COOPERATIVE NETWORKS:
THE MOBILE TETHERING GAME

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Master of Science Thesis

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Abstract

The thesis aims at extending the capabilities of devices and enabling cooperation, i.e., data connection sharing, among users who may or may not necessarily be related to or know each other. To achieve this objective as well as to validate the results of our theoretical analysis, we developed a smart-phone application for data connection sharing. By means of data connection sharing, users may influence the pricing schemes of mobile network operators, increase spectrum utilization and build their own cooperative network.

We define the mobile tethering game and investigate what makes the cooperation work and what are the economic requirements for building a cooperative network. The mobile tethering game may pave the way for a new business model where users not only get Internet connection service but also sell it in a mobile fashion.

Using the results of the conjoint analysis integrated with the game theoretic model and the smart-phone application, the thesis will present a clear picture as to the interactions among players of the mobile tethering game and the influential preference factors. We are interested in figuring out whether people might be willing to share their connection for incentives (money or virtual currency) or whether they are just expecting to receive the same treatment (service) in a future interaction.

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Preface

This document is a part of my Master of Science graduation work. The idea of doing my thesis on this subject came after a discussion with my supervisors Ertan Onur and Yunus Durmus and after adapting it to TNO requirements and involvement of Miodrag Djurica. It was a broad and bold idea and hopefully will be applied in a near collaborative future.

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Special thanks to my parents for their sacrifice, to my fiancee and to my friends. Without them I would not be the person I am.

"If we knew what it was we were doing, it would not be called research, would it?"

— *Albert Einstein (1879 - 1955)*

Chapter 1

Introduction

Even though cooperation can be observed in nature, in many animals, the human being is the only species in which extensive cooperation has been observed, among large numbers of genetically unrelated individuals. Both evolutionary and rational choice theorists have tried to explain it. Besides family members providing for one another, people give to charity, volunteer for public service, support each other and there are many other examples of cooperation in real life.

Starting with the question of why people share their resources, this thesis focuses on a more specific problem and aims to find out why and in what conditions people share their mobile data connection.

Sharing satisfies our need to be included into society and is a basic unit of socializing. Humans are social beings so sharing represents the foundation of who we are, and in this way we maintain and grow relationships. Other reasons for sharing might be reciprocal altruism or financial incentives but, in general, this behavior depends on personalities. Each individual is defined by their emotional motivations, desired presentation of themselves or value of sharing in their life.

Through cooperation of individuals, a cooperative network can be achieved and it is expected that this phenomenon will be growing in numerous directions. We envisage a social and economic system driven by network technologies that enable sharing in ways and on a scale never possible before.

Scenario: *Dan is a Romanian tourist visiting The Netherlands. He is in Delft and he would like to find out the history of the place and the most important highlights of the city. He does not have a tourist guide of Delft and he is looking now for an Internet connection in order to look up the details. Unfortunately there are no free Wi-Fi networks in the area and he is not willing to pay for his roaming data connection which he considers to be too expensive. Wilfred who is Dutch may share his data connection using his mobile phone tethering application. What might be* *his motivation for sharing? Is he a friend of Dan or does he just want money in exchange of his service? How can they find each other?...*

The thesis proposes to ease the above scenario by maximizing the potential of current applications available and by exploiting wireless resources on mobile devices. We base our work on the existing need of mobile users for innovative services that enable social cooperation. Mobile users can choose to share their resources, such as their mobile data connection and mobile services should enable the scenario. Social sharing of resources in mobile environments can be beneficial in many applications and our scenario is just one of them. Further chapters will provide more examples on the existing domains that take advantage and form a cooperative network.

With the growing need to be online anytime anywhere, the current research activities will hopefully contribute to the realization of a social sharing service. Our research could pave the way to the next frontier of social networking, i.e., dynamic community-oriented use of available resources in mobile environments, by fully exploiting the wide set of available resources generated by the ubiquitous presence of portable wireless devices.

Most of the latest mobile devices have a feature called *tethering* which enables them to carry out tasks beyond legacy services such as telephony, email and web browsing. Via tethering, a mobile device may act as a Wi-Fi hot-spot and provide Internet access to other devices by sharing its own (3G/4G) data connection. The mobile devices connect to a mobile data network, and act as a Wi-Fi access point for the nearby devices. Wireless Internet coverage can be significantly increased through mobile tethering.

