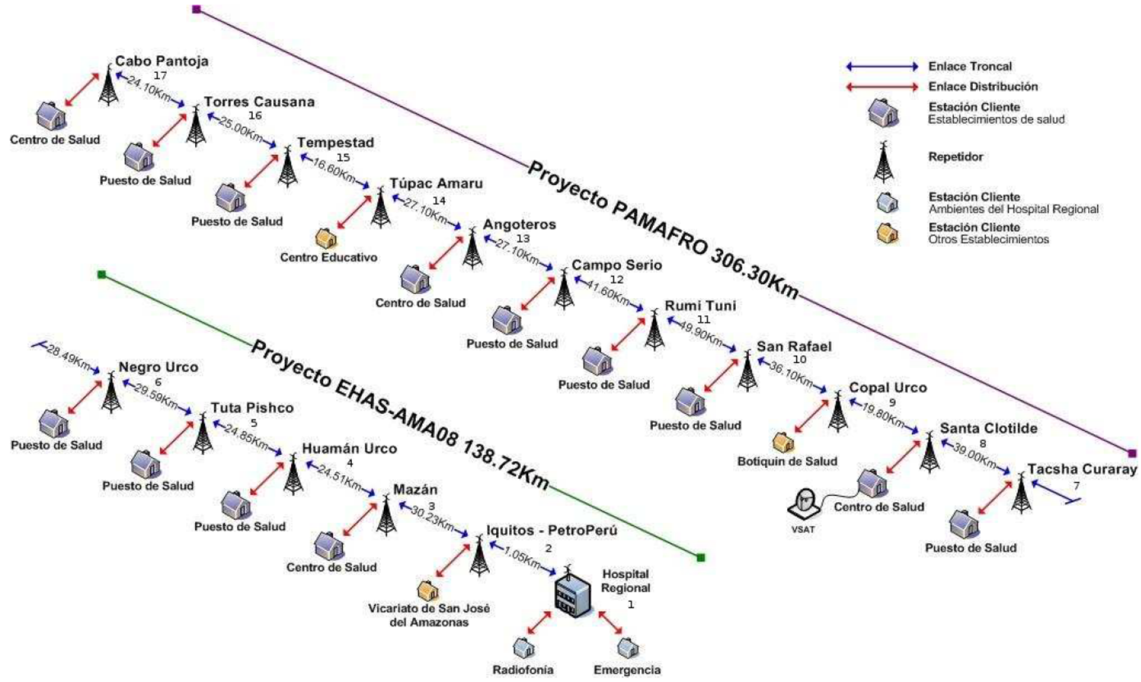

Figure B.3: Backhaul chain of TUCAN3G (Rey-Moreno et al., 2011, p.3)

The area of study also prone to weather disruptions, such as lightning. An electrical protection system, comprising a Franklin lightning conductor, a grounding well and coaxial line protectors, has been installed to protect the infrastructure and its electronic devices from lightning damages (Rey-Moreno et al., 2011).

The households of both Napo and Paranapura are scattered and low density. However, the market research found that 68.9% of the households in these communities already had a 3G device (Prieto Egido et al., 2020). To avoid significant barrier to the project's success by forcing the low-resource local population to purchase 4G devices while maximising the existing 3G device penetration in the communities, these pilots deployed a 3G network (Prieto Egido et al., 2020). To address the low density and scattered population issue, it uses femtocells.

It has been proven that a multi-hop network based on WiLD or WiMAX links may be a good solution for rural 3G backhaul (Simó-Reigadas et al., 2019). The use of low-cost technology operating in unlicensed bands (Wi-Fi and WiMAX) can be adopted here due to low or nonexistent interference. In this context, a combination of WiLD and/or WiMAX systems operating in non-licensed bands is a viable solution to provide a sufficiently high capacity and an acceptable delay and packet loss. Experimental tests proved that a point-to-point WiLD link operating in 20 MHz channels allows capacities over 45 Mbps at 20 km and over 20 Mbps at 55 km while keeping the average delay under 5 ms and a negligible packet loss (Martínez-Fernández et al., 2016). Meanwhile, WiMAX allows approximately 60 per cent of capacities offered by WiLD with 10 MHz channels for the same delay and packet loss figures (Simó-Reigadas et al., 2019). This type of backhaul is then considered better than a geostationary satellite in its propagation delay and operational cost. Geostationary satellite backhaul's round-trip time can hit 500 ms, and it requires a recurring expensive monthly cost (around US$3000/dedicated Mbps) (Martínez-Fernández et al., 2016). Moreover, the use of unlicensed bands for backhaul also allows a lower power consumption for the backhaul site (Rey-Moreno et al., 2011).

Moreover, femtocells as the access network ensure coverage in sparsely rural settlements at a meagre cost. Femtocells are generally used inside buildings, flexible, and have a much lower cost than standard base stations. Moreover, the use of femtocells also allows a lower power consumption. Each femtocell only consumes around 5-10 watt, while the micro base station requires around 100W (Auer et al., 2012). As a result, the cell would only need one to three solar panels (85 W per panel) to work 24 days and can survive three days without solar radiation.

Assuming an ARPU of US$7 and 50% penetration of 3G mobile telecommunication of all population in the area, Martínez-Fernández et al. (2016) showed that the proposed wireless terrestrial network backhaul solution could significantly reduce the number of inhabitants required to reach the break-even point. The calculation that considers the total cost of ownership (TCO) in five years of satellite backhauling estimate that around 800 inhabitants per community are required to reach the break-even point, while with TUCAN3G backhaul solution, it only needs a half of it (around 400). It is even feasible economically to reach around 200 inhabitants if there are existing towers that it can use or supported with public funds.

It is important to note that deploying femtocells would be suitable if the community has less than 1000 inhabitants (270 users) (Prieto Egido et al., 2020). One femtocell should be used for one clustered households. That means, if a clustered households consist of more than 1000 person, micro BTS would be more suitable and cost-efficient as femtocell would not provide proper coverage in that situation.

The use of shared backhaul infrastructure between rural areas is the core of TUCAN3G's economic viability. The studies of TUCAN3G implied that this type of solution would be suitable to advance coverage to the rural region that consists of several smaller settlement areas. The backhaul deployment, installation and operational costs then can be shared equally among all households in that region to allow sustainability of all network points. Although the use of unlicensed bands for the proposed backhaul network is inexpensive, the use of terrestrial backhaul may require expensive infrastructures due to the required high towers to guarantee the LOS and to avoid interference (Simó-Reigadas et al., 2019). This is particularly important in unlicensed bands, where the maximum transmission power is strictly limited. In countries where licensed bands are mandatory for mobile network backhaul, WiMAX is the only low-cost alternative for TUCAN3G terrestrial backhaul solution (Simó-Reigadas et al., 2019).

As the backhaul capacity is shared between ANs, traffic and QoS management of this network architecture need special attention. The QoS management must be designed so that each AN gets acceptable quality regardless of the traffic generated by other ANs connected to the backhaul. Therefore, delay and packet loss limit should be set carefully, traffic prioritisation should be applied (voice and signalling traffic over data traffic), and distribute/channelling the traffic fairly so that no link is saturated (Martínez-Fernández et al., 2016). Different strategies could be used to ensure end-to-end QoS over the shared infrastructure: distributed QoS architectures based on differentiated services (DiffServ) at the IP layer or multiprotocol label switching (MPLS) at a lower layer and traffic control system in every backhaul router (Simó-Reigadas et al., 2019).

Since the network points are located in remote locations, MNOs need to cooperate with local people for managing, troubleshooting and maintaining the network. TUCAN3G project in Peru carried out several training courses to teach locals to maintain and repair the network (Rey-Moreno et al., 2011). However, it would be not easy to train somebody without any basic technical knowledge to learn in the short term.

B.1.2 Cached GEO-satellite backhaul network

Satellite connectivity has been suggested in many studies (Chiha et al., 2020; Philip et al., 2017; Wright, 1995) to solve the connectivity problem in remote and rural areas as it can cover almost any location under its global coverage area, flexible and does not involve large infrastructure deployment (such as towers and big antennas). However, the operational cost for using an end-to-end satellite solution might, in some cases, not be cost-effective (Chiha et al., 2020). On the other hand, there is a need to address the tremendous potential growth of the video content request in the future. It was predicted that, in 2022, 80 per cent of all internet traffic would be video traffic led by the expansion of video on-demand services (Cisco, 2019 as cited in Chiha et al. (2020)). This growth will create a heavy load on the backhaul links and long latency on the traditional centralised network (Wang et al., 2017).

Chiha et al. (2020) proposed a hybrid satellite-wireless solution to deliver broadband to rural areas based on caching strategy. It employs a geostationary satellite (GEO satellite) network as backhaul and 4G as the fronthaul. The complete network is composed of a 4G core network, a satellite gateway that connects the 4G core network with the satellite hub station via fibre connection, a satellite terminal near the access network to connect the eNodeB(s) to the satellite, eNodeBs that carry traffic to and from end-users and Multi Edge Computing (MEC) infrastructure on edge. The network architecture is illustrated in Figure B.4. To reduce the amount of traffic carried out via satellite link and decrease the OPEX, it proposed to cache a percentage of the popular contents on edge. This way, the end-users do not have to download it from a central location in the network but the edge network. Caching solution transforms the backhaul bandwidth requirement into a storage requirement (Borst et al., 2010). The amount of data stored in the edge follows the Pareto law, i.e., 20% of the most popular videos (Chiha et al., 2020). Therefore, 80% of the video requests can be served from the cached data, resulting in 64% of the total user traffic being served from the local cache. A use case with characteristics in Table B.1 is used to evaluate the proposed solution.

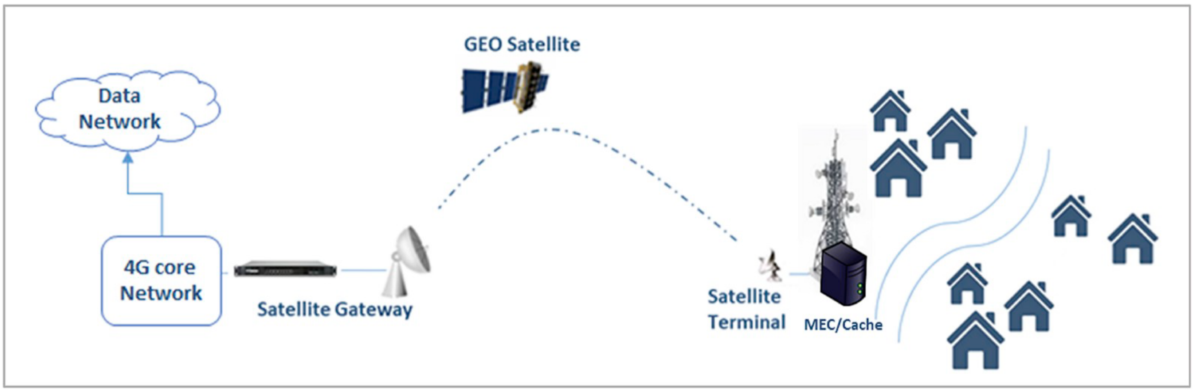

Figure B.4: Architecture of cached GEO-satellite backhaul (Chiha et al., 2020, p.11)

Table B.1: Chiha et al. (2020)'s use case description

Parameter	Conservative scenario	Aggressive scenario
Study period	5 years (2020-2024)	
Total users	1050 users (3 users x 350 families)	
Area	78.5 km^2	
Number of cell tower	1	
Data rate per user	2 Mbps	30 Mbps
Average busy hour data rate per site	630 Mbps	9450 Mbps
Average active hours per user	9	
Active user rate (%)	80	
Cost of 1 kWh (€)	0.114	
Conversion rate ($ to €)	0.9	
Time value of money	5%	

Two scenarios were proposed in this solution: conservative and aggressive. The conservative scenario targets the network to accommodate 2 Mbps per user, while the aggressive scenario 30 Mbps per user. Without caching, the average cost per user (ACPU) for this network is 12 and 155 euros, respectively, which equals around 200,000 rupiahs and 2.7 million rupiahs (ACPU here does not yet include the profit margin for MNOs). With caching, the ACPU is 6.7 euros and 66.6 euros, respectively. It equals around 120,000 rupiahs and 1.2 million rupiahs. The use of caching proves a reduction of 60.5% in OPEX costs, resulting in a 57.2% decrease of ACPU. This ACPU might be significantly lowered if 2G or 3G technology is used as the access network since they require less satellite link capacity.

Satellite backhaul offers a far more simple network component than terrestrial backhaul. Major infrastructure development is only needed in the target users' location, mainly for Radio Access Network (RAN). No chain of the terrestrial network has to be established to reach the location. It means the logistics needed to transport the network component would be much lower than if using terrestrial backhaul. It makes this solution possible to be utilised for an extremely isolated or remote area.

Assuming a WTP of 19 euros per month for a decent broadband connection in a rural area, the study showed that this technique offers an economically-viable way to provide internet service 2 Mbps per user to rural areas. However, this WTP level was based on European and US data, which are developed countries. Thus, there is a chance that a country's WTP, especially developing countries, is lower than 19 euros per month. In such case, this solution might be suitable as the total cost of ownership will exceed the potential revenue and the site will not be commercially sustainable.

The calculated ACPUs is based on a case study in which two villages with 1050 users in total are served by one macro-cell tower, and the total area is 78.5 sq km (Chiha et al., 2020). It means the population density is about 14 persons per sq km. Therefore, the ACPU would be higher if the solution is implemented in areas with a population density lower than 14 persons per sq km. Furthermore, the ACPU would be even higher if the populations or households are sparsely placed far from others, as this situation would require more than one tower to serve the users. The more towers needed, the higher the CAPEX would be.

This solution might not be suitable for areas with electricity scarcity. It consumes high power for the RAN, satellite terminal, air conditioning and MEC. More than 50,000 kWh per year needed to operationalise the network (Chiha et al., 2020). This electricity need would be tough to accommodate efficiently with solar panels.

As this solution employs 4G macro-cell as the access network technology, the area's topography type would significantly matter. Macro-cell needs a tower to stand on, but it is difficult to stand on slopes and does not perform well on a valley or in a rainforest—unless it is made really tall. The taller tower requires higher capital costs.

B.1.3 Unmanned Aerial Vehicle

Providing coverage to rural areas is difficult due to their problematic characteristics, such as the sparsely distributed population, low population and the lack of an electricity grid. Regarding the first two challenges, providing wireless coverage with a typical fixed base station over 100% of the area would result in a clear waste of radio resources as most of the coverage area would be useless. Meanwhile, the unavailable and unreliable electricity source in rural areas leads to higher cost of deployment, either for installing the new power grid or for the power maintenance costs. These challenges impose the need to utilise renewable energy as the primary source.

Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) presented an optimised and cost-effective mobile network architecture based on Unmanned Aerial Vehicle (UAV) powered by solar panels to provide 5G coverage in low income and rural areas. UAV is a remotely controllable vehicle that flies at low altitudes, moves over a territory and carries radio cells. The radio cell mounted on a UAV consists of a remote radio head (RRH) and antennas. RRH runs the basic radio functionalities, such as digital processing, digital to/from analogue conversion, power amplification and filtering (Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017). As a result, UAV-cells can provide flexible and targeted coverage by only serving zones where the users are located.

Based on (Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017; Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017), the main components of UAV-based cellular architecture are summarised in Figure B.5 and B.6. There is a Dedicated Hardware (DHW) that functions as RRH and is carried by the UAV. DHW and UAV compose the aerial part of the network. This aerial part is connected to the ground site that consists of another DHW, Commodity Hardware (CHW) that provide a virtual function of a Baseband Unit (BBU), solar panels and batteries. The BBU performs baseband signal processing operations. The ground site is also called SP-node, as there are solar panels used to generate power for the network in the site. Fibre optical link is used to connect ground sites if there is more than one site in the area. Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) scheme was designed specifically for rural areas of moderate size, in which the negative impact of interference is negligible. Amorosi et al. (2019) designed algorithms to plan UAV networks over a set of areas while managing their energy consumption efficiently.

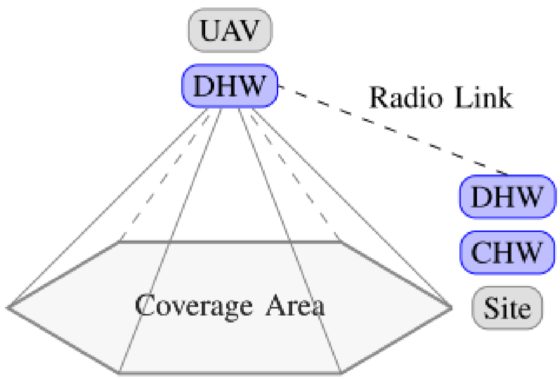

Figure B.5: Components of UAV for a coverage area (Chiaraviglio et al., 2019, p.904)

Some types of UAV can be used to mount RRH. In their research, (Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017) used rotary wings and balloons as the UAVs. Another UAV option is tethered helikite. Balloon and tethered helikites have a higher flight time compared to the rotary-wing UAVs.

Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) and Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) combined the use of rotary-wing UAV and balloon UAV in providing coverage. The rotary-wing UAV provides coverage for non-basic services, such as the internet or high traffic volume capacity, while the balloon UAV provides basic coverage and emergency services. For that reason, balloon UAVs will continuously fly, while rotary-wing UAVs may be turned off during the night (when the capacity is not much needed). The connection between the aerial part and ground site is maintained wirelessly (via microwave radio

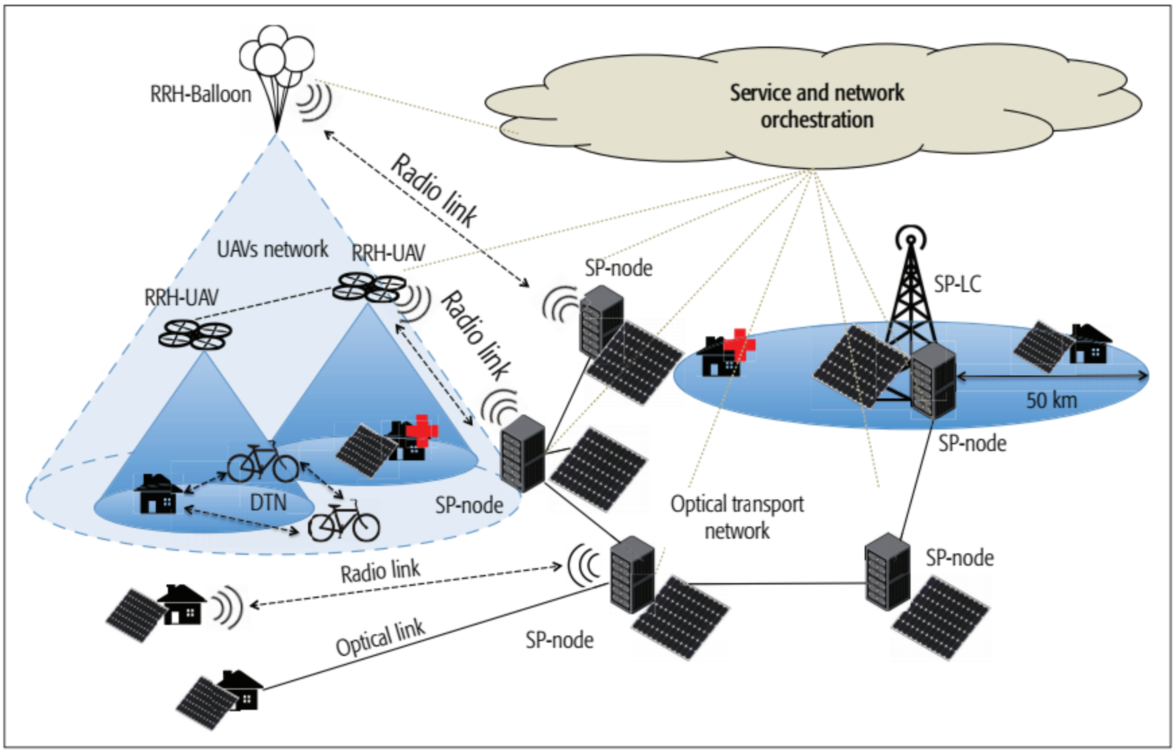

Figure B.6: UAV-based 5G architecture (Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017, p.53)

link) in Chiaraviglio et al. (2019)'s study as it employed rotary-wing and balloon UAVs. If tethered helikite is used as the UAV, then optical fibre can link the ground and aerial sites.

This network scheme can rely solely on renewable energy source (RES). Solar panels are installed in each ground site. Periodically, UAV will go down to the ground site and recharge its and RRH power. While recharging, UAV will not provide coverage and another UAV will take over the area (Chiaraviglio et al., 2019). The power unit in each site consists of solar panels and batteries. The batteries are the power source during the night and bad weather conditions and recharged during the day by the sun.

A centralised orchestrator will coordinate the whole UAV-based network architecture. This entity acts as the system brain that manages the network and virtual computing resources across elements and computes and coordinates UAV trajectories over the area. The resource allocation and UAV trajectories are decided according to the traffic volume level or time (predicting the busy and non-busy period) and SP available power.

(Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al., 2017) performed an economic analysis on the network model assuming a deployment of such model in two rural scenarios located in Italy and Cook Islands, and a low-income zone in Zimbabwe. Considering relevant cost items, they concluded that the UAV-based network 5G would be able to generate profit even when the monthly subscription fee is close to 1.7 euro.

In another study (Zhang et al., 2019), an airship was used as the UAV. This study did not focus on a specific type of technology which showed that a UAV-based network could also accommodate non-5G technology. The UAV operates in two bands simultaneously, high and low (e.g. UHF and S-bands). The combination of these bands improved the coverage and reliability while offered higher network throughput.

UAV is also known as Stratospheric Communication Platform (SCP) (Ilcev and Singh, 2004) and Aerial Base Station (ABS) (Zhang et al., 2019). Ilcev and Singh (2004) explained that UAV-based cellular networks are much more cost-effective to provide coverage in environments with low population densities. They also argued that it could have a better transmission rate than even optical medium. Positioned in high altitude allows the aerial station system to reuse frequency more frequent, resulting in a higher capacity than other wireless systems (Ilcev and Singh, 2004). It also can be easily integrated with current satellite and cellular systems.

Compared to a traditional cellular architecture for 5G composed of fixed base stations, UAVs provides several advantages. The UAV-based network is highly possible to cover only the target populations. Meanwhile, it is also highly adaptable; changing the UAV trajectory and coverage area is relatively easy by adequately scheduling the UAV's configuration through the centralised orchestrator. It also provides good channel conditions to users as the base station connects with users in LOS. According to Chiaraviglio et al. (2019), the use of UAV as the access network for 5G can reduce the costs compared to using fixed base stations. The network deployment is also less complicated as fewer physical infrastructures involved in the network. Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017) identified that the number of ground sites required in a UAV-based network is less than in the classic fixed base station network; hence the UAV-based network's OPEX is concluded to be lower than the classic network.

The use of RES makes this solution independent from the electricity establishment in the area. As another result, the energy required to recharge the UAVs will not impact the OPEX. Moreover, as the SP-node may be relatively close to the household, the locals may even use the excess generated power.

Dimensioning this network is way more challenging than the usual type of network. Ensuring the correct number of SPs, batteries, ground sites and UAVs are essential to make the network economically feasible and well-perform. Moreover, configuring the optimum distance between the UAV and the ground site is tricky as it would be a trade-off between the coverage area and the UAV-ground site connectivity. In addition, UAV's trajectory, recharging schedule and interference management also need to be considered.

Rotary-wing UAVs network, as proposed by Chiaraviglio, Blefari-Melazzi, Liu, Gutierrez, Van De Beek, Birke, Chen, Idzikowski, Kilper, Monti, et al. (2017), is also not yet commercially available, as far as we know. As reviewed by Song et al. (2021), this technology seems to be in the prototyping stage. There are some other type of UAVs have been commercially introduced, such as Loon by Google. Nevertheless, different type of UAV might have different characteristic that influencing its feasibility. In the literature reviewed, there is no discussion about any commercially available UAV project.

On the other hand, this solution does not include the backhaul link. The backhaul components were not stated in the cost analysis either. Therefore, this solution needs to be coupled with backhaul technology. As a result, the network performance of this solution can be limited/bottlenecked by the backhaul link capacity, and the overall cost is subject to be increased by the backhaul link cost. The backhaul link options are satellite, fibre optic and wireless.

B.1.4 VillageCell

Sometimes, rural networks cannot be sufficiently served by voice call services even within a single village. Large MNOs are reluctant to deploy a mobile network in remote areas due to its complexity and high cost while the profitability remains uncertain (Anand et al., 2012), leaving the areas with either limited or no connectivity at all. The villages in which Anand et al. (2012) took study had established an internet network via satellite gateway, which is accessible through a Wi-Fi local area network and standard GSM handsets, but no cellular network. As such, the service quality was so poor as a call between persons in the same village has to go to the app server, then over the highly congested satellite link, then to the external server, and back to the village through the same satellite link (Anand et al., 2012). Residents in both villages expressed that they frequently experience Skype call drops (Anand et al., 2012).

VillageCell is specifically tailored to the rural villages spatial layout and rural population's lifestyle. Their lack of transportation infrastructure, high illiteracy levels and migrant labour characterise rural villages that emphasise the need for real-time voice communication (Anand et al., 2012). Through their study in two rural villages in South Africa, Anand et al. (2012) also found that rural people prefer local voice and intra-village communications to global connectivity. Seventy-three per cent of their interviewees used the voice call service through applications such as gTalk and Skype, 80% of which was for intra-village communication). It contributed up to 26% of all traffic volume in the villages of their case study. The population density in one of the village is 25 person per sq km.

VillageCell is a rural network architecture proposed by Anand et al. (2012). GSM (2G) mobile network was employed in conjunction with local area network as a backbone. The solution uses a Software Defined Radio (SDR) acting as a local BTS for transmitting and receiving the GSM signals to the user equipment. It is controlled by OpenBTS, a software that implements and provides a complete cellular GSM process, from location updating, registration and mobility management to interconversion of GSM and VoIP data. Each access network of this solution would only consist of a radio front end of SDR and a general-purpose computer (PC) for conducting signal processing of SDR and OpenBTS. Multiple BTSs are connected through a local wireless (Wi-Fi) network, which allows for intervillage communication. All traffic calls are managed, monitored and routed via Private Branch Exchange (PBX) servers implemented in Asterisk as VoIP packets. An Asterisk server also maintains a database of all users across the VillageCells and allows connectivity to the global telephone system.

Figure B.7 illustrates an example of the proposed VillageCell network architecture where OpenBTS, cellphones, Asterisk and satellite gateway entities interconnect to offer widespread cellular connectivity.

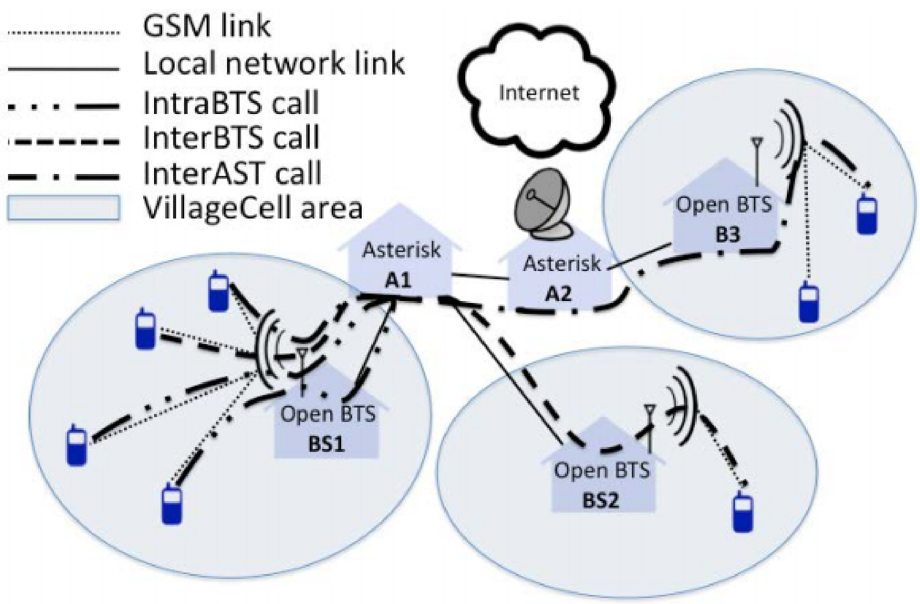

Figure B.7: VillageCell network architecture (Anand et al., 2012, p.181)

VillageCell implies a community cellular network. It is established not by any mobile operator and uses the community's existing local area network. Furthermore, when it is established, the community needs to maintain and protect the network themselves.

There are benefits of implementing VillageCell in rural areas. Its low cost and simple network components make this solution implementable even in areas with less than 25 person/sq km density. As the voice call would be free of charge, people with low income can use this service conveniently. The simple components also do not require special transportation carrier and complex infrastructure deployment, which is the major challenge in remote areas. Although the network architecture and components are straightforward and low cost, the experimental study by Anand et al. (2012) showed that this solution could achieve an excellent local voice call quality, represented by the mean opinion score (MOS) values for all scenarios (intraBTS, interBTS same Asterisk and interAsterisk) above 4. Moreover, the system capacity was shown to be adequate in all scenarios. By experimenting with up to six simultaneous calls, the system showed a less than 0.3% increase in packet loss compared to the base case (1 simultaneous call). It demonstrated that VillageCell could provide high voice call quality under various network conditions and scale well with the number of concurrent calls in the system. On top of the local communication, it can also connect to the outside world over the internet through a satellite gateway using commercial VoIP networks, such as Skype and gTalk. On top of that, since a VillageCell is small in scale and does not necessarily need a tower for base stations or backhaul, the villages' topography type also does not matter. If the households in a village cannot be served by one cell due to topography obstacle, another cell can be quickly established as the deployment cost per cell is very low.

Using OpenBTS as the lastmile for the VillageCell is possible (Panji, 2013). It would require only around 12-15 million rupiahs (less than 1000 euros) to establish one OpenBTS site that can serve 5-10 meter radius (Panji, 2013; Pitoyo, 2013). Extending the coverage to more than 5 km would only need an additional amplifier which costs around 120 million rupiahs (less than 7000 euros) (Panji, 2013). Only 100 miliwatt is required for an OpenBTS, and 10 watt if an amplifier is used. Therefore, it is an option for villages without electricity grid.

There are potential challenges in applying this solution. First, the network arrangement can be very tricky to balance and get efficient routes. Since this solution is limited in capacity due to OpenBTS and Asterisk, inefficient routes could create unnecessary link's capacity consumption that may affect the communication quality, especially on VoIP. Thus, ensuring that frequent connections are placed within the same BTS and Asterisk as much as possible is essential.

Second, the need to use GSM bands for radio access and numbering blocks for user IDs would require government permission (Kominfo, 2013). Implementing this solution would be illegal for non-MNO in countries where the mobile network spectrum licenses and numberings are granted to MNOs nationally, no free mobile network spectrum and number blocks are available to use and no spectrum/numbering sharing or trading policy is established.

Third, VillageCell by Anand et al. (2012) does not address the network maintenance and operation. The new components VillageCell brought would need technical expertise to maintain. Training the locals to maintain the network themselves would be more efficient. In Anand et al. (2012)'s case, since the villages owned and built the existing local area network, there might be already a group of people who have the technical expertise to take care of the VillageCell network, thus would be less problematic. If the VillageCell network is about to built from scratch, training locals to maintain the network would be required and might be challenging.

Lastly, finding the villages that suitable for this solution may not be easy. The villages should have residents who prefer local calls to long-distance ones and prefer or need voice calls instead of internet services. A careful assessment of service demand is needed before establishing the network to avoid loss. It would be wasteful if the intravillage traffic is lower than the commercial VoIP or data traffic. Moreover, the way it focuses on local communication may not be beneficial to reduce the digital divide and connect the isolated populations to the rest of the world, thus improving their economy. A supplement solution is needed to improve the link between the village and the rest of the country or world.