Some of the mobile subscribers may not have a data connection option due to coverage issues or they consider the prices too high. However, they might still need Internet access, for example, in an emergency situation or when they roam abroad. At present, Wi-Fi access coverage is not sufficient, and most of the hot-spots are not free, but a user who needs temporary Internet connection may obtain this service from other subscribers. This strategic situation may also be reciprocal. Mobile users having data connection subscriptions with different pricing schemes may help each other flatten the pricing of data connectivity provided by different mobile network operators.

This thesis focuses on sharing the mobile data connection and what motivates people to use this service in particular. We aim at extending the capabilities of devices and enabling cooperation i.e., data connection sharing among users who may or may not necessarily be related or know each other, based on random encounters. We do not only exploit available resources but the intrinsic mobility of devices. To achieve this objective as well as to validate the results of our theoretical analysis, we developed a smart-phone application for data connection sharing. By means of data connection sharing, users may influence the pricing schemes of mobile network operators, increase spectrum utilization and build their own cooperative network.

1-1 Research challenges

There are a series of challenging issues such as the opportunistic collaboration of users and devices for a limited and transient interval of time, prediction of resource mobility, non-utilization degree, users' sharing attitude, and incentives for resource sharing.

As a main research challenge, we will study whether cooperation may evolve without any external cooperation enforcement mechanisms, and analyze how it would evolve in an open environment. Cooperation for the mobile tethering game may evolve following some basic rules that exist in *nature*. These rules assume that individuals cooperate if they are relatives of each other (kin selection) or if there is a possibility of future interaction and altruistic reciprocity. Cooperation may also emerge among individuals, based on reputation. An individual helps another person if that person has a good reputation. The thesis will analyze all the possible scenarios and which of the above mechanism can indeed improve capabilities of tethering and can change users interactions.

Why should a user cooperate and share the *paid* data connection and why should he allow others to exploit his private connection?

We will address some further questions such as what makes the cooperation work, and what are the economic implications for both mobile operators and subscribers. We are interested in figuring out whether people might be willing to share their connection for incentives (money or virtual currency) or whether they are just expecting to receive the same treatment (service) in a future interaction.

Even though applications that enable tethering do exist, they do no yet offer the opportunity to connect and create a network of users that cooperate. Even though they might be willing to share their resources, we need to investigate if and how this can be possible and how users that are looking for such a mobile service can get access to it.

1-2 Methodology

In order to answer these questions, we will further proceed with a series of steps in order to have a better understanding of the situation and offer the best answers.

We will first employ game theory because it is a central method to understanding human behavior and studying strategic decision making. We use game theory because it is appropriate for our cooperative goal and we will analyze the strategic human decisions of data connection sharing. We define the mobile tethering game where the players have two strategies: cooperate (share) or defect (not share). Then, we investigate what the user's payoffs may be and the dependency of the payoffs on the user's preferences.

Acting as a mobile hot-spot and enabling mobile tethering for data connection sharing is a strategic situation. The rational players of the mobile tethering game are the connection provider and the consumer adopting the best response strategy. The connection provider may choose to cooperate and share its connection or to defect and hence not share. The consumer may connect to cooperate, or reject to defect. Each combination of actions from the strategy profile produces an outcome with a certain payoff. If the provider decides to share his connection, it might reduce his bandwidth and deplete the battery. The cooperator provides a benefit to the other player at some cost, while defectors attempt to exploit the common resources. This leads to a classic conflict of interest between the individuals and the community performance - and hence the dilemma.

In the mobile tethering game, defection might seem to be the dominant strategy at first sight or at least as long as there are limited resources to be shared. But this premise needs to be confirmed and justify if indeed this is a dilemma and people naturally tend to defect. If this is the case, then external enforcement mechanisms such as incentives may enable cooperation. The mobile tethering game may pave the way for a new business model where users not only get Internet connection service but also sell it in a mobile form.

Considering only the external incentives and disregarding the other influential factors, impacting the payoffs such as security and quality of service (QoS) will be misleading. There are many cost factors such as energy consumption, QoS or security, or benefit factors such as reduced fees. Our objective in this work is to identify those factors, quantize the costs and benefits based on generic use cases and construct the payoff matrix of the mobile tethering game.