B.1.5 Solar power source

Rural areas are known for their hard-to-access location, leading to difficulties for electricity providers to expand their grid to the areas. The absence of the power grid complicates the network infrastructure operation as it means the operator has to establish a power source for their sites in rural areas. The most common and easiest alternative to the electricity grid is using a fossil-fueled electricity generator. However, this type of power source is often unstable and requires regular refuelling (Surana et al., 2008). Especially for remote areas, this situation makes the site operation not economically feasible as the transportation cost for refuelling can be really high and the human resources to transport the fuel are limited.

Due to the limited power grid capacity, periodical electricity power-off and power outage occur in some areas. In such cases, the unstable electricity supply makes the network devices easier to broke, hence increasing the maintenance cost of the site. If the site were down due to a power issue, MNOs would get revenue loss, decreasing the RoI of the rural sites. Therefore, MNOs usually unwilling to establish a network if there is no stable source of electricity in the site location.

Kabir et al. (2018) and Thakur, Mishra, et al. (2017) studied in 2017 the possibility to use a solar PV system to be the primary source of electricity for network infrastructures in rural areas. Solar power, along with grid and storage batteries, could produce about 77% of the base station's total energy need, while 23% is generated from the grid. Their case study in Pakistan showed that a solar PV system could produce energy higher than the power needed to run the site during the day, resulting in excessive energy stored in the batteries and used during the night. The daily electricity purchase profile of the site showed that no electricity had ever been purchased from the grid during the daytime. Therefore, they concluded that the electricity generated by the proposed system is reliable and sufficient to meet the site's energy demand at a low cost. Additional femtocell's power reduction can be achieved using Load Aware Sleep Strategy (LASS) and Energy Efficient Cell Selection (EECS) scheme proposed by Thakur, Narayan Swain, et al. (2017).

In another study by Martínez-Fernández et al. (2016), solar power was proven to be able to be the only source of the mobile network's power, including access and backhaul network. The network (TUCAN3G used femtocells which under the worst case would allow 1-3 solar panels (85 watts per panel) and 1-3 units battery (12 V 100 Ah) to fulfil each cell's 24h power need and allow three days without solar radiation. The network's backhaul used unlicensed bands, which was found to further lower the power consumption (Rey-Moreno et al., 2011).

B.1.6 Battery performance prediction model

Rural areas are known for their hard-to-access location, leading to difficulties for MNOs to go to the site for maintaining or repairing the site. Since an issue that requires a site visit would take a high cost and much time for transportation, MNOs would want to prevent it as much as possible. Power outage is one of the significant issues for MNOs as if it is not appropriately addressed, it will put down the site and create revenue loss for them. MNOs provide batteries in each of their sites to prevent network service disruption on their sites due to power outage. Thus, the battery is a vital component of a site, and MNOs will always try to ensure its performance.

Seeing the significance of batteries for rural networks, Fan et al. (2016) suggested a model to predict the battery voltage and lifetime accurately. It is based on Multi-Instance Multi-labels Learning (MIML) algorithm. The prediction enables MNOs to timely schedule battery maintenance and replacement to minimise the service interruptions caused by power outages. The model can improve the mobile network service availability up to 18.09%.

This solution, however, is not off-the-shelf, which means that it is not available to purchase on the market. Unless there is a vendor that produces this software and makes it commercially available, MNOs will not be able to utilise it.

B.1.7 Store-and-Forward network

Rural areas are known to be commercially unattractive for network operators to invest in a network infrastructure. Even though solutions exist, they are considered expensive or at least require time to be actuated (Fabrikant et al., 2002). Therefore, a solution that may provide telecommunication service with the lowest cost possible and implementable quickly may be favourable to enhance network access to rural populations. On the other hand, an adequate level of penetration of mobile devices with Wi-Fi feature was found in the rural areas (Barela et al., 2016; Palazzi et al., 2011).

Mobile Delay/Disruption Tolerant Network (MDTN) is an opportunistic networking or a store-and-forward communication model, proposed by Palazzi et al. (2011), that connect mobile users in an ad-hoc fashion to internet services by leveraging on public vehicles' mobility to reach an internet access point (AP). Public buses with onboard Wi-Fi AP are used as the carrier nodes. The buses have routes going to and from rural areas and city centre (or the locations with Wi-Fi services available). Wi-Fi connection was chosen instead of UMTS or other licensed technologies to minimise the users' usage cost. It was designed based on the DTN scheme used for outer space interplanetary communication as studied in (Burleigh et al., 2003). DTN accommodates long delays communications and supports networks interoperability by translating between network communication characteristics (Palazzi et al., 2011)). It also accommodates limited power evolving wireless communication devices in providing those functions.

Palazzi et al. (2011)'s MDTN involves two main entities:

1. the MDTN client - users owning handheld devices with Wi-Fi feature that send tasks (to send or receive emails, to download or upload contents, or other asynchronous communication services)
2. the MDTN server - the carrier; Here is the public bus with Wi-Fi AP that locally stores users requests tries to accomplish them when the internet connection is available and notifies the respective users for their requests output.

Both of the clients and servers have to run and operate the MDTN software. It is a Java-based application built for Android devices and has been tested on several types of devices. The services it allows are:

1. MDTN-Status: handle service connection and logs;
2. MDTN-Email: send e-mail;
3. MDTN-Files: require and download Internet resources (e.g. web page, multimedia document)

Moreover, since a communication link to the next hop may not be available in the near time and a message may need to be retransmitted when an error occurs at the upstream link of the internet AP, the MDTN server then is not only equipped with a typical Wi-Fi router but also persistent storage to store tasks queues.

Just like DTN (Burleigh et al., 2003), the MDTN's communication process is as follows.

1. A user get on or get near the carrier bus and connect to its Wi-Fi AP (i.e. the server),
2. The user delegates a task, such as sending emails or request to download or upload a file. By delegation, the MDTN software installed in the user device locally encodes the tasks and forwards them to the carrier. He also may specify another bus or a list of potential buses he might take later on (so that he can receive the task outputs when he takes that bus)
3. The carrier stores the task locally for later execution
4. The carrier bus perform its travel route until it arrives at the internet point (e.g. at a bus stop or other designated points). If needed (such as if the user demands so or more time-efficient), the carrier bus can transfer its tasks to another carrier bus and let the latter accomplish the tasks.
5. The carrier connects to the available internet and accomplishes all the tasks in its storage. It stored all the requested files and the accomplished tasks receipts locally.
6. The carrier bus perform its travel route again, and when it meets the user (the user is connected to its server again), it sends back the task outputs (e.g. if a user requested to download a file, then the MDTN server will send the requested file to the user when it reencounters the user after it got the file).

The communication model of DTN is depicted in Figure B.8. In Palazzi et al. (2011), a node is represented by the MDTN server or the carrier bus. A bunch of tasks or messages are forwarded from a storage place on one node to another along a path until they reach their destination.

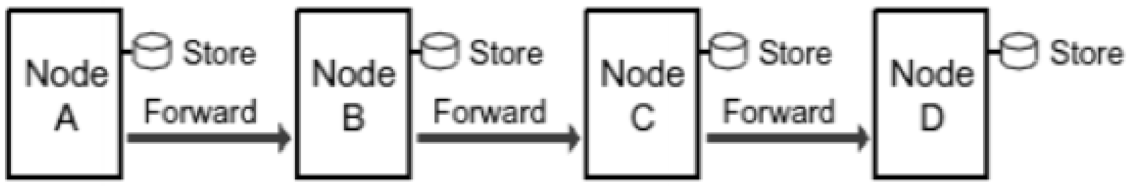

Figure B.8: MDTN communication model (Palazzi et al., 2011, p.2)

The software allows an entirely transparent process for the client. The client will get notified when his tasks have been accomplished and for his tasks output. The client can disconnect from the server anytime and the task output or notification will be forwarded the next time they are paired.

Palazzi et al. (2011) argued that store-and-forward networking seems a feasible solution in filling in blank spots by providing service connectivity where an infrastructure does not sustain it. As it does not require any infrastructure deployment, the cost required is minimal and it can be actuated in relatively no time.

The proposed solution, MDTN, offers the end-user access to push/pull services like email on the go and content retrieval like a web page or multimedia file downloading (Palazzi et al., 2011). It may encourage a high usage rate as it uses free internet service as the users will not have to worry about the costs.

There are potential challenges regarding this solution. This solution heavily relies on entities with routine mobility. Hence, it might not be effective in areas with no public transportation or other routine transportation activities. It might be able to use cars owned by the local population, significantly reducing the certainty of when the messages/tasks would be delivered. However, the use of private local vehicles instead of public transportation facility would make the management and maintenance arrangement challenging. Just as other electrical devices, MDTN servers sometimes get malfunctioned, thus need to be monitored regularly and repaired occasionally.

MDTN might not apply to areas which is not accessible by 4-wheeled vehicles and any vehicles that can carry MDTN server. Many rural areas in developing countries located in the rainforest, or between mountains or on an island can only be accessed by canoe, small boat or two-wheeled vehicles. In that case, there will be no means to carry the MDTN server.

B.1.8 Ambient Network

Grampín et al. (2007) proposed a solution to provide internet services to rural areas through a network that is cost-efficient and self-maintained, called Rural Ambient Network. Rural Ambient Network followed the IETF reference architecture and equipped with an algorithm that makes it autonomic, self-healing and capable of reacting to network events in an intelligent fashion. Without any end-user intervention, it can solve network issues that arise. This feature was called the policy-based management approach, which ”defines system behaviour according to high-level rules (the policies) expressed by a wise network administrator with a deep knowledge of the underlying reality” (Grampín et al., 2007, p.21). For example, in the event of a network outage, the policies would restrict the usage of a traffic-intensive application.

Wi-Fi and GSM are considered suitable for the last-mile access technology of this system (Grampín et al., 2007). It implemented a Layer 2 Extended Service Set (ESS) as the wireless distribution architecture, which is a type of mesh network based on multi-hop routing. Additional nodes will become active as soon as their adjacent nodes are available. It makes this system does not require network-wide planning in advance. Example of Rural Ambient Network architecture in some case studies (e.g. Fray Marcos and Totoral Del Sauce) can be seen in Figure B.9.

The algorithm allows optimum routing for the traffic between nodes (Grampín et al., 2007). Hence, it led to more efficient usage time and lower internet costs for the users and the local network provider in a multinodes network. The policy-based management approach further lower the operational costs of the network provider as it reduces the need for a technician site visit in case there are network issues (Grampín et al., 2007).

However, Grampín et al. (2007) mentioned that the Ambient Network he proposed has many limitations. One of them was that it did not consider the security threat.

B.2 Organisation solutions

B.2.1 Community Cellular Network

A community cellular network (CCN) is a solution in which users provide themselves with telecommunications infrastructures for their internal communication and access to the Internet and to MNOs through common gateways (Prieto Egido et al., 2020). The objective of this solution is to provide sustainable mobile network service in economically unattractive areas. This solution allows local owners and operators to have the freedom in deciding the network's properties, such as its design, operation, offered service, pricing and billing policies (Barela et al., 2016). Community cellular network (Barela et al., 2016) solution in other literature is

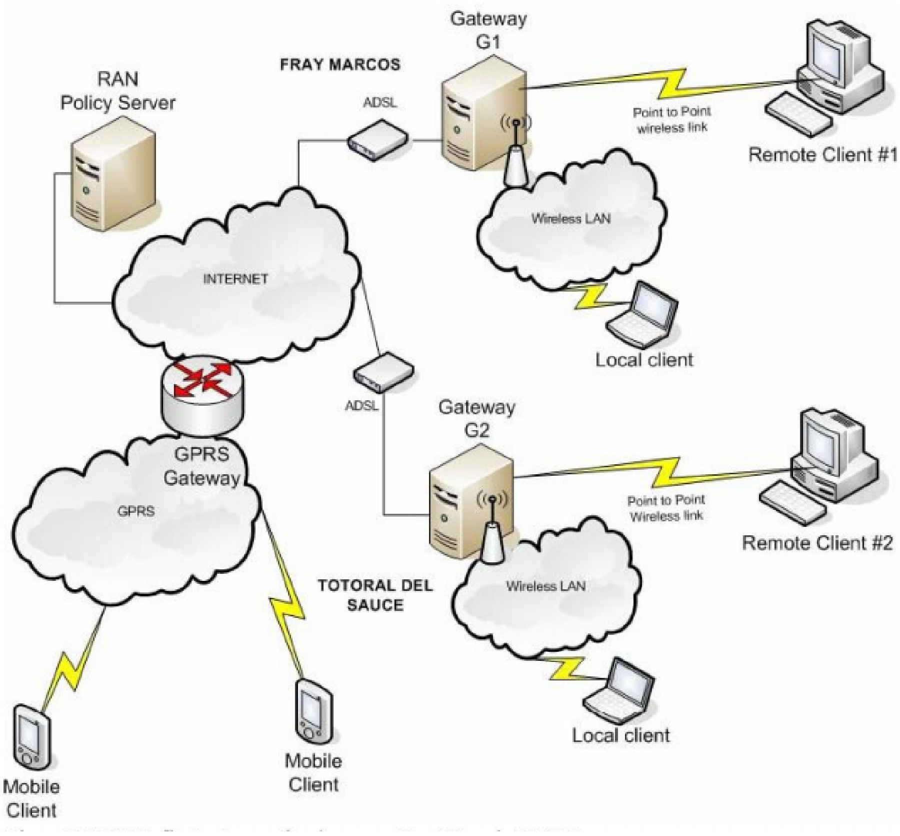

Figure B.9: Example architecture of Rural Ambient Network (Grampín et al., 2007, p.26)

also called as participatory society, community network paradigm (Prieto Egido et al., 2020), community-led model (Philip et al., 2017), regional/local governments and citizens' initiatives (Salemink and Strijker, 2018), local cellular network, bottom-up cellular network or inverse infrastructure (Heimerl et al., 2013). CCN promotes self-reliant communities and gives local citizens more responsibility in the telecommunication provision for themselves (Gieling, 2018). The access network technology chosen for this solution is varied between WiFi (Rey-Moreno et al., 2011), 2G/3G/4G (Barela et al., 2016) and OpenBTS (Heimerl et al., 2013).

In general, based on the literature, there are two kinds of schemes to implement this solution. The first is by fully relying on the local community. It means the users who will use the service will be fully responsible for the network and decide the network design and operation. This type of scheme is used by Heimerl et al. (2013), Barela et al. (2016) and Rey-Moreno et al. (2011). The second is by local government's support and usually initiated by the local governments. In this second scheme, local governments initialise the project by calling for local group initiatives, provide incentives and clarify the rules (Salemink and Strijker, 2018). The second scheme might rise from the responsibility endowment of the national government.

An example of this is the Netherlands. In the Netherlands, its national government considers the lack of broadband provision in rural areas as a marginal problem which provincial or municipal governments should solve instead of the national government (Letter to the Parliament DGETM-TM/16181300, 2016 as cited in Salemink and Strijker (2018)). In this country, CCN is not entirely from the local community but also supported by the provincial or municipal government. Salemink and Strijker (2018) explained that the local governments ought to facilitate citizens' initiatives in what they want to achieve. In the period 2012–2015, from the forerunning participatory society projects in the Netherlands, there are eight general stages for delivering rural broadband network with this solution (Salemink and Strijker, 2018) (see Table B.2).

Table B.2: Stages of Community Cellular Network in the Netherlands (Salemink & Strijker, 2018, p.759)

Stage 1: Incentive	Recognition of the problem, i.e. poor broadband provision
Stage 2: Familiarisation	Introduction to the actors and issues of rural broadband deployment
Stage 3: Inventory of demand	Assessing the potential demand in the target area
Stage 4: Campaigning	Campaigning in order to reach the target percentage of subscribers
Stage 5: Bundling demand	Formally bundling the demand (subscriptions) and forming the business case
Stage 6: Tendering and contracting	Composing a tender based on the business case and formally contracting a company for the deployment
Stage 7: Construction and commissioning	Process management of the construction as the commissioning party
Stage 8: Management and maintenance	Managing the network (cooperative) and outsourcing the maintenance

On the other hand, Heimerl et al. (2013) envisioned CCN as the network that is operated primarily by agents within the community, built with existing local infrastructure when available, low cost and financeable by small entrepreneurs or NGOs and sustainable, with profit staying in the community. The CCN implemented by Heimerl et al. (2013) did not involve government at all. The network used its own SIM cards; hence the project included buying and provisioning SIM cards and credits and local credit checking mechanism and provided intra-community SMS and voice services and SMS service out of network. The network is jointly owned and operated by both an NGO and a for-profit wireless Internet service provider. They provide both operation base and the technical knowledge required for sustainable deployment. This network is proved to operate profitably.

Heimerl et al. (2013) provides their network specification in their article. It used GSM access network technology (OpenBTS) and satellite backhaul (VSAT) to deliver the service in a village located in highland topography. RAN was installed on a pole, mounted using a tree. The electricity was sourced from a micro hydropower generator backed up with batteries as there was no electricity grid in the location. The revenues from this network are the SIM cards (around 100,000 rupiahs per year per card), global SMS service (around 1000 rupiah per SMS), local SMS service (230 rupiahs per SMS) and local calls (230 rupiahs per minute). With these price scheme, the network was predicted to reach its break-even point in 5 years, and the people felt the price reasonable. Prior to deploying the network Heimerl et al. (2013) found that the initial customer base size is around 356 users.

From the business model point of view, community-owned networks may lower the cost of access to communications services and provide the community with some additional advantages. Researchers have found that this solution can actually have lower costs by leveraging the local existing infrastructure (Galperin and Bar, 2007). Meanwhile, the decentralised network this solution proposed could potentially empower the local community, increasing opportunities and freedom (Sen, 1999).

Network sustainability is more likely to achieve with this solution. The local ownership incentivises local communities to support and maintain the network (Heimerl et al., 2013). In addition, the feature Heimerl et al. (2013)'s solution has in which the profit of the network operation returned to the community increase the local actors' care to the network failure (Heimerl et al., 2013). It also is proven to reduce theft, since people would be less likely to steal from people whom they know and know them than from big corporations which have no social relationship with them (Heimerl et al., 2013). It might solve the vandalism and theft issues that often occur on network infrastructures in rural areas.

The challenges for this solution might be the shortage of technical personnel in the local community, the high cost of some elements of the network, such as the base station controller, the difficulty to interconnect to other operators' networks, and the regulatory constraints on the use of frequencies for mobile services. This last aspect is the most substantial restrictions for this type of project (Prieto Egido et al., 2020). However, some studies have proposed solutions to this challenge. The first option is using MNO's mobile bands that were not used locally like one of the Rhizomatica projects in Mexico (Wade, 2015) where it obtained the Mexican government's permission to use the bands, and a pilot project in Philipines (Barela et al., 2016). However, in some countries, utilising an MNO's unused frequency in an area cannot be done without coordinating with the regulatory agency and the assigned frequency owner. In such a situation, the second option can be used, i.e., using WiFi free bands (IEEE 802.11) as adopted in Peruvian rural areas (Rey-Moreno et al., 2011).

Another challenge for participation society has to do with its need for technically skilful and resourceful personnel (Philip et al., 2017; Salemink and Strijker, 2018). The call for local initiatives urges some citizens to organise themselves. These citizens are mostly those who well-educated and resourceful (as cited in Salemink and Strijker (2018)). A considerable resource fund will be needed to purchase high-cost network elements. These people might be challenging to find in rural areas in developing countries known for their low income, high poverty rates, and low education compared to urban areas. In addition, when implementing this solution using the government scheme, the empirical study by Salemink and Strijker (2018) pointed out some potential impediments. It conveyed that often local governments (the provinces and municipalities) do not have sufficient expertise to deal with this issue. Without central guidance, they took a lot of time and resources to get familiar with the broadband provision in general, i.e., knowledge about its technologies, network design, market situation, financial models, etc. It might then also be difficult for them or for the national government to design suitable and effective policies (Salemink and Strijker, 2018).

Being able to interconnect the local network to other networks might also be problematic. As experienced by Heimerl et al. (2013), in the end, their network can only connect with the external network via SMS outbound, while their usage record showed that out-of-network connectivity is a critical need for any local telecommunication. Interconnection is wild and confusing in the cellular network business, where who you know is matter (Heimerl et al., 2013). MNOs might not want to provide interconnection unless they are sure of their network's safety and profitability. Heimerl et al. (2013) ended up with Nexmo, the only company they found able to route to Indonesia consistently.

B.2.2 Small Rural Operator

There is a dilemma for the MNOs about expanding the network to rural areas. MNOs prefer urban deployment since it offers a much higher RoI (Trendov et al., 2018) and it needs high investments to maintain (Prieto Egido et al., 2020). The demand is from the local people and the government who considers telecommunication services in rural areas as strategic to improve public services and institutional presence. On the other hand, operators actually consider unserved areas as their best opportunity to increase the number of customers and expand their market (Prieto Egido et al., 2020), yet the risk is high. Small Rural Operator (SRO) aims to fulfil the demand for mobile network service in rural areas, where MNOs are usually unwilling to invest.

Prieto Egido et al. (2020) proposed SRO to be an operator that is responsible for deploying and maintaining mobile network infrastructure (access and backhaul network) in rural areas, while the core network is owned and operationalised by MNOs (Prieto Egido et al., 2020). Under this scheme, MNOs act as virtual operators in rural area that use the SRO's infrastructure to reach rural customers. The rural users pay the service costs to MNOs and MNOs pay a percentage of the revenues generated by the SRO's network to SRO. A pilot project of SRO in Peru give SRO 70% of the total income from the rural network, while the rest for the MNO (Prieto Egido et al., 2020). This kind of solution is also proposed by Cruz and Touchard (2018), called

Single Wholesale Network (SWN). The main differences between the SRO and the MNO are summarised in Table B.3.

Table B.3: Differences between MNO and SRO (Prieto Egido et al., 2020, p.4)

	MNO	SRO
Main business goal	To obtain new customers and keep existing ones by competing with other MNOs in areas where there is a clear business case.	To obtain and serve new clients for the MNOs by providing coverage in sparse communities previously unconnected, where a particular business strategy is needed and infrastructures may need to be shared.
Frequencies	They pay for the frequencies they use.	They use the unused frequencies of the MNO under an agreement.
Infrastructure	They deploy a whole network with equipment for the core, backhaul and access segments.	They deploy the access network and the segment of the backhaul network required for the interconnection of users with one or several MNO networks.
Customers	Their customers are the users of mobile networks.	Their customers are the MNOs who are willing to expand their coverage to uncovered communities.
Main expertise	To deploy and maintain mobile networks in urban areas with a high density of clients and high traffic demand.	To deploy and maintain mobile networks in rural areas with a low density of clients and low traffic demand.
Mean Time To Repair (MTTR)	It must be very low to prevent customers from migrating to another MNO, but it is easy for technical staff to repair the access network in a short time.	It is tough to access the access network in a short time to have a low MTTR, so their maintenance model is very adapted to lower it as much as possible, and they also need to have strategies that result in a small Mean Time Between Failures (MTBF).
Threats	The clients can migrate to another MNO if they are not satisfied with the price and/or quality of the service.	The MNO can cancel the contract if the quality of the service, very related to the MTTR, is insufficient.
Energy	They can generally rely on the power grid.	There is not always access to a power grid and they have to deploy isolated power systems. Energy systems are critical for the MTBF.

Prieto Egido et al. (2020) proposed SRO to use TUCAN3G as the network deployment technique. TUCAN3G network employs unlicensed bands for the backhaul and the unused MNOs' frequencies for the access network. The unlicensed bands, such as Wi-Fi 5 GHz band, are considered usable in isolated areas due to the lack of interference. More elaboration on TUCAN3G can be found in Subsection B.1.1.

This solution allows better profitability for the operator in rural areas. By becoming the only operator in the area, SRO can fully take benefit from its market area. Since SROs specialise in deploying networks in rural areas, they will address the 'common' problem more efficiently. Furthermore, if the SRO solution is combined with TUCAN3G, SRO could reduce CAPEX and OPEX by using low cost wireless terrestrial backhaul (Prieto Egido et al., 2020), such as Wi-Fi and WiMAX as explained in (Simo-Reigadas et al., 2015). The network infrastructure it established can be offered to and used by more than one MNOs by employing RAN virtualisation. The use of RAN virtualisation makes SRO's networks more flexible and scalable, thus increasing profitability. Moreover, the SRO does not need to make expenses on advertising campaigns as it will be MNOs who has a relation with end-users, which contributes to reduced OPEX (Prieto Egido et al., 2020). The financial and management structure of SROs is also much more straightforward, which lowers its SGA (Selling, General Administrative) costs.

With this solution, MNOs can expand their market area and increase their number of users to rural areas while avoiding significant risks:

- Regulators sanctions for network quality of service. In many countries, MNOs must fulfil a certain level of network availability and mean time to repair. These parameters are usually more difficult to achieve in rural areas due to access difficulties.

- Unprofitable allocated resources. MNOs need to address resources (staff, investment, network resources) for deploying and maintaining the network in rural areas. Whereas the profitability of rural areas is lower than urban areas. There is even a possibility that rural areas are not profitable, making their allocated resources unprofitable.

On the other hand, since the operators responsible for rural areas are already specified and limited, coordinating work regarding rural areas would be easier for the government. It would also make public subsidy management and evaluation easier for the government or other organisations supporting funding for rural developments.

There may be cases where a sustainable network cannot be achieved due to too insufficient revenue potential or too difficult topography, or cases where the government's subsidy is needed (Prieto Egido et al., 2020). The study by Prieto Egido et al. (2020) showed that the implementation of SRO solution in villages located in highland are mostly sustainable as the revenue is high and there were existing towers that can be used, but those in rainforests needed public subsidy to sustain.

Prieto Egido et al. (2020) noted that this approach might require a complex and time-consuming process until initial agreements among MNOs and SROs are reached. Nevertheless, the success of this solution in Peru proved that it is feasible.

On the other hand, letting an SRO handle specific areas means letting it monopolise the area. This monopoly situation can discourage innovation and lead to inefficient use of resources and abuse of position. Furthermore, the economic development of rural areas evolves along with the telecommunication service development, allowing these areas to be economically viable for MNOs in the future. The existence of SROs would discourage the deployment of new networks and crowd out private investment (Cruz and Touchard, 2018). There are also operational difficulties experienced by countries implementing SRO that often lead to abandoned projects or project failure (GSMA, 2019).

B.2.3 Mobile Virtual Network Operator in rural areas

Unlike SRO, MVNOs (Mobile Virtual Network Operators) solution focused on increasing the existing network's usage, increasing the MNOs' RoI and the existing network's sustainability. Mobile network in rural and remote areas are known to be difficult to maintain (Surana et al., 2008), leading to high operational cost, while the revenue per site is much lower than urban sites due to the low population density. In typical situations, when the revenue is lower than the operational costs and no financial support from the government, the disadvantageous sites would be dismantled by MNOs. A measure to increase the network usage by users, hence the ARPU, by providing new attractive mobile services, would help the existing network in rural and remote areas sustainable.

Son et al. (2019) suggested that establishing and regulating MVNOs can increase the ARPU of mobile networks in rural areas. MVNOs can increase the ARPU by providing access service, which MNOs overlooked. In addition, they also can provide numerous services that may be too expensive for large MNOs to provide (Cricelli et al., 2011).

MVNOs provide mobile subscription without spectrum, instead of using radio networks of the existing MNOs (Son et al., 2019). Some MVNOs have their infrastructure, including MSC, HLR, billing, intelligent network systems, customer care, and value-added service platforms, while the others only re-package the services or operators and issue SIM cards (Kristensson and Gahnström, 2001). Since MVNOs do not own spectrum licenses and mobile network infrastructure, MVNOs solely rely on the MNOs' network facilities and utilise them via commercial arrangements (MVNOs pay rental fees to MNOs) (Kiiski and Hämmäinen, 2004).

This scheme is the opposite of the SRO scheme proposed by Prieto Egido et al. (2020). Under SRO's scheme, SRO owns and maintains the mobile network infrastructure (access and backhaul network) in rural areas while the core network is owned and operationalised by MNOs. The rural users pay the service costs to MNOs, and MNOs pay a percentage of the revenues generated by the SRO's network to SRO. Moreover, under MVNO's scheme, the mobile network infrastructures are owned by MNOs that MVNOs rent; MVNOs have their own SIM cards and brands and offer attractive services (that are not provided by MNOs). The rural users pay the service costs to MVNOs, and MVNOs pay the rental fees to MNOs.

In some countries, MVNOs have been encouraged by regulators as a way to increase competition and reduce prices. Hence, applying it under a certain framework can contribute to the decline of ARPU, too. To prevent this counterproductive effect, Son et al. (2019) suggested a regulatory framework to govern MVNOs in order to achieve better network coverage and QoS:

1. MVNOs should also be required to have a spectrum license so that the government can control them.
2. MVNOs must have a commercial agreement in place before MVNOs will receive a license and commence operations.
3. Number of MVNOs attached to each MNO should be limited either by limiting the number of MVNOs in a particular area or limiting the spectrum available to the MNO. By only allowing MVNOs to operate in rural and remote areas, its disproportionate effect on reducing the ARPU of the existing network in urban areas could be mitigated.
4. No roll-out obligations for MVNOs, since MVNOs mainly provide telecom services in remote and rural areas. It can encourage more entries by MVNOs.
5. Number blocks should be assigned directly from the authorised body to the MVNO, or the MVNO should share number blocks from the MNO. The agreement between the MVNO and the MNO should contain a clause to address the numbering issue.
6. To maintain a satisfactory quality of service, the MVNO should have a service-level agreement with MNO, while the regulatory body prescribes the minimum level of standard to be maintained by telecom licensees (including MVNOs). The MVNO has the final responsibility for maintaining the quality of service to its subscribers.

MVNOs make a business game plan by renting access to the mobile network (Son et al., 2019). It motivates new concepts and strategies for telecom and non-telecom organisations to provide mobile services, especially to remote areas. As a result, both MNO and MVNO can be favoured by this plan of action: the MNO can benefit from new revenue streams by exploiting its network capacity, IT infrastructure, services, and product portfolio to acquire integrated segments, and the MVNO benefits from low-cost entry into the mobile market and the ability to offer services to clients (Son et al., 2019).

Challenges are encountering for implementing MVNOs as a solution for the mobile coverage problem in rural areas. Under a particular framework, MVNOs existence can contribute to the decline of ARPU. From the MNOs' point of view, handshaking with MVNO may put them at risk of revenue loss, particularly for operators whose subscribers are looking for alternatives. Only if MNOs can get MVNOs to agree to pay rent fees as much as their current revenue level, or if MVNOs target different market segments from MNOs', they might be guaranteed from revenue loss.

B.2.4 Central and local authority's support

Local-level rules and regulations significantly affect the site deployment costs for MNOs. Although mobile networks are designed at the national level, they are built locally, obliging MNOs to comply with local (per region, province, municipality, district, and so on) rules when deploying, maintaining and upgrading their infrastructure (Cruz and Touchard, 2018). An overly strict set of rules, complex and lengthy permit process, rent-seeking opportunistic behaviour and arbitrary charges for site approvals from local authorities limit the ability and increase the costs for MNOs to build new sites. The extra costs may offset the potential revenues in rural areas, while the revenues are already low, making MNOs unwilling to deploy a network in rural areas (Cruz and Touchard, 2018). Moreover, the heterogeneous local rules prevent MNOs to streamline their deployment process at the national level (Cruz and Touchard, 2018), making it unnecessarily more complex and time-consuming. Whereas the established rules at the local level often are ill-conceived due to the lack of technical expertise at local governments (Cruz and Touchard, 2018). Therefore, two main problems need to be addressed to achieve a higher network coverage, according to Cruz and Touchard (2018), are the unfounded bans on wireless network deployments and the high costs and delays for deploying the network in rural areas.