The generic notion of costs can be applied to bandwidth, energy or subscription costs. Bandwidth reduction can be perceived as a degradation of the device performance and data connection. Sharing the bandwidth with multiple devices and their simultaneous usage also produces an impact. We can analyze the degradation per use, per traffic type or traffic size. Energy consumption is a device- and traffic-dependent phenomenon, whereas the monthly subscription fees for data connection vary per use and per operator. After defining the game and performing tests on devices regarding the impact of the costs, we will move on to construct the payoff function. We will consider several benefits (money, reputation, virtual currency) and determine under which circumstances cooperation might evolve without requiring external enforcement.

Because in real life people are not actually as rational as game theory assumes, or may not always base their actions on self-interests, our previous game theoretical analysis needs the help of another method. Players do not always play the dominant-strategy equilibrium, but often play the cooperative strategy pair. Therefore a questionnaire is used in order to determine people's reasoning regarding tethering and their behavior in different scenarios.

To study the mobile tethering game, we first need to determine the factors that affect the payoffs of the game, along with their significance. The questionnaire is also devised to collect the personal preference relations among the influential factors. With the payoff matrix, we can then find out the exact type and model of the game. Furthermore, considering the payoff values in the game, the explanations of the evolution of cooperation should be incorporated to validate whether natural cooperation may evolve among users. Even if cooperation does not turn out to emerge naturally, different schemes using currency exchange may be implemented.

The purpose of the questionnaire is to investigate whether and under which circumstances people are willing to use the mobile tethering service. Using the questionnaire, we will determine the preferential significance of the factors impacting the payoffs, which rule of natural cooperation is more appealing to human behavior, and even predict the potential use of a smart-phone application.

We used conjoint analysis to investigate how people take decisions and what their hidden rules are to balance the trade-offs between the values they place on different features. This is technically performed by defining the constituent parameters and testing each of the attributes in the context of the others. By understanding precisely their decision and what they value, we can further use statistical analysis to determine the significance of each factor. Regression analysis then enables us to devise mathematical models to estimate the consumer behavior.

Finally, an android application is developed in order to add value to the existing tethering capabilities. Previous results, conclusions on the game theoretical analysis and the questionnaire will be used in the development of the application. The purpose of this application is to allow building a cooperation network of users that not just tether their data connection with own devices, but interact with other unknown users.

We also test and compare the parameters of the developed application with the ones determined for the device built in application. We are not only looking to add value to the current services, but to keep the usage within normal parameters and maybe in the future even to manage and control the resource consumption and limitations. The results show that there is need for further work in the process of creating a perfect application.

1-3 Contributions and further work

In this thesis we define and analyze the mobile tethering game and investigate what makes the cooperation work and what the economic requirements are for building a cooperative network.

We extend this game theoretical approach with a questionnaire aimed to bring complementary information on the human behavior and the decision making process. We determine and analyze all the parameters that influence tethering and people's choice.

After an analysis of current applications that enable tethering, we try to improve and develop an android application in order to encourage data connection sharing among users. The application can also confirm real behavior of users and test if the assumptions made in the game theoretical approach and the results of the questionnaire are correct.

Using the results of the conjoint analysis integrated with the game theoretic model and the smart-phone application, we will present a clear picture of the interactions among players of the mobile tethering game and the influential preference factors.

Mobile devices that either share or use resources can benefit significantly from the thesis research. We propose a series of actions required in order to enhance the performance of tethering and to build a cooperative network. We also suggest scenarios that will favor users to become willing to share their data connection or use someone else's when in need. After investigating all possible scenarios, models and mechanism, we can state in what conditions the application can work, if a cooperative network can be achieved and what further steps need to be taken in consideration.

Further work needs to be performed on the application development and published in order to test it on the market. Statistics can be gathered, and afterwards compared with the questionnaire participants' answers and thus validate it. Some further improvements can be added, for example allowing communication between peers of the cooperative network. This will improve the experience and the negotiation scheme. As a conclusion of the questionnaire results, multiple profiles can be implemented in order to differentiate familiar and unknown users and permit different access control.

As further possible development, the research can be applied to other cooperative services (i.e. cooperative web browsing for mobile devices [5]). Assuming we can share processing power or memory instead of our data connection, the results of the thesis may be valuable for mobile cloud computing.

1-4 Outline of the work

The thesis will be divided in the following chapters. Chapter 2 represents a literature survey of the existing work on cooperation and data sharing and gives examples of existing cooperative services. Chapter 3 presents tethering and the state of the art regarding applications for sharing the data connection. Chapter 4 introduces game theory, explains why and how it can be applied. The useful principles and models are briefly presented and applied to the tethering game. Chapter 5 provides the tools for analyzing the parameters required for our game and describes conjoint analysis as a main tool for the questionnaire. Chapter 6 provides actual results of a designed application and, finally, chapter 7 concludes with a clear picture of the aggregated approaches.

Chapter 2

Literature survey

2-1 Cooperation

The literature on this topic is extensive and there is a lot of research that tried and still tries to analyze the human behavior and cooperation in its complexity [6] [7] [8] [9]. Many experiments have been performed and a series of models and mechanism have been proposed by people from different fields. Economists, biologists, social and behavioral scientists have used different approaches to explain cooperation among humans and each discipline has different answers. A branch of sociology, socialization theory, and more specifically, the theory of internalization of norms, has also tried to solve the problem.

It has been tried to converge these ideas [10] combining the strengths of the classical, evolutionary, and behavioral fields. Economic concepts of rational action and material reward can be used with the biological Darwinian competition and social norms to model interaction between self-interested and altruistic behavior.

Whether it's skills, resources, goods or services, people do cooperate and share all over the world building a collaborative hub [11]. It's not just physical goods that can be shared, swapped, and bartered. People with similar interests group together to share and exchange assets and resources for free or in exchange of services or money.

Some examples of cooperative sharing are given below:

- Skill sharing (TradeSchool, Skillshare, Skilio, WeTeachMe): community of learners, teachers and students driven by common interests and by the passion to share real-world skills.
- Parking spots sharing (ParkAtMyHouse, ParkCirca, Park On My Drive): private car parking areas and garages to rent or to share all over the world

- Neighborhood Support (WeCommune, Share Some Sugar, Bright Neighbor, Streetbank, OhSoWe, ToolzDo): helps finding someone in the neighborhood who is willing to lend or rent something needed.
- Car Sharing (Whipcar, RelayRides, Drivemycar Rentals, Getaround, Tamyca, Buzzcar, Nachbarschaftsauto, autonetzer, SnappCar): sharing or renting cars from real people.
- Ride sharing (Zimride, Nuride, Liftshare, Jayride, goCarShare, Carpooling, Caronetas, DuckSeat, RewardRide, Avego, Amovens, Tickengo): connect people across 40 countries so they can share their rides.
- Peer-to-Peer Travel (CouchSurfing, Airbnb, Roomorama, One Fine Stay, Bed And Fed, 9flats, iStopover): million of connections (5.6 million connections for Couch Surfing), whether people sharing a couch, a coffee, or simply local knowledge.

Experimental evidence on [7], e.g., prisoner's dilemma, ultimatum games, snowdrift games, gift exchange games, and public good games, shows that many people are not only trying to maximize their own material payoffs, but they are also concerned about social aspects, fairness, and the desire to reciprocate. Many people are strongly motivated by other-regarding preferences not only self-interest and that concerns for fairness and reciprocity cannot be ignored in social interactions. If all participants follow the self-interested logic, however, cooperation will fail.

One explanation for why people cooperate implies reciprocal altruism as a mechanism [8] is based on the observation that people tend to reciprocate i.e, respond to cooperation with cooperation and to defection with defection. Cooperating or having the reputation of being a cooperative person may, with higher probability, be reciprocated with cooperation, to the ultimate benefit of the cooperator.

Another explanation, called pure altruism, is that people are motivated by seeing other people satisfied, so motivated by positive payoffs for others as well as for themselves. They achieve this motivations through cooperative acts. Another type of altruism that has been postulated to explain cooperation refers to the act of cooperation itself, the satisfaction of conscience as opposed to its results.