Cruz and Touchard (2018) argued that one of the critical inhibitors in coverage expansion to rural areas is the complexity of regulations and administrative processes to deploy infrastructure that leads to high administrative costs for site deployment/upgrade and even absence of coverage in rural areas. So, they recommend the government reduce it as much as possible by creating guidelines that ensure consistency, simplicity, and rapid implementation of regulations across local governments on planning regulations, health and safety regulations, permits and approvals processes, and access to land and infrastructure. Cruz and Touchard (2018) identified two main ways to reduce administrative costs of new sites deployment: 1) By improving the efficiency of permit approvals, and 2) By avoiding costs duplication by improving coordination across infrastructure sectors. They are translated into several best practices as follow (Cruz & Touchard, 2018, p.21):

For the Central Authorities
To improve the efficiency of granting permits:

- Provide standardised and simplified national procedures for permit approval, including the information requirements and a mandatory decision period. Specifically, permits about antenna, health and safety compliance, appeal, existing sites modifications, site sharing and co-location, and small cells are among the best practices for permit standardisation. Regarding health and safety compliance, some research on the wireless network impact on human health has resulted in a set of precautionary measures to limit exposure to radiofrequency radiation (ICNIRP, 1998). Since central governments are usually better equipped to evaluate these technical measures, establishing rules regarding RF exposure limits and compliance mechanism should be the central governments' responsibility. Accordingly, local authorities should follow those rules when processing deployment permits in their areas.
- Provide clear national guidance on visual integration for infrastructure and for building infrastructure in general.
- Facilitate access to public land and infrastructure (buildings, electricity, backbone network) for MNOs with standardised procedures and reasonable price
- Provide a single point of information for the permit granting that contains relevant infrastructure data, rights of way and dispute resolution for infrastructure deployment
- Provide clear criteria on low impact facilities that can be installed without the local government's approval.

To improve cross-sector coordination:

- Creating a map of relevant infrastructure, including fibre, ducting, electrical cable poles and governmental building, makes this data available through a single information point.

- Imposing a general obligation to make advance notifications of planned civil works.

For the Local Authorities

- Follow the national framework whenever possible when creating local standard procedures for handling mobile network sites construction permits and approving/disapproving health and safety permit requests.
- Defer to national agencies on expertise, policies and technical requirements.

Implementing this solution promises a more cost-effective mobile network investment that would benefit the mobile network industry in the long run. Eliminating the unnecessary delays and costs in obtaining construction permits represents indirect financial support for MNOs as it reduces their potential revenue. According to an OECD report in 2014 (OECD (2014) as cited in (Cruz and Touchard, 2018)), implementing measures to reduce administrative burdens in Greece in 2014 was estimated to result in a 5.1% reduction of all Greek MNOs' CAPEX in 2014 compared to their 2013 CAPEX.

The challenge of this solution is its implementation. The bureaucratic structure of governmental bodies in a country may not allow central authorities, such as ministries, to rule or advise local authorities. If that is the case, then changing the central ministry's mandate or creating a central governmental law would be needed to implement this solution so that its guidelines can affect the local regulations. Otherwise, mechanisms to incentivise local governments to adopt the central government's guidelines should be carefully designed so that they will voluntarily comply with the new rules.

On the other hand, the Greece case also showed that the red tape measures should be specific. Therefore, before defining guidelines and obligations, the governments need to conduct a preliminary assessment on the actual hurdles that MNOs face when seeking permits.

B.3 Regulatory solutions

B.3.1 Coverage-obligated spectrum license

This solution aims to push and accelerate the network penetration to rural areas, the areas that are known as economically unattractive and challenging. Closing the coverage gap cannot be achieved by relying on the industry alone but should be supported by governments intervention. Solely relying on the market will result in the exclusion of the unprofitable areas from the coverage and service, whereas telecommunication services are essential for and should be equally provided to everyone (Bhuiyan, 2004).

A coverage obligated spectrum license is a license given to an MNO to use a specific spectrum, in which to be eligible for using the spectrum, the MNO should agree to fulfil the coverage obligation accompanying and stated in the license. To promote coverage in rural areas, Cruz and Touchard (2018) suggested implementing this solution on coverage bands. Coverage bands are the spectrum bands for frequencies below 1 GHz, which have the characteristic to suffer less attenuation and penetrate walls better. Coverage bands are considered ideal for rural areas as they can cover larger areas than capacity bands (bands with frequencies higher than 1 GHz) with the same site configurations (height, power consumption, etc.), although they provide a lower data rate. According to the ITU, using 900MHz allows operators to cover 2 to 2.7 more area than using 1800MHz (Cruz and Touchard, 2018). As a result, operators will be able to cover more population with the same amount of costs. Subsequently, more customers can be reached with the same costs, hence higher RoI for MNOs and more incentives for MNOs to deploy a network in rural areas. Considering this aspect was needed to ensure the coverage obligation applied to MNOs will not put them in hardships and loss, but a win-win for all. Acknowledging the importance of providing enough coverage bands, in 2016, ninety countries in the world cleared and reallocated 600, 700 and 800 MHz bands for mobile services, most of them are developed countries (Cruz and Touchard, 2018). Meanwhile, many developing countries, which actually need the spectrum the most, have not yet assigned the spectrum sufficiently. Unused spectrum and delayed release of the spectrum represent a wasted resource to society.

Many countries apply coverage obligations on their released spectrum license in various schemes. In India, according to Sridhar and Prasad (2011), the licenses are divided into 22 areas, which are categorised based on their revenue potential. In each area, there are several licenses given out to MNOs. The license is given for twenty years, and the spectrum is co-terminus with the operating license. The license conditions include a roll-out obligation to cover a certain percentage of the area within a stipulated period. Meanwhile, in Sweden (Cruz and Touchard, 2018), only specific spectrum licenses that are imposed by coverage obligations and licenses applies nationwide.

To summarise, Cruz and Touchard (2018) suggested the following considerations when implementing coverage obligation as a measure to promote coverage to rural areas:

1. It should be included in the spectrum license conditions and only be applied to the low-frequency spectrum (< 1GHz), so MNOs acknowledge the obligation when bidding the spectrum
2. Realistic and compliable obligation in terms of targets and timelines
3. The license price or related tax should take into account the compliance cost
4. The spectrum blocks with coverage obligation should be limited to prevent infrastructure duplication in the low revenue areas
5. Government should allow infrastructure sharing to facilitate compliance.

The use of coverage obligation would help in pressing down the commercial orientation of MNOs by adding a new value for them, which is compliance. With this solution, the government creating a reason for MNO to deploy networks in the exact areas that government wants, allowing the government to have more direct control over the MNOs' network plan. Since spectrum is a rare resource and an essential thing for MNOs, attaching the obligation to spectrum license would create a hard-to-disagree offering. Meanwhile, applying coverage obligation on coverage bands would increase the opportunity for the MNOs to fulfil the obligation due to its higher RoI.

A careful analysis for deciding the price of the spectrum is important to ensure a successful coverage obligation policy on rural areas network deployment. As now MNOs are getting more burden due to the obligation to cover the less profitable areas, it would make sense if the spectrum price is lower than usual. The price should take into account the extra costs MNO would need for fulfilling the obligation. The price should also mitigate the risk of the spectrum going unsold after auction (Cruz and Touchard, 2018). Reaching consensus on the 'right' price might be challenging.

B.3.2 Spectrum management

The way spectrum is awarded and managed can significantly affect the quality and affordability of mobile services, particularly in less economically viable areas. Touchard (2017) argued that ensuring a sufficient quantity of spectrum available for mobile services at a reasonable price and under conditions that encourage long-term investment in mobile networks is essential for achieving the optimum level of commercially sustainable coverage.

Spectrum is one of the cost items that majorly contributes to the MNOs overall expenditure. Hence, it affects MNOs financial capacity to develop network and mobile services affordability, including in rural areas. Cutting down the unnecessary expense as much as possible, leasing spectrum efficiently and ensuring MNOs can have sufficient spectrum whenever they need, in the end, will promote better and faster network penetration to rural areas. Numerous countries worldwide have acknowledged the importance of providing enough spectrum, particularly on coverage bands (600, 700 and 800 MHz) for mobile services. Unfortunately, many developing countries fail to do so, perhaps in the misguided belief that hoarding the spectrum could increase its selling price at subsequent auctions, resulted in lower levels of mobile development (Cruz and Touchard, 2018). In fact, the unused and delayed release of the spectrum is a wasted resource for society.

In India, it is evident that the way spectrums are managed has a significant impact on enhancing network deployment. Initially, in 1990, India provided licenses through an auction mechanism in which the winning operator would pay a fixed fee (set by auction) upfront. This licensing model and the set price led to a high financial burden (even bankruptcy) of the license holders and resulted in the slowdown of new services deployment (McDowell and Lee, 2003). Seeing the situation, in 1999, the government then agreed to reduce the upfront fee in exchange for an annual charge based on the license holder's revenue and the amount of spectrum held (McDowell and Lee, 2003; Sridhar and Prasad, 2011) while the total accumulated price remain may be more or less the same. The new licensing model raised the number of telephone lines significantly from 26,5 million in 1999 to 32,4 million in 2000 (5,9 million new lines in a year), while between 1990 and 1999, only 21,9 million lines were established (McDowell and Lee, 2003). However, it was noticed from India's experiment in mobile licensing that both its initial policies in spectrum licensing focusing only on the 'spectrum' pricing had not addressed the needs of access to communication services in rural and less prosperous regions (McDowell and Lee, 2003).

This solution focuses on the management of the spectrum used in the mobile network. It includes the recommendation in spectrum's licensing model, pricing and operation. Regarding the pricing, Cruz and Touchard (2018) argued that spectrum price should be set with the primary objective to enhance connectivity. Therefore, the governments should avoid the temptation to use spectrum auctions to maximise revenue. The reserve price should be modest but non-trivial to deter the frivolous entry of non-competitive firms while ensuring that winners pay at least the "opportunity cost" of having denied the next spectrum. Sridhar and Prasad (2011) argues that regulatory levies such as spectrum charges should be equivalent to the cost of administration and uniform across all frequency bands and technologies. The auction also needs to ensure that the winner's winning will not foreclose future competition and put other MNOs' enterprise value at risk, for example, by not enabling an MNO to take over spectrum bands that may be essential for other MNOs to compete for customers. In addition, since coverage bands (sub-1GHz bands) are the essential spectrums for rural network deployment due to their transmission capacity and wide geographic propagation characteristics, further lowering the price for the coverage bands and ensuring sufficient coverage bands are available and accessible for MNOs will promote better and faster network penetration to rural areas.

Government should adequately open the accessibility to spectrums for mobile communication (Cruz and Touchard, 2018; Sridhar and Prasad, 2011). Spectrum refarming can be explored as a measure to add more spectrum for mobile telecommunication. As an example, Ultra High Frequency, traditionally used for terrestrial TV broadcasting, was advocated by the US and many countries to be refarmed for mobile services (Sridhar and Prasad, 2011). Apart from adding a new spectrum, the government also should ensure optimum efficiency in the existing available spectrums by not delaying any spectrum release and keeping any of them unused (Cruz and Touchard, 2018).

Regarding spectrum operation, Cruz and Touchard (2018) suggested for the government to provide a clear spectrum roadmap, to allow spectrum trading and sharing, and to lease it in technology-neutral in order to achieve the highest spectrum efficiency. They explained that either released through auction or beauty contest, the government should ensure spectrums are held by the actors who value it the most, with long duration (15-20 years) and assurance of renewal. However, to identify who values it most, Subscriber Linked Criterion (SLC)–in which additional spectrum is assigned as when a licensee's subscriber number hits a certain threshold, as was used in India–is not recommended for spectrum assignment (Sridhar and Prasad, 2011). A clear spectrum roadmap is considered necessary by Cruz and Touchard (2018) as it would diminish future business uncertainties for MNOs. Having informed by the spectrum roadmap, MNOs can assess the long-term value of their infrastructure investments regarding the spectrum they want to get. A spectrum roadmap should have, at least, the list of the existing spectrum licenses, licenses to be allocated, licenses to be reallocated, timings, pricing procedures and spectrum allocation framework (GSMA, 2016).

Secondary market and spectrum sharing allow flexibility hence makes the license more attractive. The secondary spectrum market allows MNOs to buy or lease spectrum from each other at any given time (Cruz and Touchard, 2018) after getting permission from the government. The spectrum buyer pays a trading fee to the government in addition to the spectrum price to the spectrum seller (Sridhar and Prasad, 2011). Since the spectrum can be transferred to the MNO that value it most, it will better use the available spectrum. One model for license sharing or trading is licensed shared access (LSA) and spectrum access system (SAS), which provide spectrum locally and in the short term at a reasonable cost and predictable quality of service (Lun et al., 2019). Figure B.10 shows the proposed architecture of the spectrum access reference system. The system's main component is the eLSA repository that holds details of spectrum usage over space and time under the national regulation agency (NRA) supervision. Based on spectrum information in the eLSA repository, MNOs can access and release spectrum via eLSA controllers for exclusive use in mobile/fixed communication networks (MFCN) for a given duration in a local area. The local area can be defined based on settlement area, polygon, or land registers. The main difference between LSA and SAS is that in LSA, the spectrum usage information is derived from the incumbent's a-priori provision, whereas, in SAS, it is based on input from sensors checking the incumbents' occupation of spectrum throughout the country. More elaboration on the secondary spectrum trading recommendation in India can be found in (Sridhar and Prasad, 2011).

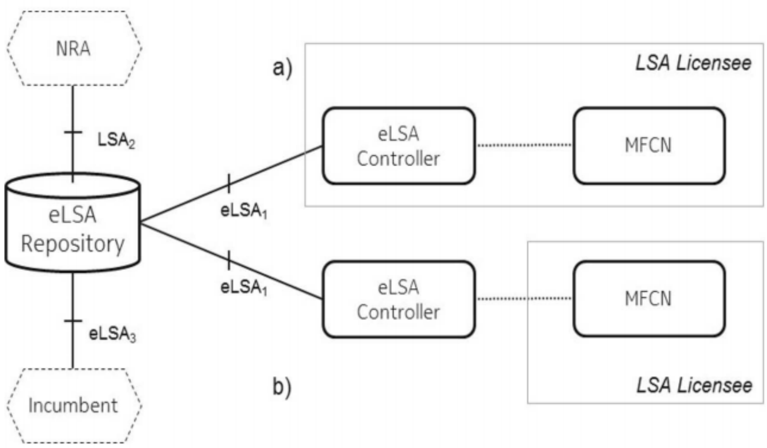

Figure B.10: Spectrum licenses access reference architecture by (Lun et al., 2019, p.3)

Spectrum efficiency can also accrue through spectrum sharing. Sridhar and Prasad (2011) suggested that sharing should be permitted by the government on sharing fee based on the quantity of shared spectrum, in the same manner as in the case of spectrum transfer/trade. When operators share spectrum, the sharing fee shall be levied on the operator(s) owning the smaller spectrum blocks being shared. Since spectrum sharing arrangements are temporary, the sharing charges should also be based on the actual sharing period on a pro-rata basis.

Neutralising the spectrum's technology means allowing the spectrum holders to use the spectrum for any technology they want that they think would best suit their needs (Cruz and Touchard, 2018). It stems from the argumentation that private operators are more knowledgeable of the market and will choose the optimum service for the customers (El-Moghazi et al., 2015). For telecoms policy, technology neutrality means that regulators should refrain from using regulations as a means to push the highly dynamic market toward a particular technology that the regulators consider optimal (Maxwell and Bourreau, 2014). As an example, if the 1800 MHz band is set to be technologically neutral, then it means all MNOs having this band are allowed to use this band for carrying 2G, 3G, 4G, 5G and/or other possible mobile network technology and government do not assign 1800 MHz to be used only for a specific technology. This licensing regime is different from the old one where 900 MHz bands are specified in MNOs' licenses only for GSM (Global System for Mobile telecommunications, 2G) technology, 1800 MHz for DCS (Digital Communication System, 2G) and 2100 MHz for UMTS (Universal Mobile Telecommunications System, 3G).

To summarise, this solution proposed for the government to:

1. make as much as possible spectrum available for mobile services, particularly the coverage bands
2. set a low but effective spectrum price, particularly the coverage bands
3. provide a clear spectrum roadmap for MNOs or publicly
4. allow spectrum trading and spectrum sharing
5. release spectrum in technology-neutral
6. release spectrum through auction or beauty contest with long duration and assurance of renewal

The proposed schemes of spectrum management were shown to accommodate a good coverage in Sweden and Myanmar. Cruz and Touchard (2018) pointed out that the 99% coverage level of 4G service in Sweden in 2018 cannot be separated from the spectrum strategy it implemented since 2014. Similar to Sweden, in 2018, Myanmar also had successfully expanded its 4G services to most of its citizens after it released several bands at a modest price in 2013 and permitted the proposed schemes.

Lowering the spectrum price will significantly increase the revenue opportunity per site as it reduces the upfront CAPEX and allow a more affordable service provision for the rural population (Touchard, 2017). He also opined that "every dollar invested in acquiring spectrum is a dollar lost to investment in infrastructure, pushing up the running costs of networks and reducing the size of the footprint that can be served" (Touchard, 2017, p.21).

Moreover, additional benefits can be derived when specified with neutral technology, applied on coverage bands, complemented with a clear spectrum roadmap and secondary market and when the spectrum price is lower. Technology neutral allows MNOs to make better and efficient use of spectrum. This type of license gives them the flexibility to use technology that best suits their needs and introduces new technologies that enable new and better services for their customers. Meanwhile, lowering the spectrum price would increase the opportunity for the MNOs to fulfil the obligation due to its higher RoI. A clear spectrum roadmap and secondary market reduce business uncertainty of MNOs that would make them more confident in investing. In addition, the secondary market also will further optimise the use of spectrum by allowing it to be transferred to actors who are more willing to make the necessary investment with it; thus a better expansion rate (Cruz and Touchard, 2018). Montenegro and Araral (2020) found that pro-competition regulations, in which the permission of secondary spectrum trading is one of the indicators, had a more substantial positive effect on increasing QoS in developed countries compared to developing ones. Spectrum trading could also make innovative activities less risky. MNOs can use it to test a new service or product based on a specific technology. If the service or product is successful, they can buy additional spectrum. Otherwise, they can resell the spectrum rather quickly and reduce the losses (Valletti, 2001).

This solution has challenges. Introducing technology neutrality to existing licences can disrupt the competition dynamics in the market. Therefore, before neutralising the spectrum's technology, the government needs to do competition assessment and stakeholder consultation to ensure a positive long-term effect on the market (Cruz and Touchard, 2018). Moreover, although it is understood that setting the 'correct' spectrum price is important, there is no single best approach nor international benchmarks to estimate fair spectrum price (Son et al., 2019). An in-depth examination in the respective country is needed for that. After spectrum trading is allowed, the regulator needs to oversee the spectrum transaction to avoid spectrum concentration that could lead to spectrum hoarding and anticompetitive behaviour (Cruz and Touchard, 2018). Furthermore, the establishment of a license repository as proposed by Lun et al. (2019) implied an ability of MNOs to see each other's coverage in specific areas. Some MNOs might consider this information as sensitive that they might refuse to share it with their competitors.

Changing the licensing regime would be uneasy. Many analysts highlighted that there are trade-offs between the need for reforming the system and the difficulty of changing policies, given the powerful political roles of certain public sector enterprises, private firms, public sector unions, farmers and voters in urban and rural regions (Kähkönen and Lanyi, 2000).

Despite all this quite detailed guidance, variations about which licensing model is better (even for one country) exist. For example, between McDowell and Lee (2003) and Sridhar and Prasad (2011) in Indian case. McDowell and Lee (2003) argued that leasing the spectrum for free in exchange for a strong set of telecommunication network performance requirements that include a specific geographic and service configuration is innovative to advance coverage penetration. A performance standard containing requirements for deployment in urban, semi-urban and rural areas was set for companies to obtain additional spectrum or retain their existing spectrum. On the other hand, Sridhar and Prasad (2011) argued that the command and control approach, in which the government defines what 'the best-use' is by, among other things, administering intervention (e.g. roll-out obligations, 'use it or lose it' conditions), possess risks of regulatory failures including lower value uses of spectrum. As an alternative, (Sridhar & Prasad, 2011, p. 179 and p 180) suggested market mechanisms such as spectrum auction, since they allow price revelation and allocate spectrum to those who are best able to use it in the highest value applications, and that any spectrum use inefficiency should be penalised by market forces and need not to be administratively monitored. This situation shows that finding the right and no-side-effect spectrum license model may be difficult and should be based on a careful assessment of the country.

B.3.3 A taxation policy that foster investments in rural areas

The level of taxation directly affects mobile operators' financial ability to invest in infrastructure and coverage, while tax complexity and uncertainty may also affect future investment incentives and ease of doing business in the region (Touchard, 2017). With frequent tax changes, returns on investment are less certain and investment may be deterred, especially in the mobile network sector, where significant upfront investments are needed to be recovered over a long time (Touchard, 2017). Revenue-based fees rather than profit-based may discourage investment and innovation, as MNOs may use revenues to invest in new infrastructure or research (Touchard, 2017). In addition, tax on network equipment (e.g. import tax) directly increases equipment cost, which increases the network deployment cost for operators (Touchard, 2017). It will subsequently hinder the coverage expansion or upgrade through infrastructure investment, which is particularly detrimental for rural areas. Touchard (2017) argued that although taxation on the mobile sector supports the government in providing public services, it may harm socio-economic development in the long run due to its distortive impact on investment and consumption behaviour.

Taxation on airtime and (mobile) devices can also affect the area's profitability and the existing site's sustainability as it directly influences the area's potential revenues. This type of taxes reduces the affordability of mobile access. Particularly in rural areas known for lower-income populations, users' affordability has already been low. Taxes on airtime and devices should be minimised in order to encourage network expansion to rural areas (Touchard, 2017).

Cruz and Touchard (2018) recommended the government to implement a tax policy that maximises the capacity and incentives of MNOs to invest in network infrastructure. The policy should non-discriminatorily eliminate sectoral taxes that distort the mobile communication market, impose taxes on profits instead of revenues to encourage reinvestment, include incentives such as import duties exemptions, and increase investor confidence by reducing complexity and uncertainty tax levels. Sectoral taxes are the levies on top of regular taxes that applied exclusively to the mobile network sector.

Sector-specific taxes on airtime and devices can also reduce the affordability of mobile access for end-users with low-income groups particularly impacted (Touchard, 2017). It is these customer groups who typically make up the addressable market opportunity for rural coverage expansion (Touchard, 2017).

Reducing sector-specific tax could stimulate investment in extending connectivity (especially in rural areas), increase mobile service adoption, deliver economic growth and increase government tax revenues in the medium-long term (Touchard, 2017). In 2014, Malaysia introduced a tax rebate system which allows MNOs to be exempted from import duties for rural last mile connectivity equipment (Cruz and Touchard, 2018), giving a direct incentive for MNOs to invest in rural coverage. The tax savings may be passed through end-users through lower service price. Lower service price may increase the number of users and the volume of usage, which in turn increase the RoI of MNOs in rural areas. Subsequently, the higher RoI can lead to higher investment capacity for expanding the network to less-profitable rural areas and maintain the existing network in those areas (Touchard, 2017).

Furthermore, though it seems that reducing sector-specific taxes on the mobile sector will reduce the government's tax revenues, the government can recover higher tax revenues in the long term by increasing digital inclusion and national economic growth. GSMA's study on the effect of mobile sector-specific tax reform in the Democratic Republic of the Congo showed that the abolition of the excise tax on mobile services could potentially increase the mobile service market penetration by 5% in 2020 compared to the reference case without tax reform. Furthermore, those additional connections could potentially create around 3200 jobs and yield almost US$ 970 million or nearly 2% of GDP over the same time horizon. The tax reduction would positively return the same amount of revenue as those generated by sector-specific taxes within four years (Touchard, 2017).

B.3.4 Infrastructure sharing

Ensuring that optimum market-driven coverage has been achieved is crucial before deciding on supplementing policies or market intervention by the government (Cruz and Touchard, 2018). On the other hand, the market-driven coverage is highly influenced by the deployment cost and the MNOs' investment capacity. Any measure that may reduce the network costs can be considered the potential solution for enhancing coverage to rural areas. The regulatory framework in many developing countries is often insufficient to encourage operators to share their network infrastructure voluntarily (Touchard, 2017).

Cruz and Touchard (2018) recommended both active and passive infrastructure sharing to be allowed under primary legislation and encouraged by regulators voluntarily. In general, network sharing can be classified into four categories (Touchard, 2017):

- Passive (mast or site) sharing – Each operator has their own backhaul equipment, antennas, etc. It can also include sharing power equipment.
- RAN sharing – MNOs share the site, mast, antenna, base transceiver station, backhaul and base station controllers but have their own separate core network.
- Spectrum (and RAN) sharing - MNOs share the site, mast, antenna, base transceiver station, backhaul, base station controllers and share their spectrum. It can also include spectrum pooling.
- National roaming – All network components are shared between operators. It means allowing mobile customers to use a network entirely not provided by their operator. National roaming does not necessarily require infrastructure co-ownership.

According to Cruz and Touchard (2018), three main concerns about anti-competitive behaviours associated with network sharing are loss of infrastructure-based competition, risk of sensitive information exchange and collusion at the service level. Regarding the competition, they found that the regulator intends to impose sharing obligations instead of purely letting it on a voluntary basis. That might be natural, especially when the regulator sees that an MNO would not agree to share if there is no enforcement. This obligation, in some cases, will be considered not investment-friendly and can be less appealing to MNOs that consider coverage as a competitive advantage. Forcing MNOs to share their infrastructure then might discourage them from investing in new areas. This condition is majorly the concern for regulators and competition authorities (Cruz and Touchard, 2018). Cruz claimed this situation could be solved by the government appropriately considers the investment risks incurred by the MNOs in the policymaking and by allowing network sharing through ex-ante regulation while keeping its veto power through competition law. Mast and site sharing are categorized as passive sharing, while RAN sharing, spectrum sharing and national roaming are categorized as active sharing. Passive sharing is generally common, while active sharing may need to be assessed on a case-by-case basis. For example, in the Telecommunications Act, USC 332(7), 1996, the United State's FCC encourages network sharing of masts, antenna and towers, whilst sharing core aspects of a network is subject to competition law assessment. Similarly, European Commission stated that passive and RAN sharing (excluding the sharing of core networks, frequencies or network controllers) do not infringe EU competition rules and concluded that the negative impact on infrastructure competition would be outweighed by the benefits consumers would derive from new 3G services competition (Cruz & Touchard, 2018, p.26). Moreover, from the active sharing experience in almost 20 countries (for example, Australia, Azerbaijan, Canada, Spain, Sweden, Vietnam, UK, etc.) over the last fifteen years, GSMA found that active sharing has no detrimental impact on competition (Touchard, 2017).

On the other hand, there are also measures to safeguard sensitive information exchange and collusion at the service level. As an example, the regulator requires operators to log all infrastructure-sharing activities and making the logs available to the regulator, if requested (Cruz and Touchard, 2018). MNOs may also want to specify this condition in their agreements. If there are unresolved disputes, the regulator can take part as an arbitrator. The government should encourage commercial negotiations and mediate terms and conditions if the negotiations fail (Cruz and Touchard, 2018).

The implementation of mobile network sharing started in 2012 in Brazil to promote 4G services nationwide is one success story of an excellent mobile network sharing strategy. It started with coverage-obligated spectrum auction in which regions are split for certain operators. Network sharing, then, was encouraged by the government for coverage fulfilment in rural areas. Operators with obligations on rural areas then entered into commercially-led agreements to do RAN sharing in areas with less than 30,000 inhabitants. Vivo and Claro are some of those MNOs. They split their region into two, in which each of them owned and maintained half of the sites. This strategy was proven to allow acceleration on mobile service provision and increase service-level competition, which is beneficial from the government's perspective. Furthermore, for

MNOs, the network sharing cooperation allowed them to gain customers more quickly and comply with their coverage obligation at a lower cost. In 2018, 3039 Brazilian cities covered by the 4G service, which is three times the number of cities required by the coverage obligation. The network sharing implementation was considered to have a significant contribution to that achievement. Figure B.11 shows some more examples of successful network sharing agreements.

	Partners	Technology Scope	Geographical Scope	NRA Role
Austria	3 and T-Mobile	Roaming	Rural	No
Bangladesh	Banglalink and Grameenphone	Passive	Rural only	No
Finland	TeliaSonera and DNA	MOCN	50% of geo., 15% of pops	No
France	SFR and Bouygues	MORAN	57% of pops	No
Greece	Vodafone and Wind	MORAN	70% of rural, 40% urban	No
Sweden	Telenor and Hutchison	MOCN	70% pops	Yes
Venezuela	Movilnet, Movistar and Digitel	Passive	30 sites in first phase	Yes

Figure B.11: Some examples of successful network sharing agreements (Touchard, 2017, p.16)

Touchard (2017) suggested that the regulation regarding infrastructure sharing be also applied to third-party infrastructure owners, such as ducts, poles and towers. Often, these infrastructures are owned by public utility companies (i.e. electricity, gas or water companies) or transportation entities (roads, railways). Therefore, the government and telecom regulator should facilitate such cross-sector infrastructure sharing as well by changing the telecom regulator's mandate or through joint regulation (as in Brazil) or some form of co-ordination (as in Costa Rica).

Infrastructure-sharing minimises the duplication of expensive infrastructure, thus reducing the deployment cost and risk and increasing the returns of investments in areas with low economic potential (Cruz and Touchard, 2018). The CAPEX and OPEX reduction can be significant, i.e. between 50% and 80% depending on market structure and the sharing model to be implemented, whilst maintaining the original revenue opportunity (Touchard, 2017). With network sharing, MNOs can increase the proportion of the population that can be covered in a commercially sustainable way. Thus, network expansion's lowered risk and costs can improve network coverage, especially in rural areas.

Additionally, the government can potentially gain benefits, including:

- Less duplication of infrastructure that can lead to more efficient use of land and energy;
- Better service quality in areas where the deployment of new towers is difficult;
- Higher product and technological innovation as MNOs compete on service differentiation; and
- Greater consumer choice due to easier network entry and expansion.

There are challenges in implementing infrastructure sharing. Montenegro and Araral (2020) argued that designing and implementing pro-competition regulatory, such as infrastructure sharing, is particularly complex and requires technical capacity and political will for detailed design, monitoring and enforcement. The implementation of network sharing can be complex for some forms of sharing, especially if involving existing sites. Considerations on the tower's load capacity, space between antennas, tilt and height of antennas in the same tower, antenna configuration and site spaces are essential to do RAN sharing to make sharing feasible while maintaining QoS. Therefore, passive sharing and network roaming are more common (Touchard, 2017).

B.3.5 Universal Service Fund

The measures to enhance coverage by strengthening the business case for MNOs to provide the network in a commercially sustainable manner are limited to a certain level of areas. It is highly possible that after optimising the market, the coverage gaps persist in some locations.

Universal Service Funds (USFs) are the collected levies from MNOs which are used to finance connectivity initiatives determined by the government (Cruz and Touchard, 2018) related to the ICT universal service for all its citizens or to encourage the network deployment in economically unattractive areas (Arakpogun et al., 2017). Usually, USF contributions are calculated as a percentage of MNOs' revenues and administered by the USF agency. According to Cruz and Touchard (2018) and Arakpogun et al. (2017), USF implementation should be:

- administered by an autonomous authority run by skilful personnel that is free from political interference;
- guided by a clear-defined legal and regulatory framework that is flexible, technology and service neutral;
- equipped with clearly specified and measurable objectives (in consultation with stakeholders), including coverage and service delivery targets;
- transparent in reporting the financial flows;
- able to work with other funding sources (e.g. Development Banks);
- efficient and innovative, with a focus on the sustainability of the proposed solutions;
- negotiable for MNOs to choose between paying the funds or investing directly in the USF-targeted areas;
- spent effectively and timely; otherwise, governments should phase out or pause collecting levies.

USF allows the government to directly address the coverage gap problem in rural areas by establishing the network in the desired locations using the fund. The site's RoI or profitability would not be the concern in deploying the network, so any areas with low potential revenue and high deployment cost can still get covered equally. With proper implementation, USF may have a tangible impact on coverage.

There are challenges in the USF implementation, such as excessive bureaucracy, inadequate oversight mechanism and stakeholder involvement (Arakpogun et al., 2017), lack of transparency, USF administrators' independence and pre-defined USF targets, and the target programs that do not take into account the reality of the market (Cruz and Touchard, 2018). On the other hand, managing and deploying USF requires technical, economic, and legal skills, which are often lacking in the USF administrator (Smith, 2000). Case studies in Africa showed that the salary limitations and the undue political influence are some reasons for the lack of qualified professionals in the USF administrators (Arakpogun et al., 2017).

B.3.6 Public subsidy on rural network development

The measures to enhance coverage by strengthening the business case for MNOs to provide the network in a commercially sustainable manner are limited to a certain level of areas. It is highly possible that after optimising the market, some locations are still commercially unviable.

Subsidies are financial support from the government in direct monetary grants or direct incentives, such as tax rebates. In addressing the coverage gap, subsidies rely on the operator's capacity to deploy infrastructure. Cruz and Touchard (2018) argued, to have an impact, subsidies must align the interests of MNOs and the government and must be allocated in a targeted, transparent and efficient way. The subsidy targets should be attractive for MNOs while also encourage coverage extensions to the areas of interest. The funds should also be allocated via a transparent public tendering process. They should also be administered and monitored as cost-efficient as possible.

The literature mentioned some countries that effectively implement subsidies to promote coverage expansion. In 2014, Malaysia introduced a tax rebate system that returns up to 70% of their capital investment in rural areas and import duties exemptions for last-mile network equipment. Another country that also provides public funding to subsidise network deployment to rural areas is the United Kingdom (UK) (Philip et al., 2017). In the 2010s, as one of the responses to the territorial digital divide, it conducted the Broadband UK (BDUK) programme, which investing £780 million public funds in the UK's digital infrastructure. It was supplemented with up to £20 million Rural Community Broadband Fund in 2011 and a £10 million Rural Broadband Trial fund in 2013.

Nevertheless, this solution can not stand on its own and is merely an enabler for other measures, meaning that it should be paired with other solution. Based on the case study in the UK to promote Broadband coverage, Philip et al. (2017) suggested the public funding to be complemented with non-fixed connection via satellite or wireless and/or community-led initiatives. Wright (1995) also mentioned that public subsidy would make the use of satellite communication for connecting rural and remote areas viable.

B.3.7 Relaxing the QoS standard for rural networks

QoS requirements such as network availability and dropped call rates are much harder to deliver in rural and remote areas (Touchard, 2017). If regulators oblige MNOs to comply with the same QoS requirements regardless of the network locations and set fines for the non-conformity, MNOs will be reluctant to develop a network in rural and remote areas. That is because that networks will potentially cause noncompliance for the network owner and drag down the overall percentage of the MNO's QoS. Meanwhile, maintaining a rural network so that its QoS meets the requirement would often not be cost-effective for MNOs. In such cases, MNOs may prevent the risks by investing in rural areas as little as possible.

Touchard (2017) argued, since MNOs investment in rural areas help the governments delivering their digital objectives, governments should minimise the cause of MNOs' unwillingness to expand their network to those areas. It would include relaxing the QoS requirements for the network located in rural areas.

By relaxing the QoS standard for rural networks, MNOs may adjust the network operation to make it financially viable. Ensuring their network to be available whenever users want to use it and drop call rates to be minimal are also of the MNOs' interests as it leads to higher RoI for them. As a result, MNOs may become more confident to invest in rural areas.

However, to implement the solution, the regulator needs to clearly define which areas are eligible for relaxation. The definition should also be regularly updated as the telecommunication service penetration may increase the economic level of rural areas, making it more commercially viable, hence no longer eligible for the relaxation.

B.3.8 Information management system platform about network coverage

Information about zones without network coverage is rarely documented or provided publicly by the government. The lack of resources (financial and personnel) often makes regulators rely on the MNOs to provide their coverage prediction. Meanwhile, understanding the current level of network coverage is important both for the government and MNOs to prevent network redundancies and to set a network plan, respectively.

Touchard (2017) suggested the authorised government establish an information system management platform consisted of information about coverage and the relevant infrastructure locations. The network coverage information should be based on network coverage assessments conducted yearly. Regulators could also provide the list of telecommunication infrastructure that could be shared or rented between operators. The platform is mainly created to be used by MNOs to facilitate collaboration and discussion.

B.3.9 Direct public investment on the critical enabling public infrastructure

Touchard (2017) suggested that, in addition to policy measures aiming for making rural areas more commercially viable, national governments should also consider directly invest in the essential national infrastructure that is supportive for mobile network development, such as electricity grid, high capacity fibre backbone network and road access. Improving these infrastructure's quality will indirectly promote network expansion as based on the literature, the lack of these infrastructure availabilities hinders the rural area's development.

Nevertheless, significant capital investment and coordination between institutions are required for this solution. At least, road access and electricity grid are usually under the authority of organisations outside the one who authorises the telecommunication sector (including fibre backbone network). Aligning different organisations on the same plan and objective can be difficult as they have different priority.

Appendix C

Correlation Analysis

Spearman Correlation Coefficient and regression analysis are used for identifying correlation between indicators in Chapter 2 Section 2.2. Therefore, here, we provide an elaboration regarding SCC and regression analysis. Afterwards, we elaborate the correlation test and regression analysis results for the global key factors: population density, poverty rates, electricity readiness, road accessibility, topography and MNO's financial capacity.

C.1 Spearman Correlation Coefficient

Spearman Correlation Coefficient (SCC), or also called Spearman rank-order correlation coefficient, is a measure of association between two variables when each of the two sets, X and Y, of data are transformed to ranks, $r_k^{(X)}$ and $r_k^{(Y)}$, $k = 1, ..., n$, respectively, where $r_1 < r_2 < ... < r_n$ (Svensson, 2012). With n is the number of data pairs, the SCC can be derived by applying the following formulae to the two sets of ranks (Gauthier, 2001):

$$SCC = 1 - \frac{6\sum_{k=1}^{n} d_k^2}{n^3 - n}$$

where $d_k = r_k^{(X)} - r_k^{(Y)}$. If there are a large number of ties are involved, the equation for SCC is (Zar, 1984):

$$SCC = \frac{\frac{(n^3-3)}{6} - \sum_{i=1}^{n} d_i^2 - \sum T_x - \sum T_y}{\sqrt{[\frac{(n^3-3)}{6} - 2\sum T_x][\frac{(n^3-3)}{6} - 2\sum T_y]}}$$

with

$$\sum T_x = \frac{\sum_{j=1}^{g}(t_j^3 - t_j)}{12}$$

$$\sum T_y = \frac{\sum_{j=1}^{g}(t_j^3 - t_j)}{12}$$

where g is the number of tied group, t_j is the number of tied data in the jth group.

SCC has a value between +1 and −1. A value of +1 shows a total positive correlation, 0 shows no correlation, and −1 shows a total negative correlation.

C.2 Linear regression analysis

Linear regression is defined by the equation:

$$y = mx + b + e$$

where x is an independent variable, y is a dependent variable, m is the slope of a regression line—which is the y's rate of change as x changes, b is the Y-intercept—the expected value of y when x equals to 0, and e is the random error term—the difference between the actual value of a dependent variable and its predicted value. A linear regression model assumes that the relationship between y and x is linear. Given n data pairs (x_i, y_i), $i = 1, ..., n$,

$$y_i = mx_i + b + e_i$$

The *least square* method was used to estimate m and b that minimizes the sum of squared e_i (Glasserman, 2001).

Microsoft Excel's linear trendline uses the least squares method for constructing the linear trendline (Microsoft, n.d.). The scatter plot and its linear trendline in Figure C.1, C.2, C.3, C.4, C.5, C.6, C.7, C.8 and C.9 are created in Microsoft Excel using its linear trendline feature.

C.3 Elaboration on the correlation test and regression analysis results for the global key factors

C.3.1 Population density

The data of Indonesia's population density per province in 2019 is used as the indicator (Badan Pusat Statistik, n.d.-e) for this factor. By examining the data of population density per province in 2019 and the number of unserved villages per province according to CovData (Ditdal PPI, 2021a), the SCC value between the two variables is -0.755. According to Cohen (1988), this value indicates a strong correlation between the population density factor and the number of unserved villages in a province.

Similarly, as depicted in C.1, the same connection is shown. The graph shows that the linear trendline of the scatter plot between the variable population density (person/sq km) and the number of unserved villages has also negative m value. The negative m value indicates the denser the province, the less unserved villages can be found.

C.3.2 Poverty rates

To represent the poverty rates, three indicators are used: regional gross domestic income per capita (PDRB) (Badan Pusat Statistik, n.d.-a), percentage of poor population in a province and the number of villages without kiosks in a province.

The second indicator is calculated by multiplying the percentage of the poor population in a province (Badan Pusat Statistik, n.d.-f) with the province's total population (Badan Pusat Statistik, n.d.-e). The percentage of poor population in a province was derived by dividing the number of populations who have a total expense below the province's poverty line. As their expense is lower than the poverty line, they are categorised as poor population. In each province, two the poverty lines are founded: for urban and for rural areas (Badan Pusat Statistik, 2020) [1]. On average, by end of 2020, the poverty line in Indonesia for urban areas is IDR 475,477.00 per capita per month, while for rural areas IDR 437,902.00 per capita per month. The third indicator counts the villages or subdistricts without any kiosk or stall to indicate their income level. The data of this indicator is based on Badan Pusat Statistik of year 2018 (Badan Pusat Statistik, n.d.-b).

[1] The classification for urban and rural areas used in this statistic is based on the Regulation of the Indonesian Central Statistical Agency Number 37 of 2010 regarding Urban and Rural Classification

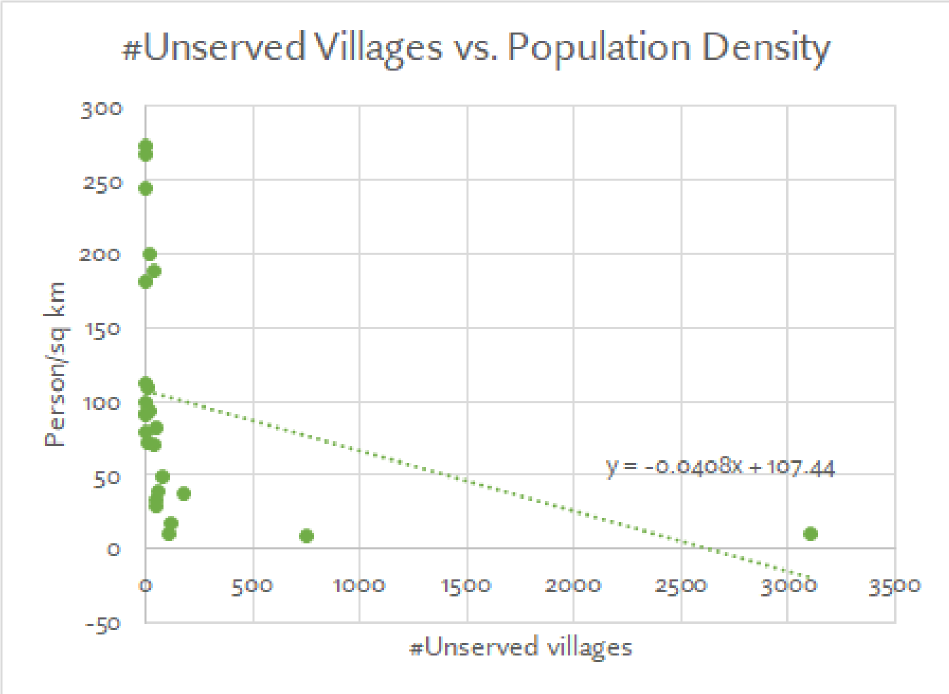

Figure C.1: Correlation between the number of unserved villages and population density in a province (Source: (Badan Pusat Statistik, n.d.-e; Ditdal PPI, 2021a))

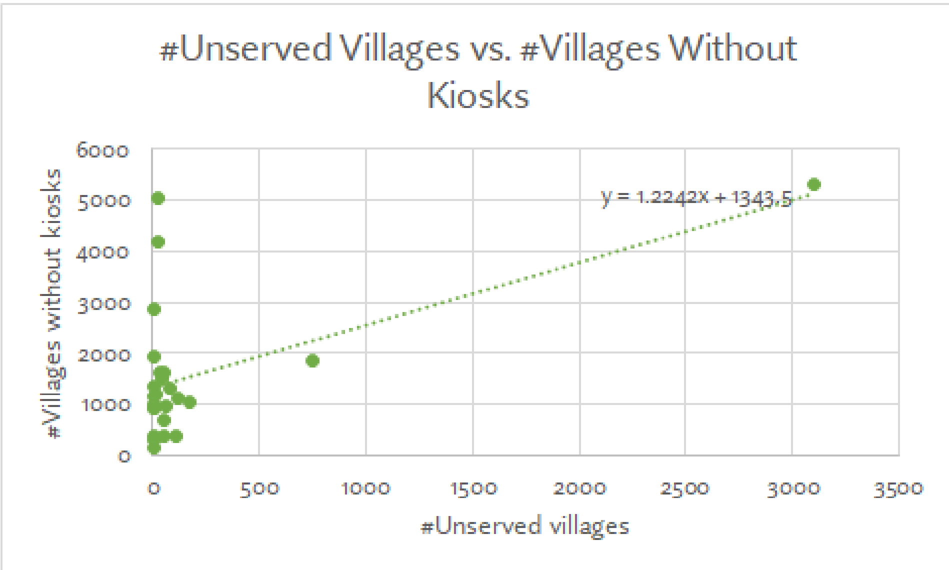

Figure C.3: Correlation between the number of unserved villages and the number of villages without commercial shops in a province (Source: (Badan Pusat Statistik, n.d.-b; Ditdal PPI, 2021a))

By examining the data of PDRB per province in 2020, the percentage of poor population per province in 2020, the number of villages without kiosks per province and the number of unserved villages per province according to CovData (Ditdal PPI, 2021a), the SCC values between each pair of variables are:

- PDRB per province and the number of unserved villages per province: 0.271
- the percentage of poor population per province and the number of unserved villages per province: 0.140

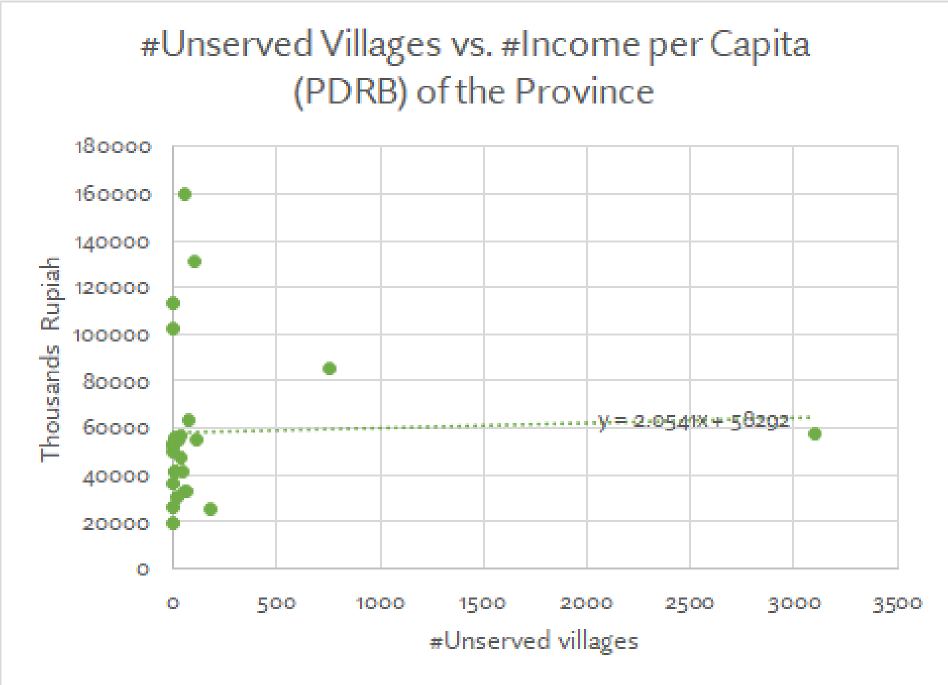

Figure C.2: Correlation between the number of unserved villages in a province and the income per capita of a province (Source: (Badan Pusat Statistik, n.d.-a; Ditdal PPI, 2021a))

- the number of villages without kiosks per province and the number of unserved villages per province: 0.234

Those values indicates weak positive correlations between the poverty rates factor and the number of unserved villages in a province (Cohen, 1988).

The SCC values above show an inconsistency of the correlation between poverty rates factor and the mobile coverage problem. The correlation between PDRB per province & the number of unserved villages per province was shown to be positive, which means the more unserved villages were found in a province with a higher income. On the contrary, from the SCC values of the remaining pairs (the percentage of poor population per province & the number of unserved villages per province and the number of villages without kiosks per province & the number of unserved villages per province), the more unserved villages were found in a province with a higher percentage of poor population and in a province with more villages without kiosk. In other words, the first variable pair's SCC shows that the more mobile coverage problems were found in a province with a lower poverty rate, while the remaining pairs' SCC show the opposite. This inconsistency of the correlation between poverty rates factor and the mobile coverage problem is affirmed by Figure C.2, Figure C.4 and Figure C.3. The figures' trendlines have all positive m values. Therefore, it is concluded that there is no correlation between the number of unserved villages in a province and the province's poverty rates.

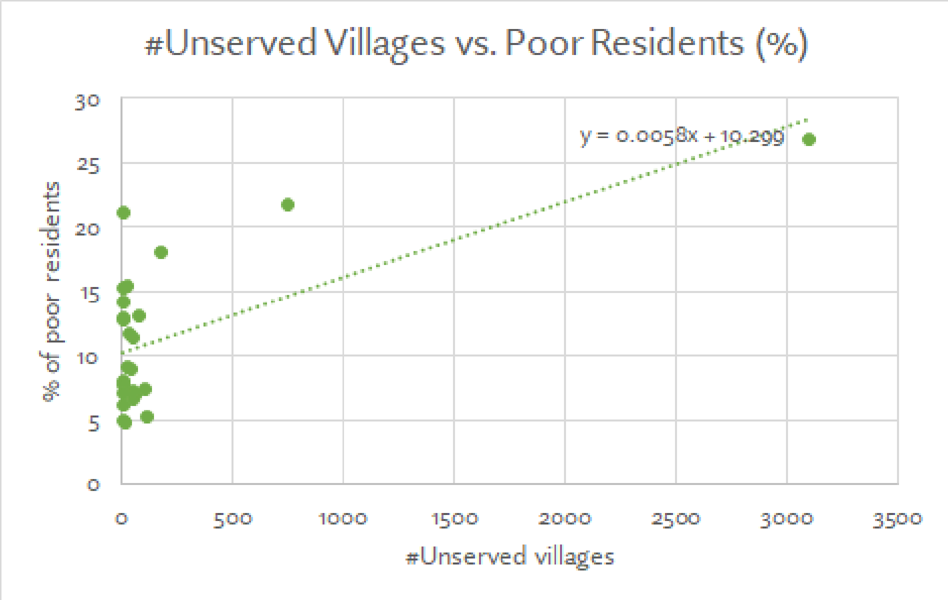

Figure C.4: Correlation between the number of unserved villages and the percentage of poor population in a province (Source: (Badan Pusat Statistik, n.d.-e, n.d.-f, 2020; Ditdal PPI, 2021a))

An informant that represents MNOs' point of view told that before deciding to establish a site in an area or village, MNOs' regional office conducts a simple techno-economic analysis on the area utilizing the knowledge of its agents who are residents of the area. This analysis is done mainly to measure the site's potential revenue and the feasibility to deploy a site there. Some site-surveys are usually performed to know the population density and exact residential location. Nonetheless, the analysis does not thoroughly assess the local's income level. Therefore, by connecting this information to the data illustrated by Figure C.4 and C.2, it can be inferred that maybe, in practice, MNOs do not specifically take into account the income level of the local population when deciding on erecting a site in an unserved area. Meanwhile, the deployed sites are eventually maintained as being a poor population does not necessarily limit their use and potential spending on mobile services. This finding aligns with Agüero and de Silva (2011), Barela et al. (2016) and the statement from the Indonesian National Development Planning Agency (Bappenas) (Alika, 2018). In their study, Agüero and de Silva (2011) concluded that telecommunication service is a necessity for the indigent population (users at the bottom of the pyramid) that they are spending up to half of their total income on telecommunication service. Similar to that, Agüero and de Silva (2011) found out that people in rural areas are willing to pay a higher rate of calls or SMS if it is commensurate with the travel cost and time to go to an area with coverage. The chief of Bappenas also mentioned that expense for telecommunication takes up to 25% of the low-income population's total monthly expenditure as their expenditure for education, electricity, house and vehicle's fuel have been subsidised by the government (Alika, 2018).

C.3.3 Electricity readiness

The number of households in a province without electricity grid and the number of villages without electricity in a province are used as the indicators for electricity readiness (Badan Pusat Statistik, n.d.-c). The first indicator's value considers the households without electricity power in their house and the households that use electricity not from the National Electricity Company (PLN) network. The households in the latter category usually get electricity from fossil-fueled electricity generator or community-based power source. While the latter represents the number of villages that use no electricity for public lights.

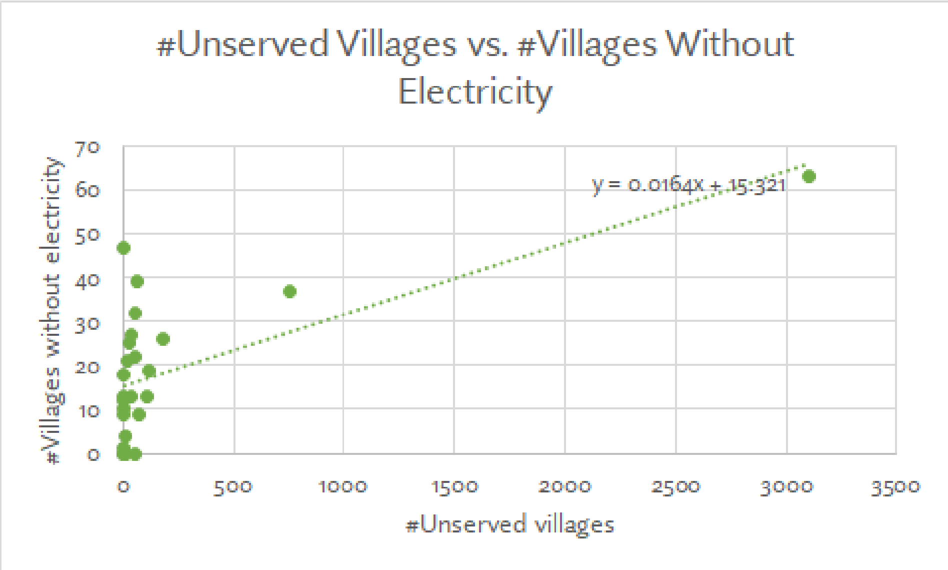

Figure C.5: Correlation between the number of unserved villages and the number of villages without electricity in a province (Source: (Badan Pusat Statistik, n.d.-c; Ditdal PPI, 2021a))

By examining the data about the number of households in a province without electricity grid in 2018, the number of villages without electricity in a province in 2018 and the number of unserved villages per province according to CovData (Ditdal PPI, 2021a), the SCC values between each pair of variables are:

- the number of households in a province without electricity grid and the number of unserved villages per province: 0.462
- the number of villages without electricity in a province and the number of unserved villages per province: 0.527

Those values indicates a moderate to strong positive correlations between the electricity readiness factors and the number of unserved villages in a province (Cohen, 1988). This positive correlation is affirmed by Figure C.6 and Figure C.5. Thus, it shows that a less mobile network coverage problem is usually found in areas where the electricity grid is more available.

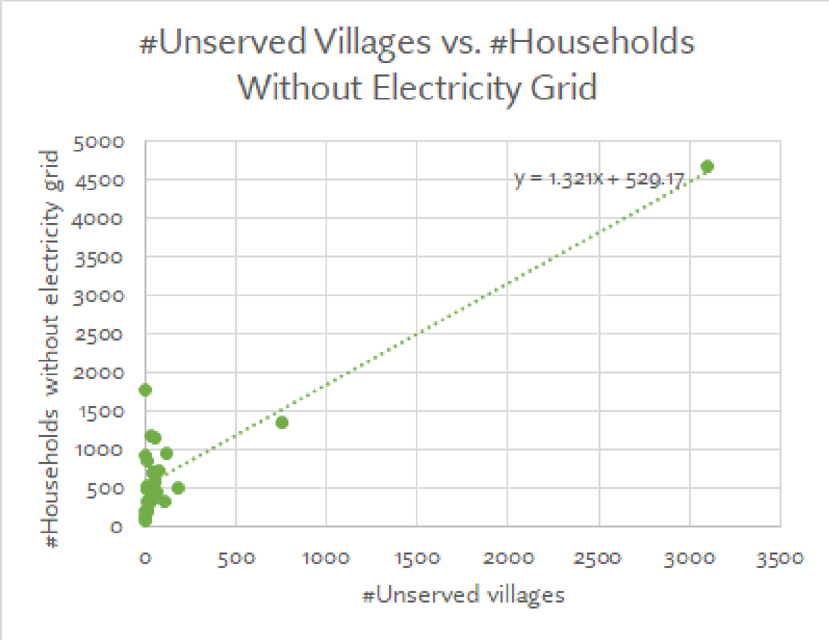

Figure C.6: Correlation between the number of unserved villages and the number of households uncovered by electricity grid in a province (Source: (Badan Pusat Statistik, n.d.-c; Ditdal PPI, 2021a))

C.3.4 Road accessibility

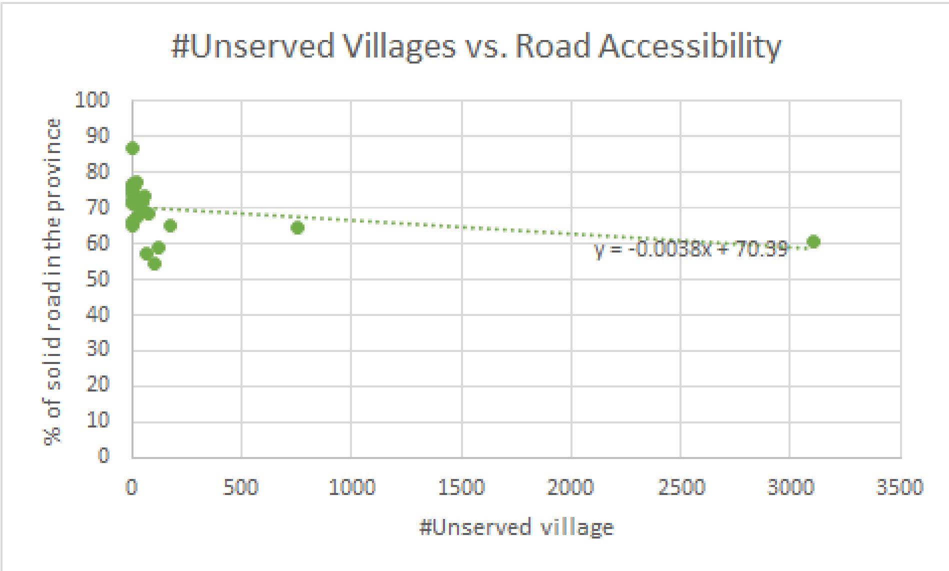

Figure C.7: Correlation between the number of unserved villages and the percentage of solid road in a province (Source: (Ditdal PPI, 2021a; Kementerian PUPR, 2019))

To represent the road accessibility, the road solidity parameter is used. Road solidity shows the percentage of solid road of all available roads in a province (Kementerian PUPR, 2019). The more solid the road, the better quality of the road is and the more accessible the province is.

By examining the data about the percentage of solid road of all available roads per province in 2014 and the number of unserved villages per province according to CovData (Ditdal PPI, 2021a), the SCC value between the two variables is -0.646. According to Cohen (1988), this value indicates a strong correlation between the road accessibility factor and the number of unserved villages in a province. The negative sign shows the negative correlation between those variables. It means, the less number of unserved villages were found in a province with higher percentage of solid road.

Figure C.7 affirms the connection. The trendline of this scatter plot has a negative m value. Hence, it can be concluded that the more unserved villages can be found in areas that are less accessible via land route.

C.3.5 Area's topography

The area's topography indicator is represented by the number of villages located on slopes or valley in the area. It is based on Badan Pusat Statistik (n.d.-d)'s data in 2018.

By examining the data about the number of villages located on slopes or valley per province in 2018 and the number of unserved villages per province according to CovData (Ditdal PPI, 2021a), the SCC value between the two variables is 0.382. According to Cohen (1988), this value indicates a moderate correlation between the area's topography factor and the number of unserved villages in a province. The positive sign shows the positive correlation between those variables. It means, the more number of unserved villages were found in a province with a higher number of villages located on slopes or valleys.

Figure C.8 supports the direction of the correlation found by SCC. The trendline of the scatter plot has a positive m value. Therefore, it can be concluded that the more unserved villages can be found in areas consist of more villages with difficult terrain.

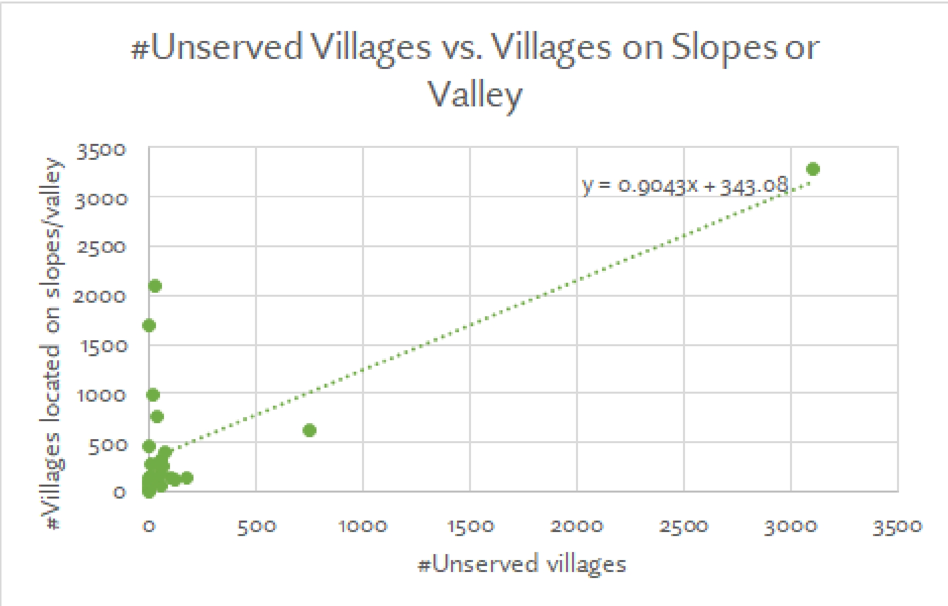

Figure C.8: Correlation between the number of unserved villages and the number of villages located on slopes or valleys in a province (Source: (Badan Pusat Statistik, n.d.-d; Ditdal PPI, 2021a))

Villages located on slopes or valleys are known as difficult to serve with line-of-sight (LOS) wireless (backhaul) technologies typically used in rural areas with low density population (Maitland, 2018).