Experimental studies [9] indicate that people tend to reciprocate favors, punish unfair behavior and provide evidence for the behavioral relevance of fairness intentions. Reciprocity theory [12] analysis suggests that cooperation can arise via reciprocity when individuals interact repeatedly (i.e in prisoners dilemma situations) and this is called the folk theorem. Thus, reciprocity and repeated game incentives reinforce each other. Some other studies, however, interpret the behavior in these experiments (games) as elementary forms of bounded rationality [13].

Therefore people have "social preferences", i.e., the utility function does not only depend on the own material payoff but also on how much the other players receive. Given these social preferences, all players are assumed to behave perfectly rational and the well-known concepts of traditional utility and game theory can be applied to analyze optimal behavior and to characterize equilibrium outcomes in experimental games.

A proposed model of social utility [14] includes two components: an absolute payoff component representing the value to the individual of his or her own payoff and a comparative payoff or fairness component representing the value to the own payoff relative to others payoffs.

2-2 Cooperation enforcement

The usage of mobile devices' own resources may influence the decisions and the actions of the users. In general, the cooperative behavior of a device will indeed result in an increase in its resource consumption and can bring extra costs. There are cooperation incentive schemes proposed [15] that respond to these concerns. Cooperation incentive mechanisms or cooperation enforcement, can be categorized basically as reputation and remuneration based.

In reputation-based mechanisms, the decision to interact with a peer is based on its reputation. Reputation mechanisms need reputation management systems for which the architecture is either centralized, or decentralized, or both.

The estimation of reputation can be performed either centrally or in a distributed fashion. In a centralized reputation system, the central authority that collects information about peers typically derives a reputation score. In a distributed reputation system, there is no central authority for obtaining reputation scores of others. However, the scores might be distributed in the devices that are part of the network.

Based on the collected information, a participant can make a decision whether he should cooperate with another peer, based on the reputation of that other peer. A remuneration-based mechanism comprises a negotiation process. The two peers may negotiate the terms of the interaction. The remuneration can consist in virtual currency units or real money (banking and micro-payment).

An option of virtual currency is represented by Bitcoin. Bitcoin [16] [17] represents a decentralized electronic cash system that uses peer-to-peer networking, digital signatures and cryptographic proof. Managing transactions and issuing money are carried out collectively by the network nodes without relying on trust. Nodes broadcast transactions to the network, which records them in a public history, after validating them. Users make transactions with bitcoins, an alternative, digital currency that the network issues according to predetermined rules.

Regarding real money, this solution assumes that every entity possesses a bank account, and that banks are enrolled in the cooperative system, directly or indirectly through some payment scheme.

2-3 Evolution of cooperation

Evolutionary theory is about the emergence, transformation, diffusion, and stabilization of forms of behavior [18].

We have a series of proposed rules for the evolution of cooperation [1] [19] [20]:

- *Kin Selection*: Individuals cooperate if they are genetic relatives of each other.
- *Direct Reciprocity*: Cooperation may emerge among the unrelated individuals if there is a possibility of future interaction where the altruistic behavior may be required in reverse direction.
- *Indirect Reciprocity*: Based on reputation. The individual help to another peer if it has enough reputation.
- *Network Reciprocity*: Not all the populations are well-mixed. In most of the populations, the interactions are limited to a portion of the population. This means that the decision on the cooperation or defection is made with respect to local information.
- *Group Selection*: The cooperator groups have higher rate of growing and splitting into two since they have higher total fitness. However inside the group defectors easily invade the group.

Each mechanism can be described using a payoff matrix as presented in Figure 2-1, which specifies the interaction between cooperators and defectors. These matrices specify the necessary conditions for evolution of cooperation. The parameters c and b denote, respectively, the cost for the provider and the benefit for the consumer.

The table presents the conditions for cooperation to become the evolutionarily stable strategy (ESS), risk-dominant (RD), or advantageous (AD) in comparison with defection. Cooperation is ESS if cooperators can resist invasion by defectors, RD if the number of defectors is less than a half and Cooperators are AD if the number of defectors is less than a third.

Kin selection implies that natural selection can favor cooperation if the involved players are related. It is stated (Hamilton rule [21]) that the coefficient of relatedness r, must exceed the cost-to-benefit ratio of the altruistic act ($r > c/b$). In wireless networks and in our case in particular, we can also talk about relatedness and we can see devices belonging to a personal network as related.