C.3.6 MNOs' financial capacity

To evaluate the influence of MNOs' financial capacity, a financial indicator: EBIT, is juxtaposed with the percentage of rural sites of each MNO. EBIT data of 2018 (Ditdal PPI, 2020a) and site data of Q4 2019 are used

(Ditdal PPI, 2020c). The financial data of the previous year before the site data are chosen, assuming that the network status of a year is influenced by the financial capacity of the previous year. The percentage of rural sites of an MNO is derived by dividing its number of sites located in rural provinces by its total number of sites. Here, rural provinces are defined as the provinces which have population density lower than 100 people per square km, following Chiha et al. (2020).

This subsection aims to examine the hypotheses identified in the previous section that says the sustainability of the existing network in rural areas and the willingness to deploy a network in rural areas are influenced by the financial capacity of the MNO owning the network. In other words, the more profit or earnings an MNO get from their existing network, the higher its financial capacity will be, and the more willing the MNO to expand its network to a more risky area (rural) and the more it can sustain its existing network in rural areas.

By examining the data regarding MNO's EBIT in 2018 and the percentage of rural sites the MNO has, the SCC value between the two variables is 0.6. This value indicates a strong correlation between the MNOs' financial capacity factor and the portion of rural sites it has (Cohen, 1988). The positive sign shows the positive correlation between those variables. It means, MNOs with a better financial capacity invest more in rural areas.

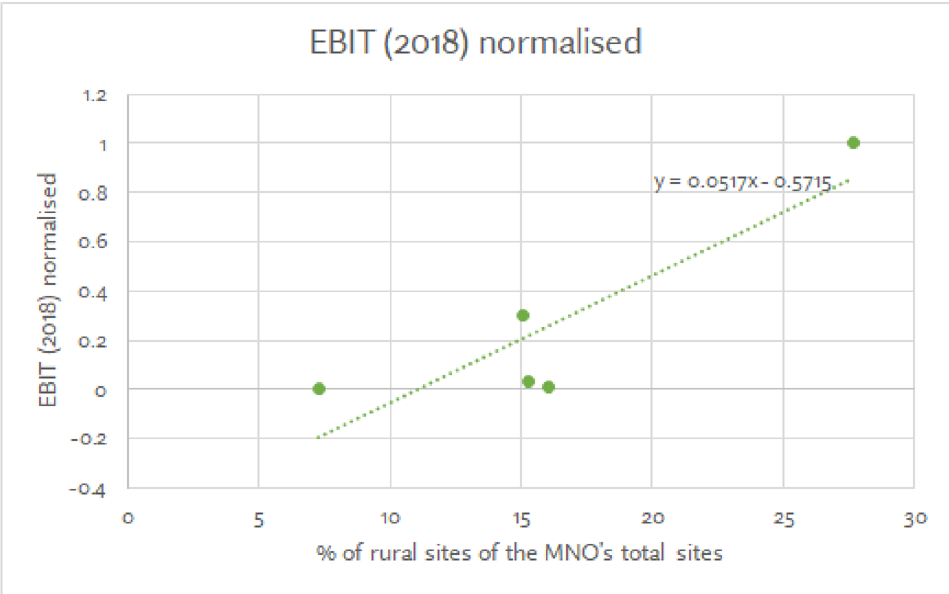

Figure C.9: Correlation between the MNO's financial capacity and the percentage of its sites located in rural areas (Source: (Ditdal PPI, 2020a, 2020c))

The positive correlation between the financial capacity and the rural sites percentage of each MNO in Indonesia as identified by SCC is supported by Figure C.9. The MNO's EBIT is normalised on a scale between zero and one and the MNOs' names are hidden to protect confidentiality. The linear trendline of the plot has a positive m value which shows a positive correlation between *% of rural sites of the MNO's total sites* and *EBIT (2018) normalised*. Therefore, it can be concluded that there is a correlation between MNOs' financial capacity and their willingness to deploy and maintain the network in rural areas.

It is important to note that, here, only five MNOs are being compared because one of the MNOs, STI, is the only one that operates in spectrum 450 MHz —a spectrum that is most beneficial for rural deployment. It makes STI's percentage of rural sites the highest among all MNOs, by any means. For that reason, we excluded it from the analysis.

Appendix D

Interview

D.1 Interview Protocol

Each interview was conducted online. All interviewees were given reading material a couple of days before the meeting time. Table D.1 informs the conducted interviews time. The material comprised of:

1. the detailed description of each exemplary villages, as written in Section 4.1,
2. the detail description of each solution, as written in Section 3.1,
3. the solution arrangements for each exemplary village, as written in Section 4.4, and
4. the interview form, as depicted in Figure D.1.

Table D.1: Interviews time

Interviewee	Organisation	Position	Interview time
1	Ministry of Communication and Informatics	Sub-Coordinator for the Allocation of Fixed Service	May 26th 2021
2	Ministry of Communication and Informatics	Sub-Coordinator for Special Telecommunications and Telecommunication Network Evaluation	May 31st 2021
3	Ministry of Communication and Informatics	Coordinator for Special Telecommunications and Telecommunication Network	June 1st 2021
4	Ministry of Communication and Informatics	Licensing Analyst for Network Operation Management	June 4th 2021
5	Ministry of Communication and Informatics	Head of Lastmile/Backhaul Infrastructure Division (BAKTI)	June 6th 2021
6	Ministry of Communication and Informatics	Coordinator of Spectrum Allocation Arrangement for Fixed and Land Mobile Services	June 8th 2021
7	Mobile Network Operator	National Vice President of Fault Analytic and End-to-End Performance	June 14th 2021
8	Mobile Network Operator	West Jabotabek Project Deployment Team	June 7th 2021

The interview objective was to fill in the interview form. Interviewees were asked to give rank 1 to 5 for each option of solution arrangements in Unipa village and Terusan village, and 1 to 4 for each option of solution arrangements in Tampang Muda village. Rank 1 means the most preferable option, while rank 5 means the least preferable one. Although the form looks simple, filling it in through a survey will not yield answers as comprehensive as if asked through an interview, particularly for filling the columns regarding the feasibility, negative impacts, requirements and risks. From the conducted interviews, many interviewees answers need to be clarified, confirmed and require subsequent questions.

Interviewee:
Date:

Village	Rank	Option	Feasibility	Consequences	Requirements	Risks
Unipa	1					
Unipa	2					
Unipa	3					
Unipa	4					
Unipa	5					
Tampang Muda	1					
Tampang Muda	2					
Tampang Muda	3					
Tampang Muda	4					
Terusan	1					
Terusan	2					
Terusan	3					
Terusan	4					
Terusan	5					

Figure D.1: Interview form

Their perspectives regarding the solution's feasibility, negative impacts, requirements and risks are noted. ***Feasibility*** describes whether or not a solution is implementable and sensible based on the interviewee's point of view. ***Negative impacts*** refer to any direct adverse effect that will *certainly* occur when the solution is implemented. ***Requirements*** list all prerequisites that have to be fulfilled to make the solution implementable. Meanwhile, ***risks*** are possible adverse effects that may or may not happen, depending on certain factors that factors that are beyond this research project.

D.2 Interview Summary

D.2.1 Interviewee 1

Date of interview	:	May 26th 2021
Interviewee name	:	Hilman Fikrianto
Position	:	Sub-Coordinator for the Allocation of Fixed Service

Tampang Muda village

Interviewee 1 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	1	It is feasible only if the residents satisfied with this kind of service. That is also because the condition of this village is also challenging that cannot afford a better service sustainably. If the residents are not satisfied with the delayed communication proposed by Store & Forward and request real-time communication, it might be more feasible to use femtocell + satellite backhaul or WiLD backhaul supplemented by the local government's fund.	High latency	Approval from the residents to ensure that this solution is effective for the village.	-
2	2	UAV will be difficult to be applied considering the national security threat and the existing air transportation regulations. The technology, especially the rotary-wing UAV proposed, also is not clearly known. Thus, it is currently difficult to see whether the UAV complies with the regulations. Currently, the government is also discussing the possibility for using an unlicensed band with more than 4 watts transmit power only for rural areas, but it has not come to a conclusion.	The consequences of the UAV technology is unknown due to the unknown system. The use of the unlicensed backhaul makes the QoS cannot be guaranteed by regulation. However, unlicensed backhaul (2.4 GHz and 5.8 GHz) is not forbidden to use as long as its transmit power is less than 4 watt.	Clarification on the compliance of the UAV model network to Indonesian regulations	-
3	4	UAV will be difficult to be applied considering the national security threat and the existing air transportation regulations. The technology, especially the rotary-wing UAV proposed, also is not clearly known. Thus, it is currently difficult to see whether the UAV complies with the regulations. Currently, the government is also discussing the possibility for using an unlicensed band with more than 4 Watt transmit power only for rural areas, but it has not come to a conclusion.	The consequences of the UAV technology is unknown due to the unknown system. The use of the unlicensed backhaul makes the QoS cannot be guaranteed by regulation. However, unlicensed backhaul (2.4 GHz and 5.8 GHz) is not forbidden to use as long as its transmit power is less than 4 watt.	Clarification on the compliance of the UAV model network to Indonesian regulations	-
4	3	This solution is clearly not possible. It clashes with many existing regulations, such as spectrum regulation. If the existing regulations are amended to accommodate mobile spectrum usage by local communities, the spectrum operation can be chaotic. That is also because the existing mobile spectrum is allocated nationally to all MNOs, not divided between zones. However, as an alternative, it can be delivered by MNOs since MNO also has started to target enterprise users for the private network. However, of course, the service would not be free like VillageCell. Alternatively, instead of using GSM bands, it can use WiFi bands. It is also impossible to have the local community get mobile spectrum since the current licensing model is nationwide. It could be possible if the mobile spectrum is allocated regionally. However, changing the licensing model from nationwide to region or zonewide is not considered by the Indonesian mobile sector and government.	Chaotic spectrum usage if mobile spectrum can be used by the local community. More complexity for the regulator to monitor the spectrum usage. If VillageCell uses WiFi bands, then only users with a smartphone can use the service.	Cooperation with the existing MNOs. Users with smartphones, if VillageCell uses WiFi bands	-

Terusan village

Interviewee 1 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	1	It is technologically feasible, but considering the number of potential users in Unipa, it would be not easy to sustain. However, the use of femtocells and unlicensed backhaul could potentially reduce the CAPEX.	-	-	-
2	3	It is technologically feasible, but considering the number of potential users in Unipa, it would be not easy to sustain. However, the use of femtocells and unlicensed backhaul could potentially reduce the CAPEX. SRO as described is also feasible and allowed by GR Number 46 of 2021 since it allows infrastructure sharing. Since the village is not among 3T areas, having BAKTI (SRO) as the network deployer would be difficult.	-	-	-
3	2	UAV will be difficult to be applied considering the national security threat and the existing air transportation regulations. The technology, especially the rotary-wing UAV proposed, also is not clearly known. Thus, it is currently difficult to see whether the UAV complies with the regulations.	The consequences of the UAV technology is unknown due to the unknown system.	Clarification on the compliance of the UAV model network to Indonesian regulations	-
4	4	UAV will be difficult to be applied considering the national security threat and the existing air transportation regulations. The technology, especially the rotary-wing UAV proposed, also is not clearly known. Thus, it is currently difficult to see whether the UAV complies with the regulations.	The consequences of the UAV technology is unknown due to the unknown system.	Clarification on the compliance of the UAV model network to Indonesian regulations	-
5	5	This solution is clearly not possible. It clashes with many existing regulations, such as spectrum regulation. If the existing regulations are amended to accommodate mobile spectrum usage by local communities, the spectrum operation can be chaotic. That is also because the existing mobile spectrum is allocated nationally to all MNOs, not divided between zones. However, as an alternative, it can be delivered by MNOs since MNO also has started to target the enterprise users for the private network. However, of course, the service would not be free like VillageCell. Alternatively, instead of using GSM bands, it can use WiFi bands. It is also impossible to have the local community get mobile spectrum since the current licensing model is nationwide. It could be possible if the mobile spectrum is allocated regionally. However, changing the licensing model from nationwide to region or zone-wide is not considered by the Indonesian mobile sector and government.	Chaotic spectrum usage if mobile spectrum can be used by the local community. More complexity for the regulator to monitor the spectrum usage. If VillageCell uses WiFi bands, then only users with a smartphone can use the service.	Cooperation with the existing MNOs. Users with smartphones, if VillageCell uses WiFi bands.	-

Unipa village

Interviewee 1 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	It is technologically feasible, but considering the number of potential users in Unipa, it would be difficult to sustain. However, the use of femtocells and unlicensed backhaul could potentially reduce the CAPEX. SRO as described is also feasible and allowed by GR Number 46 of 2021 since it allows infrastructure sharing. When the village is among 3T areas, having BAKTI (SRO) as the network deployer is also feasible.	-	-	-
2	1	It is technologically feasible, but considering the number of potential users in Unipa, it would be not easy to sustain. However, the use of femtocells and unlicensed backhaul could potentially reduce the CAPEX.	-	-	-
3	4	UAV will be difficult to be applied considering the national security threat and the existing air transportation regulations. The technology, especially the rotary-wing UAV proposed, also is not clearly known. Thus, it is currently difficult to see whether the UAV complies with the regulations.	The consequences of the UAV technology is unknown due to the unknown system.	Clarification on the compliance of the UAV model network to Indonesian regulations	-
4	2	UAV will be difficult to be applied considering the national security threat and the existing air transportation regulations. The technology, especially the rotary-wing UAV proposed, also is not clearly known. Thus, it is currently difficult to see whether the UAV complies with the regulations.	The consequences of the UAV technology is unknown due to the unknown system.	Clarification on the compliance of the UAV model network to Indonesian regulations	-
5	5	This solution is clearly not possible. It clashes with many existing regulations, such as spectrum regulation. If the existing regulations are amended to accommodate mobile spectrum usage by local communities, the spectrum operation can be chaotic. That is also because the existing mobile spectrum is allocated nationally to all MNOs, not divided between zones. However, as an alternative, it can be delivered by MNOs since MNO also has started to target the enterprise users for the private network. However, of course, the service would not be free like VillageCell. Alternatively, instead of using GSM bands, it can use WiFi bands. It is also impossible to have the local community get mobile spectrum since the current licensing model is nationwide. It could be possible if the mobile spectrum is allocated regionally. However, changing the licensing model from nationwide to region or zone-wide is not considered by the Indonesian mobile sector and government.	Chaotic spectrum usage if mobile spectrum can be used by the local community. More complexity for the regulator to monitor the spectrum usage. If VillageCell uses WiFi bands, then only users with a smartphone can use the service.	Cooperation with the existing MNOs. Users with smartphones, if VillageCell uses WiFi bands.	-

D.2.2 Interviewee 2

Date of interview	:	31st May 2021
Interviewee name	:	Iman Sanjaya
Position	:	Sub-Coordinator for Special Telecommunications and Telecommunication Network Evaluation

Tampang Muda village

Interviewee 2 - Tampang Muda village

Rank	Opt	Feasibility	Consequences	Requirements	Risks
1	3	Feasible because OpenBTS and its supporting system have been commercially available in the market and ready to be used. However, existing Indonesian regulation about spectrum does not allow for VillageCell.	The network will not be interconnected to other MNOs. The network cannot be commercialised.	Regulation amendment numbering blocks. Regulation amendment or cooperation agreement between BAKTI and MNO to use the unused spectrum.	As the network would be operated not by SRO (BAKTI), but either by the MNO employed by BAKTI, or by ISP that provide the internet service, or by the local community itself, there is a risk that either of them set a usage charge to users without BAKTI's knowing. It could deteriorate the objective of the network and make the solution ineffective. If the VillageCell is operated and commercialised by the local community, it would violate the law.
2	4	Not feasible because there is no vendor available for this technology. An unlicensed band is considered unfeasible because from our experience surveying some unserved villages, we found that many villages that are not yet served by cellular network services have been served by an internet service established by the local communities. Moreover, the local communities use Wi-Fi bands for establishing the network to provide internet services. Hence, if cellular backhaul link uses Wi-Fi bands, the risk of interference would be high. Many new ISPs have sprung up, especially in remote areas.	High interference due to the use of unlicensed bands to its network and the existing small local ISP's networks. Low quality of service due to lack of regulatory guard on the unlicensed bands.	Currently, BAKTI is obliged to work (i.e., subsidise for network development) in the underdeveloped, outermost remote, pioneering and/or border (3T) areas according to GR Number 131 of 2015. Tampang Muda village is not included in those areas. Hence, BAKTI required permission before deploying this solution. Vendor to produce the UAV technology. Cooperation agreement between BAKTI and an MNO.	Although some UAV products have been available on the market, UAV has not yet been used in the network commercially. Moreover, UAV using rotary-wing has not been commercially available. Therefore, the CAPEX and OPEX are highly unpredictable. The network might not last long considering the potential growth of ISP using unlicensed bands.

Interviewee 2 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	2	Not feasible because there is no vendor available for this technology. Using an unlicensed band is considered unfeasible because from our experience surveying some unserved villages, we found that many villages that are not yet served by cellular network services have been served by an internet service established by the local communities. Moreover, the local communities use Wi-Fi bands for establishing the network to provide internet services. Hence, if cellular backhaul link uses Wi-Fi bands, the risk of interference would be high. Many new ISPs have sprung up, especially in remote areas	If the area is excluded with QoS standard due to the implementation of the regulatory solution 'Relaxing the QoS standard for rural networks', the users in that area may experience poor quality of service and the regulator cannot do anything for that. High interference due to the use of unlicensed bands to its own network and the existing small local ISP's networks. Low quality of service due to lack of regulatory guard on the unlicensed bands.	Vendor to produce the UAV technology. The existing regulation about cellular network QoS and taxes need to be amended. Cooperation agreement between MNO and the UAV vendors.	Although some UAV products have been available on the market, UAV has not yet been used in the network commercially. Moreover, UAV using rotary-wing has not been commercially available. Therefore, the CAPEX and OPEX are highly unpredictable. The network might not last long, considering the potential growth of ISP using unlicensed bands.
4	1	Relying on the bus or public transportation is very difficult for a village that is not accessible via a land route like Tampang Muda.	Delay communication	Transportation mode that can carry the network components safely.	

Terusan village

Interviewee 2 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	Feasible because the vendor of technology (femtocell) is already available, and it does not clash with the existing law and regulation. Femtocell also has been used by MNOs, although currently for a different purpose (indoor access technology). The use of the existing fibre optic line as the backhaul link also enhance its feasibility, compared to using wireless backhaul.	-	Cooperation agreement between BAKTI and an MNO	This technology solution (femtocell) has not been used to deploy a network in rural areas outdoor; therefore, the CAPEX and OPEX are unpredictable.
2	1	Feasible because the vendor of technology (femtocell) is already available, and it does not clash with the existing law and regulation. Femtocell also has been used by MNOs, although currently for a different purpose (indoor access technology). The use of the existing fibre optic line as the backhaul link also enhance its feasibility, compared to using wireless backhaul.	If the area is excluded from QoS standard due to the implementation of the regulatory solution 'Relaxing the QoS standard for rural networks', the users in that area may experience poor quality of service, and the regulator cannot guard it.	The existing regulation about cellular network QoS and taxes need to be amended.	This technology solution (femtocell) has not been used to deploy the network in rural areas outdoor, so the CAPEX and OPEX are unpredictable.

Interviewee 2 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	5	Feasible because OpenBTS and its supporting system have been commercially available in the market and ready to be used. However, existing Indonesian regulation about spectrum does not allow for VillageCell.	The network will not be interconnected to other MNOs. The network cannot be commercialised.	The existing regulation about numbering blocks.	As the network would be operated not by SRO (BAKTI), but either by the MNO employed by BAKTI or by ISP that provides the VoIP service or by the local community itself, there is a risk that either of them set a usage charge to users without BAKTI's knowing. It could deteriorate the objective of the network and make the solution ineffective.
4	4	Not feasible because there is no vendor available for this technology	-	Vendor to produce the UAV technology. Cooperation agreement between BAKTI and an MNO	Although some UAV products have been available on the market, UAV has not yet been used in the network commercially. Moreover, UAV using rotary-wing has not been commercially available. Therefore, the CAPEX and OPEX are highly unpredictable.
5	2	Not feasible because there is no vendor available for this technology	If the area is excluded with QoS standard due to the implementation of the regulatory solution 'Relaxing the QoS standard for rural networks', the users in that area may experience poor quality of service, and the regulator cannot do anything for that.	Vendor to produce the UAV technology	Although some UAV products have been available on the market, UAV has not yet been used in the network commercially. Moreover, UAV using rotary-wing has not been commercially available. Therefore, the CAPEX and OPEX are highly unpredictable.

Unipa village

Interviewee 2 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	1	Feasible because the vendor of technology (femtocell) is already available, and it does not clash with the existing law and regulation. Femtocell also has been used by MNOs, although currently for a different purpose (indoor access technology). The use of the existing fibre optic line as the backhaul link also enhance its feasibility, compared to using wireless backhaul.	If the area is excluded from QoS standard due to the implementation of the regulatory solution 'Relaxing the QoS standard for rural networks', the users in that area may experience poor quality of service, and the regulator cannot guard it.	The existing regulation about cellular network QoS and taxes need to be amended.	This technology solution (femtocell) has not been used to deploy the network in rural areas outdoor, so the CAPEX and OPEX are unpredictable.

Interviewee 2 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	3	Feasible because the vendor of technology (femtocell) is already available, and it does not clash with the existing law and regulation. Femtocell also has been used by MNOs, although currently for a different purpose (indoor access technology). The use of the existing fibre optic line as the backhaul link also enhance its feasibility, compared to using wireless backhaul.	-	Cooperation agreement between BAKTI and an MNO	This technology solution (femtocell) has not been used to deploy the network in rural areas outdoor, so the CAPEX and OPEX are unpredictable.
3	5	Feasible because OpenBTS and its supporting system have been commercially available in the market and ready to be used. However, existing Indonesian regulation about spectrum does not allow for VillageCell.	The network will not be interconnected to other MNOs. The network cannot be commercialised.	The existing regulation about numbering blocks.	As the network would be operated not by SRO (BAKTI), but either by the MNO employed by BAKTI or by ISP that provides the VoIP service or by the local community itself, there is a risk that either of them set a usage charge to users without BAKTI's knowing. It could deteriorate the objective of the network and make the solution ineffective.
4	2	Not feasible because there is no vendor available for this technology	If the area is excluded with QoS standard due to the implementation of the regulatory solution 'Relaxing the QoS standard for rural networks', the users in that area may experience poor quality of service, and the regulator cannot do anything for that.	Vendor to produce the UAV technology	Although some UAV products have been available on the market, UAV has not yet been used in the network commercially. Moreover, UAV using rotary-wing has not been commercially available. Therefore, the CAPEX and OPEX are highly unpredictable.
5	4	Not feasible because there is no vendor available for this technology	-	Vendor to produce the UAV technology. Cooperation agreement between BAKTI and an MNO.	Although some UAV products have been available on the market, UAV has not yet been used in the network commercially. Moreover, UAV using rotary-wing has not been commercially available. Therefore, the CAPEX and OPEX are highly unpredictable.

D.2.3 Interviewee 3

Date of interview	:	June 1st 2021
Interviewee name	:	Indra Apriadi
Position	:	Coordinator for Special Telecommunications and Telecommunication Network

Tampang Muda village

Interviewee 3 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	2	Difficult considering Indonesian weather and vandalism in rural areas. In the existing regulation, there are mainly two types of QoS: 1. regarding availability, 2. regarding capacity. Differing the QoS standard should be done after assessing the site's actual condition and only applied to the necessary sites. Since Tampang Muda village is far from the existing cellular sites and fibre optic network, relaxing the QoS standard regarding capacity might be feasible for Tampang Muda. However, if there is already a solution regarding availability, such as the battery performance prediction model and the support from the local community to ensure the site availability, differing the QoS standard regarding availability would not be feasible. The sectoral taxes reduction can be objected on the telecommunication BHP, USO, regional taxes (IMB, PAD, etc.) or other taxes as long as it is formulable and easily calculable, and accommodated in the regulation. Only if it is accompanied by rural network deployment by MNOs and the government can assure it will this tax reduction policy be considered feasible.	Higher OPEX than the conventional network model	Further cost and benefit analysis for this village of using this solution versus the conventional network model (large cell) that is commonly used. To allow QoS relaxation, the criteria that clarify which site is eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality. Regarding the regulatory solution 'a taxation..', if it wants to be accommodated in the telecommunication BHP, the regulation about telecommunication BHP could be amended to include 'rural investments' or 'rural site's deficit' as one of its reduction factors. Nonetheless, this policy requires a careful tax reduction formulation, regardless of which tax it is objected to (import tax, BHP, etc.). However, since the government has taken the lead in rural network deployment (targetting all villages to be covered by 2022), this policy is no longer necessary at the moment. The fund used by the government is supplemented by APBN (25T) since USF is not sufficient. MNO's willingness to cover this village or inclusion of this village in the coverage obligation.	Infrastructures are more prone to damages due to vandalism, extreme weather and too complex operation (the autonomous scheduled trajectories, scheduled charging, etc.).
2	4	Difficult considering Indonesian weather and vandalism in rural areas. Having SRO as the network deployer is also more feasible because Unipa is categorised as BAKTI's responsibility.	Higher OPEX than the conventional network model	Permission to use USF for this village	Infrastructures are more prone to damages due to vandalism, extreme weather and too complex operation (the autonomous scheduled trajectories, scheduled charging, etc.).
3	3	Might not be preferred due to its inability to give equal cellular services, and the law would be unlikely to allow the use of mobile spectrum by local communities.	Limited cellular services to users. Violation of the law for using spectrum by non-MNOs.	Clarification on the spectrum regulation to allow the use of spectrum for this solution. Permission to use USF for this village	An ineffective network for connecting people/telecommunication.
4	1	-	-	Permission to use USF for this village	-

Terusan village

Interviewee 3 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	1	The technology is ready and available in the market, and the network deployment and operation are more tangible than UAV and VillageCell. It also can support 5G in the future. The sectoral taxes reduction can be objected on the telecommunication BHP, USO, regional taxes (IMB, PAD, etc.) or other taxes as long as it is formulable and easily calculable, and accommodated in the regulation. Only if it is accompanied by rural network deployment by MNOs and the government can assure it will this tax reduction policy be considered feasible.	More network components are placed in the village if the residential areas are too sparsely distributed, compared to only one large cell	Further cost and benefit analysis for this village of using this solution versus the conventional network model (large cell) that is commonly used. To allow QoS relaxation, the criteria that clarify which site is eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality. Regarding the regulatory solution 'a taxation..', if it wants to be accommodated in the telecommunication BHP, the regulation about telecommunication BHP could be amended to include 'rural investments' or 'rural site's deficit' as one of its reduction factors. Nonetheless, this policy requires a careful tax reduction formulation, regardless of which tax it is objected to (import tax, BHP, etc.). However, since the government has taken the lead in rural network deployment (targetting all villages to be covered by 2022), this policy is no longer necessary at the moment. The fund used by the government is supplemented by APBN (25T) since USF is not sufficient. MNO's willingness to cover this village or inclusion of this village in the coverage obligation.	The case study of TUCAN3G showed that in one village, a maximum of 2 femtocells was used. Meanwhile, if a village has a population distributed in more than two locations far from each other, more than two femtocells would be needed. In such cases, there is a risk that using femtocells or the TUCAN3G model becomes less efficient than using the conventional model (1 large cell for one village).
2	2	Difficult considering Indonesian weather and vandalism in rural areas. The sectoral taxes reduction can be objected on the telecommunication BHP, USO, regional taxes (IMB, PAD, etc.) or other taxes as long as it is formulable and easily calculable, and accommodated in the regulation. Only if it is accompanied by rural network deployment by MNOs and the government can assure it will this tax reduction policy be considered feasible.	Higher OPEX than the conventional network model	Further cost and benefit analysis for this village of using this solution versus the conventional network model (large cell) that is commonly used. To allow QoS relaxation, the criteria that clarify which site is eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality. Regarding the regulatory solution 'a taxation..', if it wants to be accommodated in the telecommunication BHP, the regulation about telecommunication BHP could be amended to include 'rural investments' or 'rural site's deficit' as one of its reduction factors. Nonetheless, this policy requires a careful tax reduction formulation, regardless of which tax it is objected to (import tax, BHP, etc.). However, since the government has taken the lead in rural network deployment (targetting all villages to be covered by 2022), this policy is no longer necessary at the moment. The fund used by the government is supplemented by APBN (25T) since USF is not sufficient. MNO's willingness to cover this village or inclusion of this village in the coverage obligation.	Infrastructures are more prone to damages due to vandalism, extreme weather and too complex operation (the autonomous scheduled trajectories, scheduled charging, etc.).

Interviewee 3 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	3	The technology is ready and available in the market, and the network deployment and operation are more tangible than UAV and VillageCell. It also can support 5G in the future. Having SRO as the network deployer is also more feasible because Unipa is categorised as BAKTI's responsibility.	More network components are placed in the village if the residential areas are too sparsely distributed, compared to only one large cell	Further cost and benefit analysis for this village of using this solution versus the conventional network model (large cell) that is commonly used. Permission to use USF for this village	The case study of TUCAN3G showed that a maximum of 2 femtocells was used in one village. Meanwhile, if a village has populations distributed in more than two locations far from each other, more than two femtocells would be needed. In such cases, there is a risk that using femtocells or the TUCAN3G model becomes less efficient than using the conventional model (1 large cell for one village).
4	4	Difficult considering Indonesian weather and vandalism in rural areas. Having SRO as the network deployer is also more feasible because Unipa is categorised as BAKTI's responsibility.	Higher OPEX than the conventional network model	Permission to use USF for this village	Infrastructures are more prone to damages due to vandalism, extreme weather and too complex operation (the autonomous scheduled trajectories, scheduled charging, etc.).
5	5	Might not be preferred due to its inability to give equal cellular service, and the law would be unlikely to allow the use of mobile spectrum by local communities.	Limited cellular services to users. Violation of the law for using spectrum by non-MNOs.	Clarification on the spectrum regulation to allow the use of spectrum for this solution. Permission to use USF for this village	An ineffective network for connecting people/telecommunication.

Unipa village

Interviewee 3 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	The technology is ready and available in the market, and the network deployment and operation are more tangible than UAV and VillageCell. It also can support 5G in the future. Having SRO as the network deployer is also more feasible because Unipa is categorised as BAKTI's responsibility.	More network components are placed in the village if the residential areas are too sparsely distributed, compared to only one large cell	Further cost and benefit analysis for this village of using this solution versus the conventional network model (large cell) that is commonly used	The case study of TUCAN3G showed that in one village, maximum of 2 femtocells were used. Meanwhile, if a village has populations distributed in more than two locations far from each other, more than two femtocells would be needed. In such cases, there is a risk that using femtocells or the TUCAN3G model becomes less efficient than using the conventional model (1 large cell for one village).
2	4	Difficult considering Indonesian weather and vandalism in rural areas. Having SRO as the network deployer is also more feasible because Unipa is categorised as BAKTI's responsibility.	Higher OPEX than the conventional network model	-	Infrastructures are more prone to damages due to vandalism, extreme weather and too complex operation (the autonomous scheduled trajectories, scheduled charging, etc.).

Interviewee 3 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	1	The technology is ready and available in the market, and the network deployment and operation are more tangible than UAV and VillageCell. It also can support 5G in the future. In the existing regulation, there are mainly two types of QoS: 1. regarding availability, 2. regarding capacity. Differing the QoS standard should be done after assessing the site's actual condition and only applied to the necessary sites. For example, if Unipa village becomes servable by fibre optic backhaul, then differing the QoS standard regarding capacity would not be feasible for Unipa. Also, if there is already a solution regarding availability, such as the battery performance prediction model and the support from the local community to ensure the site availability, differing the QoS standard regarding availability will not be feasible. The sectoral taxes reduction can be objected on the telecommunication BHP, USO, regional taxes (IMB, PAD, etc.) or other taxes as long as it is formulable and easily calculable, and accommodated in the regulation. Only if it is accompanied by rural network deployment by MNOs and the government can assure it will this tax reduction policy be considered feasible.	More network components are placed in the village if the residential areas are too sparsely distributed, compared to only one large cell	Further cost and benefit analysis for this village of using this solution versus the conventional network model (large cell) that is commonly used. To allow QoS relaxation, the criteria that clarify which site is eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality. Regarding the regulatory solution 'a taxation..', if it wants to be accommodated in the telecommunication BHP, the regulation about telecommunication BHP could be amended to include 'rural investments' or 'rural site's deficit' as one of its reduction factors. Nonetheless, this policy requires a careful tax reduction formulation, regardless of which tax it is objected to (import tax, BHP, etc.). However, since the government has taken the lead in rural network deployment (targeting all villages to be covered by 2022), this policy is no longer necessary at the moment. The fund used by the government is supplemented by APBN (25T) since USF is not sufficient. MNO's willingness to cover this village or inclusion of this village in the coverage obligation.	The case study of TUCAN3G showed that in one village, a maximum of 2 femtocells was used. Meanwhile, if a village has populations distributed in more than two locations far from each other, more than two femtocells would be needed. In such cases, there is a risk that using femtocells or the TUCAN3G model becomes less efficient than using the conventional model (1 large cell for one village).
4	2	Difficult considering Indonesian weather and vandalism in rural areas. In the existing regulation, there are mainly two types of QoS: 1. regarding availability, 2. regarding capacity. Differing the QoS standard should be done after assessing the site's actual condition and only applied to the necessary sites. For example, if Unipa village becomes servable by fibre optic backhaul, then differing the QoS standard regarding capacity would not be feasible for Unipa. Also, if there is already a solution regarding availability, such as the battery performance prediction model and the support from the local community to ensure the site availability, differing the QoS standard regarding availability would not be feasible. The sectoral taxes reduction can be objected on the telecommunication BHP, USO, regional taxes (IMB, PAD, etc.) or other taxes as long as it is formulable and easily calculable, and accommodated in the regulation. Only if it is accompanied by rural network deployment by MNOs and the government can assure it will this tax reduction policy be considered feasible.	Higher OPEX than the conventional network model	Further cost and benefit analysis for this village of using this solution versus the conventional network model (large cell) that is commonly used. To allow QoS relaxation, the criteria that clarify which site is eligible for QoS relaxation and the relaxation scheme that remains guarding the rights for rural users to receive an equal service quality. Regarding the regulatory solution 'a taxation..', if it wants to be accommodated in the telecommunication BHP, the regulation about telecommunication BHP could be amended to include 'rural investments' or 'rural site's deficit' as one of its reduction factors. Nonetheless, this policy requires a careful tax reduction formulation, regardless of which tax it is objected to (import tax, BHP, etc). However, since the government has taken the lead in rural network deployment (targetting all villages to be covered by 2022), this policy is no longer necessary at the moment. The fund used by the government is supplemented by APBN (25T) since USF is not sufficient. MNO's willingness to cover this village or inclusion of this village in the coverage obligation.	Infrastructures are more prone to damages due to vandalism, extreme weather and too complex operation (the autonomous scheduled trajectories, scheduled charging, etc.).

Interviewee 3 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	5	Might not be preferred due to its inability to give equal cellular services and the law would be unlikely to allow the use of mobile spectrum by local communities.	Limited cellular services to users. Violation of the law for using spectrum by non-MNOs.	Clarification on the spectrum regulation to allow the use of spectrum for this solution.	Ineffective network for connecting people/telecommunication.

D.2.4 Interviewee 4

Date of interview	:	June 4th 2021
Interviewee name	:	Roland Febrian Siahaan
Position	:	Telecommunication Regulation and Policy Analyst

Tampang Muda village

Interviewee 4 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. By looking at the existing spectrum regulation, VillageCell will only be feasible if it is delivered by BAKTI who employs MNO to operate the VillageCell.	Limited communication	Vendor to manufacture the battery performance prediction model with MIML. BAKTI employs MNO to operate VillageCell.	-
2	2	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. Unlicensed backhaul is feasible to be used in rural areas like Tampang Muda because this free band is rarely used there, thus less risk of interference. So far, no UAV is used commercially as a cellular site. Therefore its feasibility is doubted. Particularly for the UAV proposed here, it is not feasible unless the actual product is manufactured. The cost of this product is predicted to be relatively expensive. If the UAV is owned and operated not by the MNO (like Google Loon used to be), then this solution is also not feasible due to spectrum regulation. Sectoral taxes reduction is not feasible when looking at the existing government's mindset. The financial governments are profit-oriented. Adjustment on the QoS standard taking into account the location of the network makes sense because, at some point, different type of location (urban, rural and remote) may require a different type of service that do not necessarily have the same quality. For example, for internet services, regarding latency, urban areas, due to their daily activity (the presence of IoT, etc.) and mobility, require low latency connection. Meanwhile, rural may be okay with the medium latency. It also makes sense considering the difficulties to access the area. Tampang Muda can only be accessed via sea, might not be accessible during stormy weather.	Less country's income due to the tax reduction. More explicit QoS gap between urban and rural areas.	Vendor to manufacture the battery performance prediction model with MIML. Amendment of the existing regulations regarding sectoral taxes. Vendor to manufacture the UAV as proposed in the literature. MNO operates the UAV. Financial government and law maker's mindset changing to also consider telecommunication development as an alternative 'profit' other than cash income. QoS regulation amendment.	Expensive cost of ownership of UAV network due to its new concept. The UAVs could be more prone to damages due to Indonesian climate and the lack of local people's awareness to protect the UAVs

Interviewee 4 - Tampang Muda village

Rank	Opt	Feasibility	Consequences	Requirements	Risks
3	4	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. Unlicensed backhaul is feasible to be used in rural areas like Tampang Muda because this free band is rarely used there, thus less risk of interference. So far, no UAV is used commercially as a cellular site. Therefore its feasibility is doubted. Particularly for the UAV proposed here, it is not feasible unless the actual product is manufactured. The cost of this product is predicted to be relatively expensive. UAV currently seems intangible since the drone needs to carry the transceiver that is heavy. If it is possible to carry the load, the next concern would be the UAV's battery size. It must be big enough to allow a long flight duration. Otherwise, it requires frequent charging, which is inefficient. If the UAV is owned and operated not by the MNO (like Google Loon used to be), then this solution is also not feasible due to spectrum regulation. However, BAKTI may not be fully an SRO as described in the solution. Due to its position as a government agency with much other responsibility, being an SRO who rent out its networks to operators would be too complicated for BAKTI.	As an SRO, BAKTI's workload will be higher since it will have more assets to manage and more public fund required (also to buy the active infrastructure). It will also need more technically skilful personnel. Higher asset ownership risks due to the ownership of active infrastructure that is developed fastly and quickly out-of-date.	Vendor to manufacture the battery performance prediction model with MIML. Vendor to manufacture the UAV as proposed in the literature. UAV is operated by the MNO. More public fund to finance the active infrastructure CAPEX and more technically skilful personnel to manage the asset.	Expensive cost of ownership of UAV network due to its new concept. The UAVs could be more prone to damages due to Indonesian climate and the lack of local people's awareness to protect the UAVs.
4	1	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible.	Long waiting time when communicating, not real-time communication could lead to users' discontent.	Vendor to manufacture the battery performance prediction model with MIML	The waiting time could take more than one day when the weather is not good since it relies on sea transportation.

Terusan village

Interviewee 4 - Terusan village

Rank	Opt	Feasibility	Consequences	Requirements	Risks
1	1	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. The use of femtocell can indeed significantly reduce the CAPEX. Sectoral taxes reduction is not feasible when looking at the existing government's mindset. The financial governments are profit-oriented. Adjustment on the QoS standard taking into account the location of the network makes sense because, at some point, different type of location (urban, rural and remote) may require a different type of service that do not necessarily have the same quality. For example, for internet services, regarding latency, urban areas, due to their daily activity (the presence of IoT, etc.) and mobility, require low latency connection. Meanwhile, rural may be okay with the medium latency. It also makes sense considering the difficulties to access the area.	Less country's income due to the tax reduction. More explicit QoS gap between urban and rural areas.	Vendor to manufacture the battery performance prediction model with MIML. Amendment of the existing regulations regarding sectoral taxes. Financial government and law maker's mindset changing to also consider telecommunication development as an alternative 'profit' other than cash income. QoS regulation amendment.	-

Interviewee 4 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	3	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. The use of femtocell can indeed significantly reduce the CAPEX. However, BAKTI may not be fully an SRO as described in the solution. Due to its position as a government agency with much other responsibility, being an SRO who rent out its networks to operators would be too complicated for BAKTI.	As an SRO, BAKTI's workload will be higher since it will have more assets to manage and more public fund required (also to buy the active infrastructure). It will also need more technically skilful personnel. Higher asset ownership risks due to the ownership of active infrastructure that is developed fastly and quickly out-of-date.	Vendor to manufacture the battery performance prediction model with MIML. More public fund to finance the active infrastructure CAPEX and more technically skilful personnel to manage the asset.	-
3	5	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. By looking at the existing spectrum regulation, VillageCell will only be feasible if it is delivered by BAKTI who employs MNO to operate the VillageCell.	Limited communication	Vendor to manufacture the battery performance prediction model with MIML. BAKTI employs MNO to operate VillageCell.	-
4	2	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. So far, no UAV is used commercially as a cellular site. Therefore its feasibility is doubted. Particularly for the UAV proposed here, it is not feasible unless the actual product is manufactured. The cost of this product is predicted to be relatively expensive. UAV currently seems intangible since the drone needs to carry the transceiver that is heavy. If it is possible to carry the load, the next concern would be the UAV's battery size. It must be big enough to allow a long flight duration. Otherwise, it requires frequent charging, which is inefficient. If the UAV is owned and operated not by the MNO (like Google Loon used to be), then this solution is also not feasible due to spectrum regulation. Sectoral taxes reduction is not feasible when looking at the existing government's mindset. The financial governments are profit-oriented. Adjustment on the QoS standard taking into account the location of the network makes sense because at some point, different type of location (urban, rural and remote) may require a different type of service that do not necessarily have the same quality. For example, for internet services, regarding latency, urban areas, due to their daily activity (the presence of IoT, etc.) and mobility, require low latency connection. Meanwhile, rural may be okay with the medium latency. It also makes sense considering the difficulties to access the area.	Less country's income due to the tax reduction. More explicit QoS gap between urban and rural areas.	Vendor to manufacture the battery performance prediction model with MIML. Amendment of the existing regulations regarding sectoral taxes. Vendor to manufacture the UAV as proposed in the literature. UAV is operated by the MNO. Financial government and law maker's mindset changing to also consider telecommunication development as an alternative 'profit' other than cash income. QoS regulation amendment	Expensive cost of ownership of UAV network due to its new concept. The UAVs could be more prone to damages due to Indonesian climate and the lack of local people's awareness to protect the UAVs.

Interviewee 4 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	4	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. So far, no UAV is used commercially as a cellular site. Therefore its feasibility is doubted. Particularly for the UAV proposed here, it is not feasible unless the actual product is manufactured. The cost of this product is predicted to be relatively expensive. UAV currently seems intangible since the drone needs to carry the transceiver that is heavy. If it is possible to carry the load, the next concern would be the UAV's battery size. It must be big enough to allow a long flight duration. Otherwise, it requires frequent charging, which is inefficient. If the UAV is owned and operated not by the MNO (like Google Loon used to be), then this solution is also not feasible due to spectrum regulation. However, BAKTI may not be fully an SRO as described in the solution. Due to its position as a government agency with many other responsibilities, being an SRO who rents out its networks to operators would be too complicated for BAKTI.	As an SRO, BAKTI's workload will be higher since it will have more assets to manage and more public fund required (also to buy the active infrastructure). It will also need more technically skilful personnel. Higher asset ownership risks due to the ownership of active infrastructure that is developed fastly and quickly out-of-date.	Vendor to manufacture the battery performance prediction model with MIML. Vendor to manufacture the UAV as proposed in the literature. UAV is operated by the MNO. More public fund to finance the active infrastructure CAPEX and more technically skilful personnel to manage the asset.	Expensive cost of ownership of UAV network due to its new concept. The UAVs could be more prone to damages due to Indonesian climate and the lack of local people's awareness to protect the UAVs.

Unipa village

Interviewee 4 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. The use of femtocell can indeed significantly reduce the CAPEX. However, BAKTI may not be fully an SRO as described in the solution. Due to its position as a government agency with many other responsibilities, being an SRO who rents out its networks to operators would be too complicated for BAKTI.	As an SRO, BAKTI's workload will be higher since it will have more assets to manage and more public fund required (also to buy the active infrastructure). It will also need more technically skilful personnel. Higher asset ownership risks due to the ownership of active infrastructure that is developed fastly and quickly out-of-date.	Vendor to manufacture the battery performance prediction model with MIML. More public fund to finance the active infrastructure CAPEX and more technically skilful personnel to manage the asset.	-

Interviewee 4 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	1	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. The use of femtocell can indeed significantly reduce the CAPEX. Sectoral taxes reduction is not feasible when looking at the existing government's mindset. The financial governments are profit-oriented. Adjustment on the QoS standard taking into account the location of the network makes sense because, at some point, different type of location (urban, rural and remote) may require a different type of service that do not necessarily have the same quality. For example, for internet services, regarding latency, urban areas, due to their daily activity (the presence of IoT, etc.) and mobility, require low latency connection. Meanwhile, rural may be okay with the medium latency. It also makes sense considering the difficulties to access the area.	Less country's income due to the tax reduction. More explicit QoS gap between urban and rural areas.	Vendor to manufacture the battery performance prediction model with MIML. Amendment of the existing regulations regarding sectoral taxes. Financial government and law maker's mindset changing to also consider telecommunication development as an alternative 'profit' other than cash income. QoS regulation amendment.	-
3	5	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. By looking at the existing spectrum regulation, VillageCell will only be feasible if it is delivered by BAKTI who employs MNO to operate the VillageCell.	Limited communication	Vendor to manufacture the battery performance prediction model with MIML. BAKTI employs MNO to operate VillageCell.	-
4	2	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. So far, no UAV is used commercially as a cellular site. Therefore its feasibility is doubted. Particularly for the UAV proposed here, it is not feasible unless the actual product is manufactured. The cost of this product is predicted to be relatively expensive. UAV currently seems intangible since the drone needs to carry the transceiver that is heavy. If it is possible to carry the load, the next concern would be the UAV's battery size. It must be big enough to allow a long flight duration. Otherwise, it requires frequent charging, which is inefficient. If the UAV is owned and operated not by the MNO (like Google Loon used to be), then this solution is also not feasible due to spectrum regulation. Sectoral taxes reduction is not feasible when looking at the existing government's mindset. The financial governments are profit-oriented. Adjustment on the QoS standard taking into account the location of the network makes sense because, at some point, different type of location (urban, rural and remote) may require a different type of service that do not necessarily have the same quality. For example, for internet services, regarding latency, urban areas, due to their daily activity (the presence of IoT, etc.) and mobility, require low latency connection. Meanwhile, rural may be okay with the medium latency. It also makes sense considering the difficulties to access the area.	Less country's income due to the tax reduction. More explicit QoS gap between urban and rural areas.	Vendor to manufacture the battery performance prediction model with MIML. Amendment of the existing regulations regarding sectoral taxes. Vendor to manufacture the UAV as proposed in the literature. UAV is operated by the MNO. Financial government and law maker's mindset changing to also consider telecommunication development as an alternative 'profit' other than cash income QoS regulation amendment.	Expensive cost of ownership of UAV network due to its new concept. The UAVs could be more prone to damages due to Indonesian climate and the lack of local people's awareness to protect the UAVs.

Interviewee 4 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	4	The feasibility of the battery performance prediction model depends on the actual and cost of the product. If it can be realised accordingly and available at a reasonable price, it could be feasible. So far, no UAV is used commercially as a cellular site. Therefore its feasibility is doubted. Particularly for the UAV proposed here, it is not feasible unless the actual product is manufactured. The cost of this product is predicted to be relatively expensive. UAV currently seems intangible since the drone needs to carry the transceiver that is heavy. If it is possible to carry the load, the next concern would be the UAV's battery size. It must be big enough to allow a long flight duration. Otherwise, it requires frequent charging, which is inefficient. If the UAV is owned and operated not by the MNO (like Google Loon used to be), then this solution is also not feasible due to spectrum regulation. However, BAKTI may not be fully an SRO as described in the solution. Due to its position as a government agency with many other responsibilities, being an SRO who rents out its networks to operators would be too complicated for BAKTI.	As an SRO, BAKTI's workload will be higher since it will have more assets to manage and more public fund required (also to buy the active infrastructure). It will also need more technically skilful personnel. Higher asset ownership risks due to the ownership of active infrastructure that is developed fastly and quickly out-of-date.	Vendor to manufacture the battery performance prediction model with MIML. Vendor to manufacture the UAV as proposed in the literature. UAV is operated by the MNO. More public fund to finance the active infrastructure CAPEX and more technically skilful personnel to manage the asset.	Expensive cost of ownership of UAV network due to its new concept. The UAVs could be more prone to damages due to Indonesian climate and the lack of local people's awareness to protect the UAVs.

D.2.5 Interviewee 5

Date of interview	:	June 6th 2021
Interviewee name	:	Feriandi Mirza
Position	:	Head of Lastmile/Backhaul Infrastructure Division (BAKTI)

Tampang Muda village

Interviewee 5 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	BAKTI can take the role in covering this village using USF since it is allowed to do so by Permenkominfo Number 10/2018. It states that USF can be used for any areas in need. Private network using the existing mobile spectrum is not allowed by the existing regulations. However, there is a plan to allocate part of the 700 MHz spectrum for this purpose. The existing implementation similar to this is done by Net1 using 450 MHz for corporate internal communication, such as in mining or plantation areas. However, it is not an actual private network implementation. Allowing the spectrum sharing for the technology before 5G, as the one needed for VillageCell, is opposed by the incumbent MNO(s) since it may affect the MNO's business case.	Special SIM card (and number) only for VillageCell network will be created and used	The definition of the 'areas in need' by the government. Permission for BAKTI to work in non-3T areas. An MNO to cooperate with.	One of the risks of this solution is that irresponsible parties may impose illegal fees without Kominfo's knowledge, and the VillageCell network might be illegally commercial.

Interviewee 5 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	2	If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. By looking at the deficient number of potential users, any MNO would be highly unlikely to be interested in covering this village. Tax reduction is applicable. It can be feasible if supported with regulation and would be more effective if it is objected to the spectrum BHP, not USF. Because USF actually will be returned to the telecommunication operator since the network deployers are the existing telecommunication operators financed by USF. Differing QoS standard in rural networks are also applicable, but it depends on the policymaker willingness. In reality, indeed, maintaining rural sites takes a long time. It is exacerbated by the Covid situation where technicians from the city centre need to quarantine ten days after arriving in the village before visiting and repairing the site. At this point, this technology is not yet clear since it is not yet available on the market. If it is, to decide whether or not to use this technology, this technology needs to be massively used in another country to ensure the effectiveness.	Higher cost than if BAKTI deploys it due to the cost for the land acquisition. Unpredicted performance and costs of UAV. The service price to users can be much higher than if BAKTI deploys the site.	Amendment on the QoS regulation and sectoral taxes regulation. Coordination with border countries regarding the use of UAV. A massive implementation of UAV rotary-wing technology in another country. Coverage obligation on MNO for this village because without it, MNO will never be willing to cover it voluntarily. Supporting regulation for UAV, particularly regarding air clearance.	-
3	4	BAKTI can take the role in covering this village using USF since it is allowed to do so by Permenkominfo Number 10/2018. It states that USF can be used for any areas in need. The deployment of the network by BAKTI can be more feasible since BAKTI can request the local authority or other governmental institutions to lend their lands free of charge. If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. At this point, this technology is not yet clear since it is not yet available on the market. When it is available, this technology needs to be massively used in another country to ensure its effectiveness to decide whether to use it.	Unpredicted performance and costs of UAV.	The definition of the 'areas in need' by the government. A massive implementation of UAV rotary-wing technology in another country. Coordination with border countries regarding the use of UAV. Permission for BAKTI to work in non-3T areas. An MNO to cooperate with to provide the service, a telecommunication provider that provides the passive and active network components, and land to establish the infrastructure from the local government (with free-of-charge leasing agreement). Supporting regulation for UAV, particularly regarding air clearance.	-
4	1	BAKTI can take the role in covering this village using USF since it is allowed to do so by Permenkominfo Number 10/2018. It states that USF can be used for any areas in need. This solution is not preferable due to the delayed communication service that may not align with the users' expectations.	Delayed communication	The definition of the 'areas in need' by the government. Permission for BAKTI to work in non-3T areas. An existing ISP to cooperate with.	-

Terusan village

Interviewee 5 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	1	If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. By looking at the deficient number of potential users, any MNO would be highly unlikely to be interested in covering this village. Tax reduction is applicable. It can be feasible if supported with regulation and would be more effective if it is objected to the spectrum BHP, not USF. Because USF actually will be returned to the telecommunication operator since the network deployers are the existing telecommunication operators financed by USF. Differing QoS standard in rural networks are also applicable, but it depends on the policymaker willingness. In reality, indeed, maintaining rural sites takes a long time. It is exacerbated by the Covid situation where technicians from the city centre need to quarantine ten days after arriving in the village before visiting and repairing the site. Femtocell is feasible as long as it can cover the capacity need in the village and considers the Indonesian government's target 4G service. This technology solution is feasible and can significantly reduce the CAPEX and power need and simplify the logistical need. However, there must be a reason why femtocell, which has been there for years, has not been used for rural coverage.	Higher cost than if BAKTI deploys it due to the cost for the land acquisition. A meagre revenue potential due to a deficient number of users (around 100). The capacity the network with femtocells gives would be much lower than the large cell. The service price to users can be much higher than if BAKTI. deploys the site	Amendment on the QoS regulation and sectoral taxes regulation. Coverage obligation on MNO for this village because without it, MNO will never be willing to cover it voluntarily. Network dimensioning pays attention specifically to the capacity need and its growth potential (whether or not femtocell would be sufficient). Surveying the actual condition of the village.	Terusan, due to its mountainous topography, might not be able to be served by terrestrial backhaul.
2	3	BAKTI can take the role in covering this village using USF since it is allowed to do so by Permenkominfo Number 10/2018. It states that USF can be used for any areas in need. The deployment of the network by BAKTI can be more feasible since BAKTI can request the local authority or other governmental institutions to lend their lands free of charge. If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. Femtocell is feasible as long as it can cover the capacity need in the village and considers the Indonesian government's target 4G service. This technology solution is feasible and can significantly reduce the CAPEX and power need and simplify the logistical need. However, there must be a reason why femtocell, which has been there for years, has not been used for rural coverage. BAKTI cannot be fully an SRO because one MNO can only use the infrastructure it provides. Some of the network's active components must be added according to the number of signals it wants to transmit to allow for more than one MNO because spectrum sharing is not yet allowed by regulation.	The capacity the network with femtocells give would be much lower than the large cell.	The definition of the 'areas in need' by the government. Permission for BAKTI to work in non-3T areas. Network dimensioning pays attention specifically to the capacity need and its growth potential (whether or not femtocell would be sufficient). Surveying the actual condition of the village. An MNO to cooperate with to provide the service, a telecommunication provider that provides tower, backhaul link, power and network equipment, a land to be used for establishing the infrastructure from the Ministry of Environment and Forestry (with free-of-charge leasing agreement).	Terusan, due to its mountainous topography, might not be able to be served by terrestrial backhaul.

Interviewee 5 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	5	BAKTI can take the role in covering this village using USF since it is allowed to do so by Permenkominfo Number 10/2018. It states that USF can be used for any areas in need. Private network using the existing mobile spectrum is not allowed by the existing regulations. However, there is a plan to allocate part of the 700 MHz spectrum for this purpose. The existing implementation similar to this is done by Net1 using 450 MHz for corporate internal communication, such as in mining or plantation areas. However, it is not an actual private network implementation. Allowing the spectrum sharing for the technology before 5G, as the one needed for VillageCell, is opposed by the incumbent MNO(s) since it may affect the MNO's business case.	Special SIM card (and number) only for VillageCell network will be created and used	The definition of the 'areas in need' by the government. Permission for BAKTI to work in non-3T areas. An MNO to cooperate with.	One of the risks of this solution is that irresponsible parties may impose illegal fees without Kominfo's knowledge, and the VillageCell network might be illegally commercial.
4	2	If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. By looking at the deficient number of potential users, any MNO would be highly unlikely to be interested in covering this village. Tax reduction is applicable. It can be feasible if supported with regulation and would be more effective if it is objected to the spectrum BHP, not USF. Because USF actually will be returned to the telecommunication operator since the network deployers are the existing telecommunication operators financed by USF. Differing QoS standard in rural networks are also applicable, but it depends on the policymaker willingness. In reality, indeed, maintaining rural sites takes a long time. It is exacerbated by the Covid situation where technicians from the city centre need to quarantine ten days after arriving in the village before visiting and repairing the site. At this point, this technology is not yet clear since it is not yet available on the market. When it is available, this technology needs to be massively used in another country to ensure effectiveness before deciding whether to use it.	Higher cost than if BAKTI deploys it due to the cost for the land acquisition. Unpredicted performance and costs of UAV. A meagre revenue potential due to a deficient number of users (around 100). The service price to users can be much higher than if BAKTI deploys the site	Amendment on the QoS regulation and sectoral taxes regulation. Coordination with border countries regarding the use of UAV. A massive implementation of UAV rotary-wing technology in another country. Coverage obligation on MNO for this village because without it, MNO will never be willing to cover it voluntarily. Supporting regulation for UAV, particularly regarding air clearance.	-
5	4	BAKTI can take the role in covering this village using USF since it is allowed to do so by Permenkominfo Number 10/2018. It states that USF can be used for any areas in need. The deployment of the network by BAKTI can be more feasible since BAKTI can request the local authority or other governmental institutions to lend their lands free of charge. If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. At this point, this technology is not yet clear since it is not yet available on the market. When it is available, this technology needs to be massively used in another country to ensure effectiveness before deciding whether to use it. BAKTI cannot be fully an SRO because one MNO can only use the infrastructure it provides. Some of the network's active components must be added according to the number of signals it wants to transmit to allow for more than one MNO because spectrum sharing is not yet allowed by regulation.	Unpredicted performance and costs of UAV.	The definition of the 'areas in need' by the government. Coordination with border countries regarding the use of UAV. A massive implementation of UAV rotary-wing technology in another country. Permission for BAKTI to work in non-3T areas. An MNO to cooperate with to provide the service, a telecommunication provider that provides the passive and active network components, and land to establish the infrastructure from the Ministry of Environment and Forestry (with free-of-charge leasing agreement). Supporting regulation for UAV, particularly regarding air clearance.	-

Unipa village

Interviewee 5 - Unipa village

Rank	Opt	Feasibility	Consequences	Requirements	Risks
1	3	The deployment of the network by BAKTI can be more feasible since BAKTI can request the local authority or other governmental institutions to lend their lands free of charge. If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. Using the existing fibre optic also feasible since it is a Palapa Ring network, BAKTI has the privilege to request for termination point to the network owner. Femtocell is feasible as long as it can cover the capacity need in the village and considers Indonesian government's target 4G service. This technology solution is feasible and can significantly reduce the CAPEX and power need and simplify the logistical need. However, there must be a reason why femtocell, which has been there for years, has not been used for rural coverage. BAKTI cannot be fully an SRO because one MNO can only use the infrastructure it provides. Some of the network's active components must be added according to the number of signals it wants to transmit to allow for more than one MNO because spectrum sharing is not yet allowed by regulation.	The capacity the network with femtocells give would be much lower than the large cell.	A fibre optic termination in Unipa village since usually Palapa Ring line only is terminated in the central district of the municipality. Network dimensioning pays attention specifically to the capacity need and its growth potential (whether or not femtocell would be sufficient). Surveying the actual condition of the village. An MNO to cooperate with to provide the service, a telecommunication provider that provides tower, backhaul link, power and network equipment, a land to be used for establishing the infrastructure from the local government (with free-of-charge leasing agreement).	Unipa, due to its mountainous topography, might not be able to be served by terrestrial backhaul, including fibre optic, if it is too mountainous.
2	1	If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. By looking at the deficient number of potential users, any MNO would be highly unlikely to be interested in covering this village. Tax reduction is applicable. It can be feasible if supported with regulation and would be more effective if it is objected to the spectrum BHP, not USF. Because USF actually will be returned to the telecommunication operator since the network deployers are the existing telecommunication operators financed by USF. Differing QoS standard in rural networks are also applicable, but it depends on the policymaker willingness. In reality, indeed, maintaining rural sites takes a long time. It is exacerbated by the Covid situation where technicians from the city centre need to quarantine ten days after arriving in the village before visiting and repairing the site. Femtocell is feasible as long as it can cover the capacity need in the village and considers the Indonesian government's target 4G service. This technology solution is feasible and can significantly reduce the CAPEX and power need and simplify the logistical need. However, there must be a reason why femtocell, which has been there for years, has not been used for rural coverage.	Higher cost than if BAKTI deploys it due to the cost for the land acquisition. A meagre revenue potential due to a deficient number of users (around 200). The capacity the network with femtocells gives would be much lower than the large cell. The service price to users can be much higher than if BAKTI deploys the site	Costs for renting the fibre optic capacity to Palapa Ring Timur. Amendment on the QoS regulation and sectoral taxes regulation. Willingness from the MNO to cover the 3T areas. Network dimensioning pays attention specifically to the capacity need and its growth potential (whether or not femtocell would be sufficient). Surveying the actual condition of the village.	Unipa, due to its mountainous topography, might not be able to be served by terrestrial backhaul, including fibre optic, if it is too mountainous.