Direct reciprocity assumes repeated encounters between same individuals. Paper [1] states that direct reciprocity can lead to the evolution of cooperation only if the probability w of another encounter between the same two individuals exceeds the cost-to-benefit ration of the altruistic act ($w > c/b$).

Indirect reciprocity [22] differs from the direct case by randomly chosen pairwise encounters where the same two individuals need not to meet again. So indirect reciprocity describes the interaction between an altruistic node, a person willing to share the data connection in our case, and another one that wishes to use it.

		Payoff matrix		Cooperation is...			
		C	D	ESS	RD	AD	
Kin selection	C	$(b-c)(1+r)$	$br-c$	$\frac{b}{c}>\frac{1}{r}$	$\frac{b}{c}>\frac{1}{r}$	$\frac{b}{c}>\frac{1}{r}$	r...genetic relatedness
	D	$b-rc$	0				
Direct reciprocity	C	$(b-c)/(1-w)$	$-c$	$\frac{b}{c}>\frac{1}{w}$	$\frac{b}{c}>\frac{2-w}{w}$	$\frac{b}{c}>\frac{3-2w}{w}$	w...probability of next round
	D	b	0				
Indirect reciprocity	C	$b-c$	$-c(1-q)$	$\frac{b}{c}>\frac{1}{q}$	$\frac{b}{c}>\frac{2-q}{q}$	$\frac{b}{c}>\frac{3-2q}{q}$	q...social acquaintanceship
	D	$b(1-q)$	0				
Network reciprocity	C	$b-c$	$H-c$	$\frac{b}{c}>k$	$\frac{b}{c}>k$	$\frac{b}{c}>k$	k...number of neighbors
	D	$b-H$	0				
Group selection	C	$(b-c)(m+n)$	$(b-c)m-cn$	$\frac{b}{c}>1+\frac{n}{m}$	$\frac{b}{c}>1+\frac{n}{m}$	$\frac{b}{c}>1+\frac{n}{m}$	n...group size m...number of groups
	D	bn	0				

Figure 2-1: Rules for evolution of cooperation [1]; where parameters c and b represent the cost for the provider and the benefit for the recipient. C and D represent the *cooperate* and *defect* strategies; (ESS) represents an evolutionarily stable strategy, (RD) risk-dominant and (AD) advantageous in comparison with defectors. All conditions can be expressed as the benefit-to-cost ratio exceeding a critical value. For further explanations of the underlying calculations [2]

The basic idea of indirect reciprocity is that cooperation increases ones own reputation, while defection reduces it, so the decision to cooperate or not becomes dependent on the recipients' and one's own reputation. Interaction can be observed by others who might spread the information, but this implies substantial cognitive demands. We have to remember not only one's own interactions but also monitor the network.

As a rule, indirect cooperation promotes cooperation if the probability q of knowing that someone's reputation exceeds the cost c to benefit b ratio of the altruistic act ($q > c/b$).

Network reciprocity [23] starts from the premise that real populations are not well mixed and spatial networks or social circles determine the frequency of interaction between individuals. As presented in Figure 2-1, a rule is proposed for determining whether network reciprocity can favor cooperation. The benefit-to-cost ratio should exceed the average number of neighbors k per individual ($b/c > k$).

In the *group selection* case, selection acts not only on individuals but also on groups. Cooperators help others in their own group, defectors do not help. Individuals produce proportionally to their payoff and offspring are added to the same group. If n is the maximum group size and m is the number of groups, the group selection allows evolution of cooperation, provided that $bc > 1 + (n/m)$, as in Figure 2-1. Beyond the biological reference, applying this to our case, the groups are represented by users with similar profile, in the same social or spatial network.

So network reciprocity, group selection and kin selection are unconditioned cooperation while direct and indirect reciprocity are conditional and depend on one's own experience or other people experiences. Network reciprocity suggests that clusters of cooperators outcompete defectors, while group selection states competition is not only between individuals but also between groups. Thus, for the mobile tethering scenarios we consider kin selection, direct reciprocity and indirect reciprocity as more suitable.

Reputation induces fairness and cooperation in populations adapting through learning or imitation. Actions like antisocial punishment can have negative effects on cooperation and cooperative nodes [24]. Inclusion of reputation effects leads to the evolution of economically productive behavior, by punishing those who do not cooperate (share) and and reward those who do.