Interviewee 5 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	5	Private network using the existing mobile spectrum is not allowed by the existing regulations. However, there is a plan to allocate part of the 700 MHz spectrum for this purpose. The existing implementation similar to this is done by Net1 using 450 MHz for corporate internal communication, such as in mining or plantation areas. However, it is not an actual private network implementation. Allowing the spectrum sharing for the technology before 5G, as the one needed for VillageCell, is opposed by the incumbent MNO(s) since it may affect the MNO's business case.	Special SIM card (and number) only for VillageCell network will be created and used	An MNO to cooperate with to provide the service, an infrastructure provider that provides the network equipment.	One of the risks of this solution is that irresponsible parties may impose illegal fees without Kominfo's knowledge, and the VillageCell network might be illegally commercial.
4	4	The deployment of the network by BAKTI can be more feasible since BAKTI can request the local authority or other governmental institutions to lend their lands free of charge. If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. Using the existing fibre optic also feasible since it is Palapa Ring network, BAKTI has the privilege to request for termination point to the network owner. At this point, this technology is not yet clear since it is not yet available on the market. If it is, to decide whether or not to use this technology, this technology needs to be massively used in another country to ensure effectiveness. BAKTI cannot be fully an SRO because one MNO can only use the infrastructure it provides. Some of the network's active components must be added according to the number of signals it wants to transmit to allow for more than one MNO because spectrum sharing is not yet allowed by regulation.	Unpredicted performance and costs of UAV.	A fibre optic termination in Unipa village since usually Palapa Ring line only is terminated in the central district of the municipality. A massive implementation of UAV rotary-wing technology in another country. Coordination with border countries regarding UAV use. An MNO to cooperate with to provide the service, a telecommunication provider that provides the passive and active network components, and land to establish the infrastructure from the local government (with free-of-charge leasing agreement). Supporting regulation for UAV, particularly regarding air clearance	
5	2	If it is deployed by MNOs, the local authority and governmental institution usually cannot provide the land freely. By looking at the deficient number of potential users, any MNO would be highly unlikely to be interested in covering this village. Tax reduction is applicable. It can be feasible if supported with regulation and would be more effective if it is objected to the spectrum BHP, not USF. Because USF actually will be returned to the telecommunication operator since the network deployers are the existing telecommunication operators financed by USF. Differing QoS standard in rural networks are also applicable, but it depends on the policymaker willingness. In reality, indeed, maintaining rural sites takes a long time. It is exacerbated by the Covid situation where technicians from the city centre need to quarantine ten days after arriving in the village before visiting and repairing the site. At this point, this technology is not yet clear since it is not yet available on the market. When it is available, this technology needs to be massively used in another country to ensure effectiveness before deciding whether to use it.	Higher cost than if BAKTI deploys it due to the cost for the land acquisition. Unpredicted performance and costs of UAV. A meagre revenue potential due to a deficient number of users (around 200). The service price to users can be much higher than if BAKTI deploys the site	Costs for renting the fibre optic capacity to Palapa Ring Timur. Amendment on the QoS regulation and sectoral taxes regulation. A massive implementation of UAV rotary-wing technology in another country. Coordination with border countries regarding the use of UAV. Willingness from the MNO to cover the 3T areas. Supporting regulation for UAV, particularly regarding air clearance	-

D.2.6 Interviewee 6

Date of interview	:	June 8th 2021
Interviewee name	:	Adis Alifiawan
Position	:	Coordinator of Spectrum Allocation Arrangement for Fixed and Land Mobile Services

Tampang Muda village

Interviewee 6 - Tampang Muda village

Rank	Opt	Feasibility	Consequences	Requirements	Risks
1	3	-	Inequality of the telecommunication service provided to this village and the rest of the country. At least the village residents need to have 2 SIM cards: 1 for VillageCell and 1 for the normal cellular network when they are outside the village. If they do not have dual-SIM phones, then changing the SIM cards are needed to be done frequently for those who often are outside the village.	Compliance to the existing spectrum regulation and telecommunication operation regulation	Local population are very sensitive to the equality of the telecommunication service in their area. If they perceive that the service is impractical due to the need for them to switch the SIM card frequently, they might oppose the solution, which might spark local resentment. Sometimes, no service is better than the 'ugly' service.

Interviewee 6 - Tampang Muda village

Rank	Opt	Feasibility	Consequences	Requirements	Risks
2	4	The use of the unlicensed band for backhaul is allowed by regulation as long as it is according to the law (Permenkominfo Number 1 of 2019, transmit power/EIRP less than 4 watt and bandwidth is less than 20 MHz). It has been implemented in many existing sites. UAV as a relay node (backhaul) is considered more feasible than as the access technology. It is among the technology HAPS which has been standardised and allowed by Indonesian spectrum regulations since 2019. HAPS is High Altitude Platform Stations, such as UAV, that act as a backhaul relay node. The possibility of using it as a base station, as proposed in this solution, is still discussed by standardisation and regulatory bodies like 3GPP and ITU under the name of HIBS (HAPS for IMT Base Stations). The international mobile telecommunication association is finding the right bands for HIBS and is estimated to be decided by 2023. Hence, Indonesia would not allow UAV solution (as a base station) until the standard for HIBS is released in 2023. However, if all requirements are met, UAV can give benefits that the conventional site cannot, which is to have a way higher altitude. This higher altitude could allow a broader coverage by one node, hence could be more effective in providing the mobile network service coverage. Moreover, due to its flexibility, the UAV site can be easily relocated to a different point in need. For example, when a village is conducting an occasional event. More feasible as a temporary solution, such as in the event of forest fires, considering the cost and the operation complexity.	Higher OPEX and more complex operation due to the complexity of the UAV technology. Since this network model is significantly different from the existing mobile network technology, the knowledge and skill set of the existing operators' network personnels would not be sufficient to handle the sites. The personnel would need an additional qualification to maintain and operate this solution. Such as pilot certification, which is not among the common qualifications of a network engineer today. The Ministry of Transportation obliges anyone who operates drones to have a pilot certificate. More power needed to run the network. Much more network properties to take care of compared to the conventional solution such as large cell, such as the UAV control, powering mechanism, connectivity between the aircraft to the ground site, and so on.	-	The use of UAV tethered balloon could disturb the local activity in the surrounding areas. Suppose the UAV is installed in the residential neighbourhood. In that case, the cable may put the residents in danger unless it is protected adequately. If the UAV is operated by a company affiliated with foreign countries, like Loon is affiliated with the US' Google, it poses a threat to Indonesian national security. A foreign flag aircraft is counted as a foreign country territory that is difficult to control. Moreover, the data it captures may go to a foreign country, too. In the existing rural sites, operators employ some local site keeper to provide simple troubleshoot and maintenance for the site, such as for handling the electricity trip and cleaning the area. If the sites using UAV, the operator might not be able to do so since the troubleshoot and maintenance for UAV based network is not simple and unbearable by the local people's capacity.

Interviewee 6 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	2	The use of the unlicensed band for backhaul is allowed by regulation as long as it is according to the law (Permenkominfo Number 1 of 2019, transmit power/EIRP less than 4 watt and bandwidth is less than 20 MHz). It has been implemented in many existing sites. The tax reduction is also feasible to be done considering a good formulation of the coverage obligation Kominfo released recently and the punitive mechanism design for the non-conformities of the coverage obligation that is almost done. However, to ensure its effectiveness, those design needs to be performed accordingly. SDPPI main objectives when setting the spectrum price is not to gain income but to ensure the spectrum is used by the right MNO that values the spectrum the most. When an MNO is eager to pay more, it indicates that the MNO values it the most and will utilise the spectrum as maximum as possible so that the price they pay will return by deploying more sites. The tax reduction, indeed, can be effective in helping the MNO to reinvest in rural areas, especially if supported by the coverage obligation in their operational licenses and the coverage obligation is evaluated effectively. The punitive mechanism for the non-conformities of coverage obligation is almost done, in which the MNOs might get a certain amount of fine if they fail to comply. Hence, the coverage obligation can be the way to ensure that MNOs use the tax savings from the regulatory tax for rural network deployment as the government expected. UAV as a relay node (backhaul) is considered more feasible than as the access technology. It is among the technology HAPS which has been standardised and allowed by Indonesian spectrum regulations since 2019. HAPS is High Altitude Platform Stations, such as UAV, that act as a backhaul relay node. The possibility of using it as a base station, as proposed in this solution, is still discussed by standardisation and regulatory bodies like 3GPP and ITU under the name of HIBS (HAPS for IMT Base Stations). The international mobile telecommunication association is finding the right bands for HIBS and is estimated to be decided by 2023. Hence, Indonesia would not allow UAV solution (as a base station) until the standard for HIBS is released in 2023. More feasible as a temporary solution, such as in the event of forest fires, considering the cost and the operation complexity.	Higher OPEX and more complex operation due to the complexity of the UAV technology. Since this network model is significantly different from the existing mobile network technology, the knowledge and skill set of the existing operators' network personnel would not be sufficient to handle the sites. The personnel would need an additional qualification to maintain and operate this solution. Such as pilot certification, which is not among the common qualifications of a network engineer today. The Ministry of Transportation obliges anyone who operates drones to have a pilot certificate. More power needed to run the network. Much more network properties to take care of compared to the conventional solution such as large cell, such as the UAV control, powering mechanism, connectivity between the aircraft to the ground site, and so on.	Assessment regarding the network planning to see whether this solution is more cost-efficient than the conventional large cell solution. If tax is going to be reduced, particularly of the spectrum BHP, USF and/or the telecommunication BHP, a major change in the existing business process is required. Currently, BAKTI is perceived as the main actor responsible for the rural network deployment and is subjected to certain target related to telecommunication service provision to rural areas in Indonesia. If the tax reduction is implemented, the burden for rural network development should not be on BAKTI anymore, BAKTI should be demanded less, and MNO should be demanded more build the network in rural areas. Considering that currently, BAKTI has already been responsible for covering thousands of villages in Indonesia by 2022. At least until this target is accomplished, tax reduction could not be applied. That is because BAKTI needs public funds to finance this target, and the public funds provided to BAKTI depends on the country income Kominfo generates (the sectoral tax). More importantly, this solution requires a major change in the mindset of the government outside Kominfo and a good new business process to ensure that the tax reduction benefits rural network development. For example, a mechanism to value the MNOs rural investment for calculating their tax reduction amount, an audit mechanism by an independent auditor to ensure that Kominfo reduces the tax for MNOs according to the law, and so on.	The use of UAV tethered balloon could disturb the local activity in the surrounding areas. Suppose the UAV is installed in the residential neighbourhood. In that case, the cable may put the residents in danger unless it is protected adequately. If the UAV is operated by a company affiliated with foreign countries, like Loon is affiliated with the US' Google, it poses a threat to Indonesian national security. A foreign flag aircraft is counted as a foreign country territory that is difficult to control. Moreover, the data it captures may go to a foreign country, too. In the existing rural sites, operators employ some local site keeper to provide simple troubleshoot and maintenance for the site, such as for handling the electricity trip and cleaning the area. If the sites using UAV, the operator might not be able to do so since the troubleshoot and maintenance for UAV based network is not simple and unbearable by the local people's capacity.

Interviewee 6 - Tampang Muda village					
Rank	Opt	Feasibility	Consequences	Requirements	Risks
4	1	-	-	-	This solution would be highly opposed by the local residents. There is a real case in the existing network deployment process. The local population are very sensitive to the equality of the telecommunication service in their area. Due to the expensive cost of inter-operator voice call service in Indonesia, people want to have the same MNO to serve their area as the MNO that serve their relatives to minimise the service cost. Often local governments are threatened by the residents that if the mobile network service is not from a particular MNO, the established site would be damaged. If they perceive that the service is impractical due to the need for them to wait for hours to communicate, they might oppose the solution, which might spark local resentment. Sometimes, no service is better than the 'ugly' service.

Terusan village

Interviewee 6 - Terusan village					
Rank	Opt	Feasibility	Consequences	Requirements	Risks
1	3	Femtocell network is feasible but can be less efficient for a village with a very sparsely distributed population, like Unipa. As seen, the population density is 1.5 people/km2, which means one cluster of residents can be very far apart. When it is too far and cannot be covered by one location of femtocell node, a new femtocell node location needs to be established, and the additional cost might be higher than having one large cell	-	Assessment regarding the network planning to see whether this solution is more cost-efficient than the conventional large cell solution	More than one femtocell nodes might be needed in Terusan village could lead to a less cost-efficient solution than the large cell model

Interviewee 6 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	1	Femtocell network is feasible but can be less efficient for a village with a very sparsely distributed population, like Unipa. As seen, the population density is 1.5 people/km2, which means one cluster of residents can be very far apart. When it is too far and cannot be covered by one location of the femtocell node, a new femtocell node location needs to be established, and the additional cost might be higher than having one large cell. The tax reduction is also feasible to be done considering a good formulation of the coverage obligation Kominfo released recently and the punitive mechanism design for the non-conformities of the coverage obligation that is almost done. However, to ensure its effectiveness, those design needs to be performed accordingly. SDPPI main objectives when setting the spectrum price is not to gain income but to ensure the spectrum is used by the right MNO that values the spectrum the most. When an MNO is eager to pay more, it indicates that the MNO values it the most and will utilise the spectrum as maximum as possible so that the price they pay will return by deploying more sites. The tax reduction, indeed, can be effective in helping the MNO to reinvest in rural areas, especially if supported by the coverage obligation in their operational licenses and the coverage obligation is evaluated effectively. The punitive mechanism for the non-conformities of coverage obligation is almost done, in which the MNOs might get a certain amount of fine if they fail to comply. Hence, the coverage obligation can be the way to ensure that MNOs use the tax savings from the regulatory tax for rural network deployment as the government expected.	-	Assessment regarding the network planning to see whether this solution is more cost-efficient than the conventional large cell solution. If tax is going to be reduced, particularly of the spectrum BHP, USF and/or the telecommunication BHP, a major change in the existing business process is required. Currently, BAKTI is perceived as the main actor responsible for the rural network deployment and is subjected to certain target related to telecommunication service provision to rural areas in Indonesia. If the tax reduction is implemented, the burden for rural network development should not be on BAKTI anymore, BAKTI should be demanded less, and MNO should be demanded more build the network in rural areas. Considering that currently, BAKTI has already been responsible for covering thousands of villages in Indonesia by 2022. At least until this target is accomplished, tax reduction could not be applied. That is because BAKTI needs public funds to finance this target, and the public funds provided to BAKTI depends on the country income Kominfo generates (the sectoral tax). More importantly, this solution requires a major change in the mindset of the government outside Kominfo and a good new business process to ensure that the tax reduction benefits rural network development. For example, a mechanism to value the MNOs rural investment for calculating their tax reduction amount, an audit mechanism by an independent auditor to ensure that	More than one femtocell nodes might be needed in Terusan village could lead to a less cost-efficient solution than the large cell model

Interviewee 6 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	5	-	Inequality of the telecommunication service provided to this village and the rest of the country. At least the village residents need to have 2 SIM cards: 1 for VillageCell and 1 for the normal cellular network when they are outside the village. If they do not have dual-SIM phones, then changing the SIM cards are needed to be done frequently for those who often are outside the village.	Compliance to the existing spectrum regulation and telecommunication operation regulation	Local population are very sensitive to the equality of the telecommunication service in their area. If they perceive that the service is impractical due to the need for them to switch the SIM card frequently, they might oppose the solution, which might spark local resentment. Sometimes, no service is better than the 'ugly' service.

Interviewee 6 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
4	4	UAV as a relay node (backhaul) is considered more feasible than as the access technology. It is among the technology HAPS which has been standardised and allowed by Indonesian spectrum regulations since 2019. HAPS is High Altitude Platform Stations, such as UAV, that act as a backhaul relay node. The possibility of using it as a base station, as proposed in this solution, is still discussed by standardisation and regulatory bodies like 3GPP and ITU under the name of HIBS (HAPS for IMT Base Stations). The international mobile telecommunication association is finding the right bands for HIBS and is estimated to be decided by 2023. Hence, Indonesia would not allow UAV solution (as a base station) until the standard for HIBS is released in 2023. However, if all requirements are met, UAV can give benefits that the conventional site cannot, which is to have a way higher altitude. This higher altitude could allow a broader coverage by one node, hence could be more effective in providing the mobile network service coverage. Moreover, due to its flexibility, the UAV site can be easily relocated to a different point in need. For example, when a village is conducting an occasional event. More feasible as a temporary solution, such as in the event of forest fires, considering the cost and the operation complexity.	Higher OPEX and more complex operation due to the complexity of the UAV technology. Since this network model is significantly different from the existing mobile network technology, the knowledge and skill set of the existing operators' network personnel would not be sufficient to handle the sites. The personnel would need an additional qualification to maintain and operate this solution. Such as pilot certification, which is not among the common qualifications of a network engineer today. The Ministry of Transportation obliges anyone who operates drones to have a pilot certificate. More power needed to run the network. Much more network properties to take care of compared to the conventional solution such as large cell, such as the UAV control, powering mechanism, connectivity between the aircraft to the ground site, and so on.	A vendor to manufacture and commercialise this UAV solution. Specifically, the UAV transmitter needs to be weather-proof, light enough to be carried up with minimum power. The vehicle of the UAV also needs to consider the existing situation in the areas (topography, local activity, flights, national security, etc.). Airspace clearance. Many uncertainties need to be clarified first: - spectrum usage - data security - the safety of the UAV operation (to its surrounding people and the airspace activity) - UAV-based network resilience (to weather, for example).	The use of UAV tethered balloon could disturb the local activity in the surrounding areas. Suppose the UAV is installed in the residential neighbourhood. In that case, the cable may put the residents in danger unless it is protected adequately. If the UAV is operated by a company affiliated with foreign countries, like Loon is affiliated with the US' Google, it poses a threat to Indonesian national security. A foreign flag aircraft is counted as a foreign country territory that is difficult to control. Moreover, the data it captures may go to a foreign country, too. In the existing rural sites, operators employ some local site keeper to provide simple troubleshoot and maintenance for the site, such as for handling the electricity trip and cleaning the area. If the sites using UAV, the operator might not be able to do so since the troubleshoot and maintenance for UAV based network is not simple and unbearable by the local people's capacity.

Interviewee 6 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	2	The tax reduction is also feasible to be done considering a good formulation of the coverage obligation Kominfo released recently and the punitive mechanism design for the non-conformities of the coverage obligation that is almost done. However, to ensure its effectiveness, those design needs to be performed accordingly. SDPPI main objectives when setting the spectrum price is not to gain income but to ensure the spectrum is used by the right MNO that values the spectrum the most. When an MNO is eager to pay more, it indicates that the MNO values it the most and will utilise the spectrum as maximum as possible so that the price they pay will return by deploying more sites. The tax reduction, indeed, can be effective in helping the MNO to reinvest in rural areas, especially if supported by the coverage obligation in their operational licenses and the coverage obligation is evaluated effectively. The punitive mechanism for the non-conformities of coverage obligation is almost done, in which the MNOs might get a certain amount of fine if they fail to comply. Hence, the coverage obligation can be the way to ensure that MNOs use the tax savings from the regulatory tax for rural network deployment as the government expected. UAV as a relay node (backhaul) is considered more feasible than as the access technology. It is among the technology HAPS which has been standardised and allowed by Indonesian spectrum regulations since 2019. HAPS is High Altitude Platform Stations, such as UAV, that act as a backhaul relay node. The possibility of using it as a base station, as proposed in this solution, is still discussed by standardisation and regulatory bodies like 3GPP and ITU under the name of HIBS (HAPS for IMT Base Stations). The international mobile telecommunication association is finding the right bands for HIBS and is estimated to be decided by 2023. Hence, Indonesia would not allow UAV solution (as a base station) until the standard for HIBS is released in 2023. However, if all requirements are met, UAV can benefit that the conventional site cannot, which is to have a way higher altitude. This higher altitude could allow a broader coverage by one node, hence could be more effective in providing the mobile network service coverage. Moreover, due to its flexibility, the UAV site can be easily relocated to a different point in need. For example, when a village is conducting an occasional event. More feasible as a temporary solution, such as in the event of forest fires, considering the cost and the operation complexity.	Higher OPEX and more complex operation due to the complexity of the UAV technology. Since this network model is significantly different from the existing mobile network technology, the knowledge and skill set of the existing network personnel operators' have would not sufficient to handle the sites. The personnel would need an additional qualification to maintain and operate this solution. Such as pilot certification, which is not among the common qualifications of a network engineer today. The Ministry of Transportation obliges anyone who operates drones to have a pilot certificate. More power needed to run the network. Much more network properties to take care of compared to the conventional solution such as large cell, such as the UAV control, powering mechanism, connectivity between the aircraft to the ground site, and so on.	Assessment regarding the network planning to see whether this solution is more cost-efficient than the conventional large cell solution. If tax is going to be reduced, particularly of the spectrum BHP, USF and/or the telecommunication BHP, a major change in the existing business process is required. Currently, BAKTI is perceived as the main actor responsible for the rural network deployment and is subjected to certain target related to telecommunication service provision to rural areas in Indonesia. If the tax reduction is implemented, the burden for rural network development should not be on BAKTI anymore, BAKTI should be demanded less, and MNO should be demanded more build the network in rural areas. Considering that currently, BAKTI has already been responsible for covering thousands of villages in Indonesia by 2022. At least until this target is accomplished, tax reduction could not be applied. That is because BAKTI needs public funds to finance this target, and the public funds provided to BAKTI depends on the country income Kominfo generates (the sectoral tax). More importantly, this solution requires a major change in the mindset of the government outside Kominfo and a good new business process to ensure that the tax reduction benefits rural network development. For example, a mechanism to value the MNOs rural investment for calculating their tax reduction amount, an audit mechanism by an independent auditor to ensure that Kominfo reduces the tax for MNOs according to the law, and so on.	The use of UAV tethered balloon could disturb the local activity in the surrounding areas. Suppose the UAV is installed in the residential neighbourhood. In that case, the cable may put the residents in danger unless it is protected adequately. If the UAV is operated by a company affiliated with foreign countries, like Loon is affiliated with the US' Google, it poses a threat to Indonesian national security. A foreign flag aircraft is counted as a foreign country territory that is difficult to control. Moreover, the data it captures may go to a foreign country, too. In the existing rural sites, operators employ some local site keeper to provide simple troubleshoot and maintenance for the site, such as for handling the electricity trip and cleaning the area. If the sites using UAV, the operator might not be able to do so since the troubleshoot and maintenance for UAV based network is not simple and unbearable by the local people's capacity.

Unipa village

Interviewee 6 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	Femtocell network is feasible but can be less efficient for a village with a very sparsely distributed population, like Unipa. As seen, the population density is 1.5 people/km2, which means one cluster of residents can be very far apart. When it is too far and cannot be covered by one location of the femtocell node, a new or more femtocell node location needs to be established, and the additional cost might be higher than having one large cell. Having BAKTI as the pioneer in deploying network for this village is reasonable. Any villages that are not yet covered by mobile network signal today indicate that the village must be uneconomically feasible for the MNO. Hence it should be handled by the government (BAKTI). It would significantly lessen the MNO's burden to focus on sustaining the network, i.e., providing the service at an affordable price. BAKTI also limits the backhaul capacity only to a certain level. If the market grows and the capacity need is increased, it would be MNO's responsibility.		Assessment regarding the network planning to see whether this solution is more cost-efficient than the conventional large cell solution. Cooperation with an MNO.	More than one femtocell nodes might be needed in Unipa village could lead to a less cost-efficient solution than the large cell model

Interviewee 6 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	1	Femtocell network is feasible but can be less efficient for a village with a very sparsely distributed population, like Unipa. As seen, the population density is 1.5 people/km2, which means one cluster of residents can be very far apart. When it is too far and cannot be covered by one location of the femtocell node, a new femtocell node location needs to be established, and the additional cost might be higher than having one large cell. The tax reduction is also feasible to be done considering a good formulation of the coverage obligation Kominfo released recently and the punitive mechanism design for the non-conformities of the coverage obligation that is almost done. However, to ensure its effectiveness, those design needs to be performed accordingly. SDPPI main objectives when setting the spectrum price is not to gain income but to ensure the spectrum is used by the right MNO that values the spectrum the most. When an MNO is eager to pay more, it indicates that the MNO values it the most and will utilise the spectrum as maximum as possible so that the price they pay will return by deploying more sites. The tax reduction, indeed, can be effective in helping the MNO to reinvest in rural areas, especially if supported by the coverage obligation in their operational licenses and the coverage obligation is evaluated effectively. The punitive mechanism for the non-conformities of coverage obligation is almost done, in which the MNOs might get a certain amount of fine if they fail to comply. Hence, the coverage obligation can be the way to ensure that MNOs use the tax savings from the regulatory tax for rural network deployment as the government expected.	-	Assessment regarding the network planning to see whether this solution is more cost-efficient than the conventional large cell solution. If tax is going to be reduced, particularly of the spectrum BHP, USF and/or the telecommunication BHP, a major change in the existing business process is required. Currently, BAKTI is perceived as the main actor responsible for the rural network deployment and is subjected to certain target related to telecommunication service provision to rural areas in Indonesia. If the tax reduction is implemented, the burden for rural network development should not be on BAKTI anymore, BAKTI should be demanded less, and MNO should be demanded more build the network in rural areas. Considering that currently, BAKTI has already been responsible for covering thousands of villages in Indonesia by 2022. At least until this target is accomplished, tax reduction could not be applied. That is because BAKTI needs public funds to finance this target, and the public funds provided to BAKTI depends on the country income Kominfo generates (the sectoral tax). More importantly, this solution requires a major change in the mindset of the government outside Kominfo and a good new business process to ensure that the tax reduction benefits rural network development, i.e., the tax savings are used by MNOs to expand their network more on rural areas. For example, a mechanism to value the MNOs rural investment for calculating their tax reduction amount, an audit mechanism by an independent auditor to ensure that Kominfo reduces the tax for MNOs according to the law, etc.	More than one femtocell nodes might be needed in Unipa village could lead to a less cost-efficient solution than the large cell model. There is a risk that the reduction of tax does not promote rural network development by MNOs as expected, especially if the tax is reduced first, before the MNO cover the rural areas.

Interviewee 6 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	5	-	Inequality of the telecommunication service provided to this village and the rest of the country. At least the village residents need to have 2 SIM cards: 1 for VillageCell and 1 for the normal cellular network when they are outside the village. If they do not have dual-SIM phones, then changing the SIM cards are needed to be done frequently for those who often are outside the village.	Compliance to the existing spectrum regulation and telecommunication operation regulation	Local population are very sensitive to the equality of the telecommunication service in their area. If they perceive that the service is impractical due to the need for them to switch the SIM card frequently, they might oppose the solution, which might spark local resentment. Sometimes, no service is better than the 'ugly' service.

Interviewee 6 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
4	4	UAV as a relay node (backhaul) is considered more feasible than as the access technology. It is among the technology HAPS which has been standardised and allowed by Indonesian spectrum regulations since 2019. HAPS is High Altitude Platform Stations, such as UAV, that act as a backhaul relay node. The possibility of using it as a base station, as proposed in this solution, is still discussed by standardisation and regulatory bodies like 3GPP and ITU under the name of HIBS (HAPS for IMT Base Stations). The international mobile telecommunication association is finding the right bands for HIBS and is estimated to be decided by 2023. Hence, Indonesia would not allow UAV solution (as a base station) until the standard for HIBS is released in 2023. However, If all requirements are met, UAV can benefit that the conventional site cannot, which is to have a way higher altitude. This higher altitude could allow a broader coverage by one node, hence could be more effective in providing the mobile network service coverage. Moreover, due to its flexibility, the UAV site can be easily relocated to a different point in need. For example, when a village is conducting an occasional event. More feasible as a temporary solution, such as in the event of forest fires, considering the cost and the operation complexity.	Higher OPEX and more complex operation due to the complexity of the UAV technology. Since this network model is significantly different from the existing mobile network technology, the knowledge and skill set of the existing operators' network personnel would not be sufficient to handle the sites. The personnel would need an additional qualification to maintain and operate this solution. Such as pilot certification, which is not among the common qualifications of a network engineer today. The Ministry of Transportation obliges anyone who operates drones to have a pilot certificate More power needed to run the network. Much more network properties to take care of compared to the conventional solution such as large cell, such as the UAV control, powering mechanism, connectivity between the aircraft to the ground site, and so on.	A vendor to manufacture and commercialise this UAV solution. Specifically, the UAV transmitter needs to be weather-proof, light enough to be carried up with minimum power. The vehicle of the UAV also needs to consider the existing situation in the areas (topography, local activity, flights, national security, etc.). Airspace clearance. Many uncertainties need to be clarified first: - spectrum usage - data security - the safety of the UAV operation (to its surrounding people and the airspace activity) - UAV-based network resilience (to weather, for example)	The use of UAV tethered balloon could disturb the local activity in the surrounding areas. Suppose the UAV is installed in the residential neighbourhood. In that case, the cable may put the residents in danger unless it is protected adequately. If the UAV is operated by a company affiliated with foreign countries, like Loon is affiliated with the US' Google, it poses a threat to Indonesian national security. A foreign flag aircraft is counted as a foreign country territory that is difficult to control. Moreover, the data it captures may go to a foreign country, too. In the existing rural sites, operators employ some local site keeper to provide simple troubleshoot and maintenance for the site, such as for handling the electricity trip and cleaning the area. If the sites using UAV, the operator might not be able to do so since the troubleshoot and maintenance for UAV based network is not simple and unbearable by the local people's capacity.

Interviewee 6 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	2	UAV as a relay node (backhaul) is considered more feasible than as the access technology. It is among the technology HAPS which has been standardised and allowed by Indonesian spectrum regulations since 2019. HAPS is High Altitude Platform Stations, such as UAV, that act as a backhaul relay node. The possibility of using it as a base station, as proposed in this solution, is still discussed by standardisation and regulatory bodies like 3GPP and ITU under the name of HIBS (HAPS for IMT Base Stations). The international mobile telecommunication association is finding the right bands for HIBS and is estimated to be decided by 2023. Hence, Indonesia would not allow UAV solution (as a base station) until the standard for HIBS is released in 2023. However, if all requirements are met, UAV can benefit that the conventional site cannot, which is to have a way higher altitude. This higher altitude could allow a broader coverage by one node, hence could be more effective in providing the mobile network service coverage. Moreover, due to its flexibility, the UAV site can be easily relocated to a different point in need. For example, when a village is conducting an occasional event. More feasible as a temporary solution, such as in the event of forest fires, considering the cost and the operation complexity. The tax reduction is also feasible to be done considering a good formulation of the coverage obligation Kominfo released recently and the punitive mechanism design for the non-conformities of the coverage obligation that is almost done. However, to ensure its effectiveness, those design needs to be performed accordingly. SDPPI main objectives when setting the spectrum price is not to gain income but to ensure the spectrum is used by the right MNO that values the spectrum the most. When an MNO is eager to pay more, it indicates that the MNO values it the most and will utilise the spectrum as maximum as possible so that the price they pay will return by deploying more sites. The tax reduction, indeed, can be effective in helping the MNO to reinvest in rural areas, especially if supported by the coverage obligation in their operational licenses and the coverage obligation is evaluated effectively. The punitive mechanism for the non-conformities of coverage obligation is almost done, in which the MNOs might get a certain amount of fine if they fail to comply. Hence, the coverage obligation can be the way to ensure that MNOs use the tax savings from the regulatory tax for rural network deployment as the government expected.	Higher OPEX and more complex operation due to the complexity of the UAV technology. Since this network model is significantly different from the existing mobile network technology, the knowledge and skill set of the existing operators' network personnel would not be sufficient to handle the sites. The personnel would need an additional qualification to maintain and operate this solution. Such as pilot certification, which is not among the common qualifications of a network engineer today. The Ministry of Transportation obliges anyone who operates drones to have a pilot certificate. More power needed to run the network. Much more network properties to take care of compared to the conventional solution such as large cell, such as the UAV control, powering mechanism, connectivity between the aircraft to the ground site, and so on.	Assessment regarding the network planning to see whether this solution is more cost-efficient than the conventional large cell solution. If tax is going to be reduced, particularly of the spectrum BHP, USF and/or the telecommunication BHP, a major change in the existing business process is required. Currently, BAKTI is perceived as the main actor responsible for the rural network deployment and is subjected to certain target related to telecommunication service provision to rural areas in Indonesia. If the tax reduction is implemented, the burden for rural network development should not be on BAKTI anymore, BAKTI should be demanded less, and MNO should be demanded more build the network in rural areas. Considering that currently, BAKTI has already been responsible for covering thousands of villages in Indonesia by 2022. At least until this target is accomplished, tax reduction could not be applied. That is because BAKTI needs public funds to finance this target, and the public funds provided to BAKTI depends on the country income Kominfo generates (the sectoral tax). More importantly, this solution requires a major change in the mindset of the government outside Kominfo and a good new business process to ensure that the tax reduction benefits rural network development. For example, a mechanism to value the MNOs rural investment for calculating their tax reduction amount, an audit mechanism by an independent auditor to ensure that Kominfo reduces the tax for MNOs according to the law, and so on.	The use of UAV tethered balloon could disturb the local activity in the surrounding areas. Suppose the UAV is installed in the residential neighbourhood. In that case, the cable may put the residents in danger unless it is protected adequately. If the UAV is operated by a company affiliated with foreign countries, like Loon is affiliated with the US' Google, it poses a threat to Indonesian national security. A foreign flag aircraft is counted as a foreign country territory that is difficult to control. Moreover, the data it captures may go to a foreign country, too. In the existing rural sites, operators employ some local site keeper to provide simple troubleshoot and maintenance for the site, such as for handling the electricity trip and cleaning the area. If the sites using UAV, the operator might not be able to do so since the troubleshoot and maintenance for UAV based network is not simple and unbearable by the local people's capacity.

D.2.7 Interviewee 7

Date of interview	:	June 14th 2021
Interviewee name	:	-
Position	:	National Vice President of Fault Analytic and End-to-End Performance Indosat

Tampang Muda village

Interviewee 7 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	The feasibility of using solar panel depends on the reliability of the solar power source in Tampang Muda village. If the sunlight is predicted to be unreliable for a long time, then the site would need a bigger power capacity to prevent downtime. If the cost to accommodate this is high, it would be better to use a fuel electricity generator than solar power. VillageCell is currently not accommodated by the spectrum regulation. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient. Moreover, fossil-fueled electricity generator is considered more effective since it is more reliable than solar power. The MNO can predict when to visit the site for refuelling.	Initial CAPEX would be higher since there is a higher cost for a power system. Upskilling the power engineer in MNOs.	Higher CAPEX for solar power system. Amendment on the existing spectrum regulation to allow the use of MNO's spectrum by other party and the other party pays the usage fee to the MNO. When the MNO's spectrum is used, MNO's brand should not be used. Otherwise, the MNO has to operate the network to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected. More research on the usability of solar power for Indonesian mobile network in rural areas. Relaxing the QoS.	Solar panel is not commonly used as the power source for a mobile network in Indonesia, so MNOs are not yet familiar with the system. When it is disrupted or got an issue, it might take a longer time to repair it because the engineer is less capable of handling solar power and the solar power engineers are not many in Indonesia yet. Since the performance of solar power relies on the weather, it becomes less predictable. Unscheduled maintenance usually leads to a longer time to repair than having the maintenance scheduled.

Interviewee 7 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	4	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. There is no commercial use of a UAV-based mobile network until this date. Hence, it is not easy to see the feasibility of this solution. Suppose it is successfully manufactured according to the literature and fit in the Indonesian cellular business case. In that case, MNOs must be interested in trying too. The feasibility of using solar panel depends on the reliability of the solar power source in Tampang Muda village. If the sunlight is predicted to be unreliable for a long time, then the site would need a bigger power capacity to prevent downtime. If the cost to accommodate this is high, it would be better to use a fuel electricity generator than solar power.	Initial CAPEX would be higher since there is a higher cost for the power system. The network quality is lower due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link, instead of wireline. Higher OPEX, one of them is due to the use of battery for the UAV. Direct electricity source from PLN's grid is always more cost-efficient than any other power source. Higher CAPEX for the UAV, since it looks very sophisticated and intelligent.	Higher CAPEX for the solar power system. Technology readiness. Vendor to produce and commercialise the UAV. Moreover, the vendor's after-sales needs to be assuring.	Unsustainable or failed site economically that could lead to a loss for the MNO

Interviewee 7 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	2	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. The UAV was described to be able to steer itself for recharging and flying automatically. However, seeing that this technology is not yet available in the market, it is difficult to see whether this advanced technology is real and feasible. The feasibility of using solar panel depends on the reliability of the solar power source in Tampang Muda village. If the sunlight is predicted to be unreliable for a long time, then the site would need a bigger power capacity to prevent downtime. If the cost to accommodate this is high, it would be better to use a fuel electricity generator than solar power. In addition, fossil-fueled electricity generator is considered more effective since it is more reliable than solar power. The MNO can predict when to visit the site for refuelling.	Initial CAPEX would be higher since there is a higher cost for a power system. Upskilling the power engineer in MNOs. The network quality is lower due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link, instead of wireline. Higher OPEX, one of them is due to the use of battery for the UAV. Direct electricity source from PLN's grid is always more cost-efficient than any other power source. Higher CAPEX for the UAV, since it looks very sophisticated and intelligent.	Higher CAPEX for solar power system. Technology readiness. Vendor to produce and commercialise the UAV. Moreover, the vendor's after-sales needs to be assuring. More research on the usability of solar power for Indonesian mobile network in rural areas. Relaxing the QoS.	Unsustainable or failed site economically that could lead to a loss for the MNO. Solar panel is not commonly used as the power source for a mobile network in Indonesia, so MNOs are not yet familiar with the system. When it is disrupted or got an issue, it might take a longer time to repair it because the engineer is less capable of handling solar power and the solar power engineers are not many in Indonesia yet. Since the performance of solar power relies on the weather, it becomes less predictable. Unscheduled maintenance usually leads to a longer time to repair than having the maintenance scheduled.
4	1	Although it seems feasible, this solution does not provide an adequate telecommunication service. It would be better to focus only on basic services (voice call and SMS) and use satellite backhaul. The feasibility of using solar panel depends on the reliability of the solar power source in Tampang Muda village. If the sunlight is predicted to be unreliable for a long time, then the site would need a bigger power capacity in order to prevent downtime. If the cost to accommodate this is high, it would be better to use a fuel electricity generator than solar power.	Initial CAPEX would be higher since there is a higher cost for the power system.	Higher CAPEX for the solar power system.	-

Terusan village

Interviewee 7 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	Battery prediction model has been used in the existing network that informs when the battery would run out. But it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.	Femtocell has very small coverage, as small as Wi-Fi router, plug and play hence do not require backhaul because can directly connect to the internet.	Otherwise, the MNO has to operate the network to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected.	-
2	4	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. There is no commercial use of a UAV-based mobile network until this date. Hence, it is not easy to see the feasibility of this solution. Suppose it is successfully manufactured according to the literature and fit in the Indonesian cellular business case. In that case, MNOs must be interested in trying too.	Initial CAPEX would be higher since there is a higher cost for the power system. The network quality is lower due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link, instead of wireline. Higher OPEX, one of them is due to the use of battery for the UAV. Direct electricity source from PLN's grid is always more cost-efficient than any other power source. Higher CAPEX for the UAV, since it looks very sophisticated and intelligent.	Higher CAPEX for solar power system. Technology readiness. Vendor to produce and commercialise the UAV. Furthermore, the vendor's after-sales needs to be assuring.	Unsustainable or failed site economically that could lead to a loss for the MNO.

Interviewee 7 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	5	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. VillageCell is currently not accommodated by the spectrum regulation. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.		Amendment on the existing spectrum regulation to allow the use of MNO's spectrum by other party and the other party pays the usage fee to the MNO. When the MNO's spectrum is used, MNO's brand should not be used. Otherwise, the MNO has to operate the network to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected.	-
4	1	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.	Femtocell has very small coverage, as small as Wi-Fi router, plug and play hence do not require backhaul because can directly connect to the internet.	The MNO has to operate the network to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected.	-

Interviewee 7 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	2	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. The UAV was described to be able to steer itself for recharging and flying automatically. However, seeing that this technology is not yet available in the market, it is difficult to see whether this advanced technology is real and feasible.	The network quality is lower due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link, instead of wireline. Higher OPEX, one of them is due to the use of battery for the UAV. Direct electricity source from PLN's grid is always more cost-efficient than any other power source. Higher CAPEX for the UAV, since it looks very sophisticated and intelligent.	Technology readiness. Vendor to produce and commercialise the UAV. Moreover, the vendor's after-sales needs to be assuring. Relaxing the QoS.	Unsustainable or failed site economically that could lead to a loss for the MNO

Unipa village

Interviewee 7 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	3	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.	Femtocell has very small coverage, as small as Wi-Fi router, plug and play hence do not require backhaul because it can directly connect to the internet.	The MNO has to operate the network to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected.	-

Interviewee 7 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	4	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. There is no commercial use of a UAV-based mobile network until this date. Hence, it is not easy to see the feasibility of this solution. Suppose it is successfully manufactured according to the literature and fit in the Indonesian cellular business case. In that case, MNOs must be interested in trying too. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.	The network quality is lower due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link, instead of wireline. Higher OPEX, one of them is due to the use of battery for the UAV. Direct electricity source from PLN's grid is always more cost-efficient than any other power source. Higher CAPEX for the UAV, since it looks very sophisticated and intelligent.	Technology readiness. Vendor to produce and commercialise the UAV. Moreover, the vendor's after-sales needs to be assuring. The MNO has to operate the network to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected.	Unsustainable or failed site economically that could lead to a loss for the MNO.
3	5	Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. VillageCell is currently not accommodated by the spectrum regulation. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.		Amendment on the existing spectrum regulation to allow the use of MNO's spectrum by other party and the other party pays the usage fee to the MNO. When the MNO's spectrum is used, MNO's brand should not be used. Otherwise, the MNO has to operate the network to guard its brand image. If others manage it and fail to meet the QoS standard, the MNO's image will be affected.	-

Interviewee 7 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
4	1	The use of fibre optic is feasible only if there is the core that MNO can use. Also, the feasibility heavily affected by the location of the nearest MNO's network termination. The nearer it is from the Palapa Ring Timur's line, the more feasible the solution will be since the cost for connecting the Palapa Ring Timur's line and the MNO's network. Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.	Femtocell that I know have a very small coverage, as small as Wi-Fi router, plug and play hence do not require backhaul because can directly connect to the internet.	Connection from Palapa Ring network to the MNO's network	Unsustainable or failed site economically could lead to a loss for the MNO.

Interviewee 7 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	2	The use of fibre optic is feasible only if there is the core that MNO can use. Also, the feasibility heavily affected by the location of the nearest MNO's network termination. The nearer it is from the Palapa Ring Timur's line, the more feasible the solution will be since the cost for connecting the Palapa Ring Timur's line and the MNO's network. Battery prediction model has been used in the existing network that informs when the battery would run out. However, it does not inform when the battery needs to be replaced. Using the battery prediction model is feasible as long as the cost for using the system is reasonable. When innovation or idea is found by the MNO that is not yet realised or manufactured, the MNO could approach the available vendor to find out whether or not they can realise the idea. No MNO in Indonesia has an RnD department, and researching new technology is not of MNOs' interests. Therefore, MNOs rely on vendors for developing technology innovation. Nevertheless, vendors also rely on the MNOs who will employ vendor's products in their business. Many manufactured products of vendors failed in the market because the products did not fit in the MNOs business cases. The UAV was described to be able to steer itself for recharging and flying automatically. However, seeing that this technology is not yet available in the market, it is difficult to see whether this advanced technology is real and feasible. However, the solution's feasibility compared to the conventional large cell + satellite backhaul is doubtful. In planning and dimensioning the rural sites, Indosat always discusses with its vendors who understand the technology option more. Therefore, the design must be the most cost-efficient.	The network quality is lower due to the connection between the RRU in the aircraft and the RRU in the ground site is made via radio link, instead of wireline. Higher OPEX, one of them is due to the use of battery for the UAV. Direct electricity source from PLN's grid is always more cost-efficient than any other power source. Higher CAPEX for the UAV, since it looks very sophisticated and intelligent.	Connection from Palapa Ring network to the MNO's network. Technology readiness. Vendor to produce and commercialise the UAV. Moreover, the vendor's after-sales needs to be assuring. Relaxing the QoS.	Unsustainable or failed site economically that could lead to a loss for the MNO.

D.2.8 Interviewee 8

Date of interview	:	June 7th 2021
Interviewee name	:	Bimo Jago Prasetyo
Position	:	West Jabotabek Project Deployment Team Telkomsel

Tampang Muda village

Interviewee 8 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	4	The use of UAV seems to be unfeasible considering its operational challenges. It also seems inconvenient as a long term solution. Especially in the village with centred settlement areas, UAV can reduce the CAPEX since it does not require tower erection and big antennas installation, which would address the accessibility challenges in rural areas. However, due to more aspects of the network operation prone to network problems, such as the drone's issue, the power issue, and so on, technicians from the central office might need to visit the site more often, which lower the solution's effectiveness. The use of terrestrial wireless backhaul for this village is considered feasible since the LOS link from the village to the nearest existing site (either in Kuta Kakhang or Putih Doh village) can be made. Telkomsel also has some sites powered by solar panel, so solar power is technically feasible, and the power capacity depends on the solar panel and battery capacity.	There are four main components of a site: power, equipment, infrastructure and backhaul. Normally, the operator (either SRO/MNO) only needs to monitor the power and backhaul of all four types of components. Infrastructure (tower and other passive components) and equipment (active components) are relatively static that, once installed, do not require daily monitoring. With UAV, all four components require daily monitoring. Some of the UAV infrastructure and equipment (the UAV and the network devices in it) is mobile and could be affected by the daily weather. It gives a higher possibility that some engineers are required to visit the site. Hence, the complexity and cost of the operator's daily monitoring would be double.	UAV and the base station components that are weatherproof. Backhaul capacity in the nearest existing site for serving the Tampang Muda's site.	Higher overall TCO due to higher OPEX.
2	3	Local private network is also served by Telkomsel but not using the opensource system. The service is paid monthly with a fixed price for the local communication service to be rolled out by an MNO. Meanwhile, for the external communication service, it would be charged per use. The opensource system, such as OpenBTS and asterisks, gives a system security threat if it is interconnected to MNO's network. Therefore, an MNO cannot deliver VillageCell. Moreover, it may be effective for corporate users in rural areas, such as mining sites or plantation areas, because they are less sensitive to the services' price. Telkomsel also has some sites powered by solar panel, so solar power is technically feasible, and the power capacity depends on the solar panel and battery capacity.	If an MNO deploys it, the service cost would be not free and more expensive since one controller needs to be dedicated to one private network. The use of satellite as the backhaul for the VillageCell's VoIP service can result in a delayed communication.	The respondent has no idea regarding the requirement of the solution when BAKTI deploys it	The respondent has no idea regarding the solution's risk when it is deployed by BAKTI

Interviewee 8 - Tampang Muda village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	2	The use of UAV seems to be unfeasible considering its operational challenges. It also seems inconvenient as a long term solution. Especially in the village with centred settlement areas, UAV can reduce the CAPEX since it does not require tower erection and big antennas installation, which would address the accessibility challenges in rural areas. However, due to more aspects of the network operation prone to network problems, such as the drone's issue, the power issue, and so on, technicians from the central office might need to visit the site more often, which lower the solution's effectiveness. The use of terrestrial wireless backhaul for this village is considered feasible since the LOS link from the village to the nearest existing site (either in Kuta Kakhang or Putih Doh village) can be made. Telkomsel also has some sites powered by solar panel, so solar power is technically feasible, and the power capacity depends on the solar panel and battery capacity.	There are four main components of a site: power, equipment, infrastructure and backhaul. Normally, the operator (either SRO/MNO) only needs to monitor the power and backhaul of all four types of components. Infrastructure (tower and other passive components) and equipment (active components) are relatively static that, once installed, do not require daily monitoring. With UAV, all four components require daily monitoring. Some of the UAV infrastructure and equipment (the UAV and the network devices in it) is mobile and could be affected by the daily weather. It gives a higher possibility that some engineers are required to visit the site. Hence, the complexity and cost of the operator's daily monitoring would be double.	UAV and the base station components that are weatherproof. Backhaul capacity in the nearest existing site for serving the Tampang Muda's site.	Higher overall TCO due to higher OPEX.
4	1	Not feasible because it does not provide real-time communication and heavily depends on the weather. The delayed service is considered very inappropriate in this digital era. Telkomsel also has some sites powered by solar panel, so solar power is technically feasible, and the power capacity depends on the solar panel and battery capacity.	When the weather is bad and no boat trip is going to and from the village, the communication service would be down.	-	-

Terusan village

Interviewee 8 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
1	5	Local private network is also served by Telkomsel but not using the opensource system. The service is paid monthly with a fixed price for the local communication service to be rolled out by an MNO. Meanwhile, for the external communication service, it would be charged per use. The opensource system, such as OpenBTS and asterisks, gives a system security threat if it is interconnected to MNO's network. Therefore, an MNO cannot deliver VillageCell. Moreover, it may be effective for corporate users in rural areas, such as mining sites or plantation areas, because they are less sensitive to the services' price. To use the existing fibre optic line as the backhaul is feasible. However, it still needs steps to do before the line can be used, such as creating a termination point near the site's location.	If an MNO deploys it, the service cost would be not free and more expensive since one controller needs to be dedicated to one private network. The use of satellite as the backhaul for the VillageCell's VoIP service can result in a delayed communication.	The respondent has no idea regarding the requirement of the solution when BAKTI deploys it	The respondent has no idea regarding the solution's risk when it is deployed by BAKTI

Interviewee 8 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
2	3	Using femtocell is also considered feasible since Telkomsel has been used femtocell in many indoor sites. The femtocell's capacity depends on the backhaul capacity. The femtocell device the Telkomsel uses to connect to backhaul via ethernet cable; the backhaul is the internet, which directly links it to its RNC or BSC. Finding this product must be easy in the market. Femtocell also plugs and plays. Some femtocell products that are used by Telkomsel specifically only allow for CS call and SMS service. It can significantly reduce the cost, but the coverage area will be much smaller than the large cell. Femtocell products that can also serve broadband or data service are highly likely to be available too in the market. If not available and many femtocells roll out in rural planned to be carried out, the MNOs or BAKTI can request the existing vendor to create the desired femtocell. It would be easy. The battery performance prediction system has also been used in the existing network. Although it is not the same as the proposed solution, the one that is available and used today is sufficient to inform the battery performance and predict when the batteries need to change. However, the use of terrestrial wireless backhaul for this solution might be not feasible since LOS link from Terusan village to the nearest existing site in Tanjung Belit village. There are some mountains between the villages, so some relay node should be established. If there is no potential users in the location of the relay nodes, covering the Terusan village would not be feasible for MNO since the CAPEX and OPEX spent for the relay nodes are not going to be returned. Moreover, establishing a site on a location where there is no one nearby is operationally difficult as no residents can be requested to help to maintain the site, and the site would be difficult to access too. However, terrestrial backhaul might be less effective than using satellite due to the low number of users and the relay nodes needed. The use of terrestrial backhaul might be less effective than satellite due to the low number of users and the relay nodes needed.	The service radius may be less than 2 km, maybe less than 100 m, due to the use of femtocells. Relay nodes are needed for backhaul due to the obstacles between Terusan and Tanjung Belit village. When the relay nodes get a network problem, it would be difficult to remotely analysed due to no base station's NMS for that site. Usually, network engineers require data from three NMS to analyse the network problem: NMS of power system, NMS of backhaul system and NMS of radio base station system. Relay nodes only have power and backhaul systems. Installing the radio base station system on the relay nodes are wasteful since no users around the relay nodes.	The femtocell devices with the desired features. The location for relay nodes on the villages between Terusan and Tanjung Belit that can also generate revenues.	The revenue generated cannot compensate the CAPEX and OPEX for Terusan village due to the need for establishing the relay nodes

Interviewee 8 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	1	Using femtocell is also considered feasible since Telkomsel has been used femtocell in many indoor sites. The femtocell's capacity depends on the backhaul capacity. The femtocell device the Telkomsel uses to connect to backhaul via ethernet cable; the backhaul is the internet, which directly links it to its RNC or BSC. Finding this product must be easy in the market. Femtocell also plugs and play. Some femtocell products that are used by Telkomsel specifically only allow for CS call and SMS service. Femtocells can significantly reduce the cost, but the coverage area will be much smaller than the large cell. Femtocell products that can also serve broadband or data service are highly likely to be available too in the market. If not available and many femtocells roll out in rural planned to be carried out, the MNOs or BAKTI can request the existing vendor to create the desired femtocell. It would be easy. The battery performance prediction system has also been used in the existing network. Although it is not exactly the same as the proposed solution, the one that is available and used today is sufficient to inform the battery performance and predict when the batteries need to change. However, the use of terrestrial wireless backhaul for this solution might be not feasible since LOS link from Terusan village to the nearest existing site in Tanjung Belit village. There are some mountains between the villages, so some relay node should be established. If there is no potential users in the location of the relay nodes, covering the Terusan village would not be feasible for MNO since the CAPEX and OPEX spent for the relay nodes are not going to be returned.	The service radius may be less than 2 km, maybe less than 100 m, due to the use of femtocells. Relay nodes are needed for backhaul due to the obstacles between Terusan and Tanjung Belit village. When the relay nodes get a network problem, it would be difficult to remotely analysed due to no base station's NMS for that site. Usually, network engineers require data from three NMS to analyse the network problem: NMS of power system, NMS of backhaul system and NMS of radio base station system. Relay nodes only have power and backhaul systems. Installing the radio base station system on the relay nodes are wasteful since no users around the relay nodes.	The femtocell devices with the desired features. The location for relay nodes on the villages between Terusan and Tanjung Belit that can also generate revenues	The revenue generated cannot compensate the CAPEX and OPEX for Terusan village due to the need for establishing the relay nodes

Interviewee 8 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
4	4	The use of UAV seems to be unfeasible considering its operational challenges. It also seems inconvenient as a long term solution. Especially in the village with centred settlement areas, UAV can reduce the CAPEX since it does not require tower erection and big antennas installation, which would address the accessibility challenges in rural areas. However, due to more aspects of the network operation prone to network problems, such as the drone's issue, the power issue, and so on, technicians from the central office might need to visit the site more often, which lower the solution's effectiveness. The battery performance prediction system has also been used in the existing network. Although it is not exactly the same as the proposed solution, the one that is available and used today is sufficient to inform the battery performance and to predict when the batteries need to change. However, the use of terrestrial wireless backhaul for this solution might be not feasible since LOS link from Terusan village to the nearest existing site in Tanjung Belit village. There are some mountains between the villages, so some relay node should be established. If there is no potential users in the location of the relay nodes, covering the Terusan village would not be feasible for MNO since the CAPEX and OPEX spent for the relay nodes are not going to be returned. The use of terrestrial backhaul might be less effective than satellite due to the low number of users and the relay nodes needed.	There are four main components of a site: power, equipment, infrastructure and backhaul. Normally, the operator (either SRO/MNO) only needs to monitor the power and backhaul of all four types of components. Infrastructure (tower and other passive components) and equipment (active components) are relatively static that, once installed, do not require daily monitoring. With UAV, all four components require daily monitoring. Some of the UAV infrastructure and equipment (the UAV and the network devices in it) is mobile and could be affected by the daily weather. It gives a higher possibility that some engineers are required to visit the site. Hence, the complexity and cost of the operator's daily monitoring would be double. Relay nodes are needed for backhaul due to the obstacles between Terusan and Tanjung Belit village. When the relay nodes get a network problem, it would be difficult to remotely analysed due to no base station's NMS for that site. Usually, network engineers require data from three NMS to analyse the network problem: NMS of power system, NMS of backhaul system and NMS of radio base station system. Relay nodes only have power and backhaul systems. Installing the radio base station system on the relay nodes are wasteful since no users around the relay nodes.	UAV and the base station components that are weatherproof. The location for relay nodes on the villages between Terusan and Tanjung Belit that can also generate revenues.	Higher overall TCO due to higher OPEX. The revenue generated cannot compensate the CAPEX and OPEX for Terusan village due to the need for establishing the relay nodes.

Interviewee 8 - Terusan village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	2	The use of UAV seems to be unfeasible considering its operational challenges. It also seems inconvenient as a long term solution. Especially in the village with centred settlement areas, UAV can reduce the CAPEX since it does not require tower erection and big antennas installation, which would address the accessibility challenges in rural areas. However, due to more aspects of the network operation prone to network problems, such as the drone's issue, the power issue, and so on, technicians from the central office might need to visit the site more often, which lower the solution's effectiveness. The battery performance prediction system has also been used in the existing network. Although it is not exactly the same as the proposed solution, the one that is available and used today is sufficient to inform the battery performance and to predict when the batteries need to change. However, the use of terrestrial wireless backhaul for this solution might be not feasible since LOS link from Terusan village to the nearest existing site in Tanjung Belit village. There are some mountains between the villages, so some relay node should be established. If there is no potential users in the location of the relay nodes, covering the Terusan village would not be feasible for MNO since the CAPEX and OPEX spent for the relay nodes are not going to be returned. The use of terrestrial backhaul might be less effective than satellite due to the low number of users and the relay nodes needed.	There are four main components of a site: power, equipment, infrastructure and backhaul. Normally, the operator (either SRO/MNO) only needs to monitor the power and backhaul of all four types of components. Infrastructure (tower and other passive components) and equipment (active components) are relatively static that once installed, do not require daily monitoring. With UAV, all four components require daily monitoring. Some of the UAV infrastructure and equipment (the UAV and the network devices in it) is mobile and could be affected by the daily weather. It gives a higher possibility that some engineers are required to visit the site. Hence, the complexity and cost of the operator's daily monitoring would be double. Relay nodes are needed for backhaul due to the obstacles between Terusan and Tanjung Belit village. When the relay nodes get a network problem, it would be difficult to remotely analysed due to no base station's NMS for that site. Usually, network engineers require data from three NMS to analyse the network problem: NMS of power system, NMS of backhaul system and NMS of radio base station system. Relay nodes only have power and backhaul systems. Installing the radio base station system on the relay nodes are wasteful since no users around the relay nodes.	UAV and the base station components that are weatherproof. The location for relay nodes on the villages between Terusan and Tanjung Belit that can also generate revenues.	Higher overall TCO due to higher OPEX. The revenue generated cannot compensate the CAPEX and OPEX for Terusan village due to the need for establishing the relay nodes.

Unipa village

Interviewee 8 - Unipa village

Rank	Opt	Feasibility	Consequences	Requirements	Risks
1	3	To use the existing fibre optic line as the backhaul is feasible. However, it still needs steps to do before the line can be used, such as creating a termination point near the site's location. Using femtocell is also considered feasible since Telkomsel has been used femtocell in many indoor sites. The femtocell's capacity depends on the backhaul capacity. The femtocell device the Telkomsel uses to connect to backhaul via ethernet cable; the backhaul is the internet, which directly links it to its RNC or BSC. If the backhaul is optic, it is also possible to use femtocell devices with an optic interface. Finding this product must be easy in the market. Femtocell also plugs and play. It can significantly reduce the cost, but the coverage area will be much smaller than the large cell. Some femtocell products used by Telkomsel specifically only allow for CS call and SMS service. However, femtocell products that can also serve broadband or data service are highly likely to be available too in the market. If not available and many femtocells roll out in rural planned to be carried out, the MNOs or BAKTI can request the existing vendor to create the desired femtocell. It would be easy. The battery performance prediction system has also been used in the existing network. Although it is not exactly the same as the proposed solution, the one that is available and used today is sufficient to inform the battery performance and to predict when the batteries need to change.	The service radius may be less than 2 km, maybe less than 100 m. Similar to the Wi-Fi modem.	If there is no termination point in the village, to use the fibre optic line, a new line needs to be pulled from the nearest termination point that might be far from Unipa village. The femtocell devices with the desired features.	
2	1	To use the existing fibre optic line as the backhaul is feasible. However, it still needs steps to do before the line can be used, such as creating a termination point near the site's location. Using femtocell is also considered feasible since Telkomsel has been used femtocell in many indoor sites. It can significantly reduce the cost, but the coverage area will be much smaller than the large cell. The femtocell's capacity depends on the backhaul capacity. The femtocell device the Telkomsel uses to connect to backhaul via ethernet cable; the backhaul is the internet, which directly links it to its RNC or BSC. If the backhaul is optic, it is also possible to use femtocell devices with an optic interface. Finding this product must be easy in the market. Femtocell also plugs and play. Some femtocell products that are used by Telkomsel specifically only allow for CS call and SMS service. However, femtocell products that can also serve broadband or data service are highly likely to be available too in the market. If not available and many femtocells roll out in rural planned to be carried out, the MNOs or BAKTI can request the existing vendor to create the desired femtocell. It would be easy. The battery performance prediction system has also been used in the existing network. Although it is not exactly the same as the proposed solution, the one that is available and used today is sufficient to inform the battery performance and to predict when the batteries need to change.	The service radius may be less than 2 km, maybe less than 100 m. Similar to the Wi-Fi modem. Initial CAPEX would be higher since there is a higher cost for the power system.	If there is no termination point in the village, to use the fibre optic line, a new line needs to be pulled from the nearest termination point that might be far from Unipa village. The femtocell devices with the desired features. Higher CAPEX for solar power system.	-

Interviewee 8 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
3	5	Local private network is also served by Telkomsel but not using the opensource system. The service is paid monthly with a fixed price for the local communication service to be rolled out by an MNO. Meanwhile, for the external communication service, it would be charged per use. The opensource system, such as OpenBTS and asterisks, gives a system security threat if it is interconnected to MNO's network. Therefore, an MNO cannot deliver VillageCell. Moreover, it may be effective for corporate users in rural areas, such as mining sites or plantation areas, because they are less sensitive to the services' price. To use the existing fibre optic line as the backhaul is feasible. However, it still needs steps to do before the line can be used, such as creating a termination point near the site's location.	If an MNO deploys it, the service cost would be not free and more expensive since one controller needs to be dedicated to one private network.	The respondent has no idea regarding the requirement of the solution when it is deployed by BAKTI	The respondent has no idea regarding the solution's risk when it is deployed by BAKTI
4	4	The use of UAV seems to be unfeasible considering its operational challenges. It also seems inconvenient as a long term solution. Especially in the village with centred settlement areas, UAV can reduce the CAPEX since it does not require tower erection and big antennas installation, which would address the accessibility challenges in rural areas. However, due to more aspects of the network operation prone to network problems, such as the drone's issue, the power issue, and so on, technicians from the central office might need to visit the site more often, which lower the solution's effectiveness. To use the existing fibre optic line as the backhaul is feasible. However, it still needs steps to do before the line can be used, such as creating a termination point near the site's location.	There are four main components of a site: power, equipment, infrastructure and backhaul. Normally, the operator (either SRO/MNO) only needs to monitor the power and backhaul of all four types of components. Infrastructure (tower and other passive components) and equipment (active components) are relatively static that once installed, do not require daily monitoring. With UAV, all four components require daily monitoring. Some of the UAV infrastructure and equipment (the UAV and the network devices in it) is mobile and could be affected by the daily weather. It gives a higher possibility that some engineers are required to visit the site. Hence, the complexity and cost of the operator's daily monitoring would be double.	UAV and the base station components that are weatherproof.	Higher overall TCO due to higher OPEX.

Interviewee 8 - Unipa village					
Rank	**Opt**	**Feasibility**	**Consequences**	**Requirements**	**Risks**
5	2	The use of UAV seems to be unfeasible considering its operational challenges. It also seems inconvenient as a long term solution. Especially in the village with centred settlement areas, UAV can reduce the CAPEX since it does not require tower erection and big antennas installation, which would address the accessibility challenges in rural areas. However, due to more aspects of the network operation prone to network problems, such as the drone's issue, the power issue, and so on, technicians from the central office might need to visit the site more often, which lower the solution's effectiveness. To use the existing fibre optic line as the backhaul is feasible. However, it still needs steps to do before the line can be used, such as creating a termination point near the site's location.	There are four main components of a site: power, equipment, infrastructure and backhaul. Normally, the operator (either SRO/MNO) only needs to monitor the power and backhaul of all four types of components. Infrastructure (tower and other passive components) and equipment (active components) are relatively static that once installed, do not require daily monitoring. With UAV, all four components require daily monitoring. Some of the UAV infrastructure and equipment (the UAV and the network devices in it) is mobile and could be affected by the daily weather. It gives a higher possibility that some engineers are required to visit the site. Hence, the complexity and cost of the operator's daily monitoring would be double.	UAV and the base station components that are weatherproof.	Higher overall TCO due to higher OPEX.