Analysis [25] suggests that reputation is essential for nurturing social behavior among selfish nodes (users), and is considerably more effective with punishment than with reward.

2-4 Sharing mobile resources

The increased use and the popularity of wireless devices opens exciting possibilities for users to share their resources. This interaction can provide access to well-known resources, as well as to novel services, features and content. The capabilities or gaps of a device can be extended through access to and utilization of other devices [26]. There are studies trying to predict the use of a new technology and that are also interested in what makes people willing to share mobile resources.

The approach [27] analyses context and user related characteristics that influence people's decision whether or not to adopt a new technology. It is a valuable model for our work, however, even though related work on sharing the resources of a mobile device exists, though regarding tethering and its possible future implications, work is quite scarce.

Peer-to-peer resource sharing [28] is expected to play an important role in forthcoming wireless networks. There are some proposals for resource sharing frameworks. Through better control of the limited resources on a mobile device, it is hoped to encourage resource sharing and the realization of new network services [29]. A general economic framework in peer-to-peer systems is presented in [30] and the authors propose a virtual currency for peer-to-peer systems.

Much of the existing work in peer-to-peer networking assumes that users will follow prescribed protocols without deviation [31]. This assumption ignores the user's ability to modify the behavior of an algorithm for self-interested reasons, as it is the case of tethering. A different model in which peer-to-peer users are expected to be rational and self-interested is required.

Other fields of work, such as mobile cloud computing, have also distinguished the new opportunities to use the increasingly ubiquitous mobile devices (smart phones) themselves as a cloud computing resource (pool of shared resources) [32] [33]. Mobile devices are ever more powerful and feature-rich due to hardware and software advances and integration of sensor functionality, making it increasingly feasible to perform resource intensive tasks on smart phones themselves.

Thus, mobile services could utilize the mobile cloud for services based on combined smart phone resources. Users could be "rewarded" in various forms for providing their smart phone resources and this is related to our research. Collaborative applications based on multiple devices are possible, enabling a new breed of mobile services. Regardless of these opportunities, mobile cloud computing currently only exists as a concept, and as a number of prototypes and architectures.

In conclusion, there are many models and explanations proposed for cooperation and our further goal is to investigate what can be applied to sharing the data connection, and how a cooperative network can be built in this case. We will be investigating if people are indeed (or in what cases) altruist or if the only mechanism that can be used is introducing financial incentives.

Chapter 3

Sharing the data connection

Most of the latest mobile devices (smart-phones or tablets) have a "hidden" but interesting ability, that few people take advantage of and it is the starting point of our study. The feature, as previously mentioned, called *tethering* facilitates a device to carry out tasks beyond the legacy services such as calling, sending an email or web surfing. Tethering refers to connecting devices together using available interfaces and in the context of mobile technologies, it is the only available option to allow sharing the data connection with others.

Tethering involves forwarding of traffic from one network interface to another and by doing this, the mobile device may act as a "portable" Wi-Fi hot-spot and supply Internet access to nearby devices as presented in Figure 3-1. Via tethering, a mobile device may act as a Wi-Fi hot-spot and provide Internet access to other devices by sharing its own (3G/4G) data connection. The mobile devices connect to a mobile data network, and act as a Wi-Fi access point for the nearby devices.

In regions with underdeveloped or missing infrastructure, in emergency situations or when restrictions on data are applied, mobile tethering may be the only source of Internet access to individuals. Tethering provides a valuable service for those with existing Internet access and an invaluable necessity for those that are in need of one. Tethering mobile devices might reduce network congestion and offload traffic from an overburdened access route, or extend service coverage, thus perform as femtocells [34] [35].

This ability of a smart-phone or tablet to connect to a mobile data network (3G/4G) and share it with other devices, can be accomplished by using the available tethering interfaces: Wi-Fi, Bluetooth or USB. We focus on Wi-Fi mobile hot-spot tethering because it is more suitable due to range, bandwidth and mobility reasons and can service more than one client at a time. Wherever and whenever a mobile data connection can be enabled, it can be also advertised and shared through it's interfaces.

Depending on model of device and carrier, most latest (Q2 2012) Android smart-phones and tablets have implemented in their firmware tethering capabilities. If

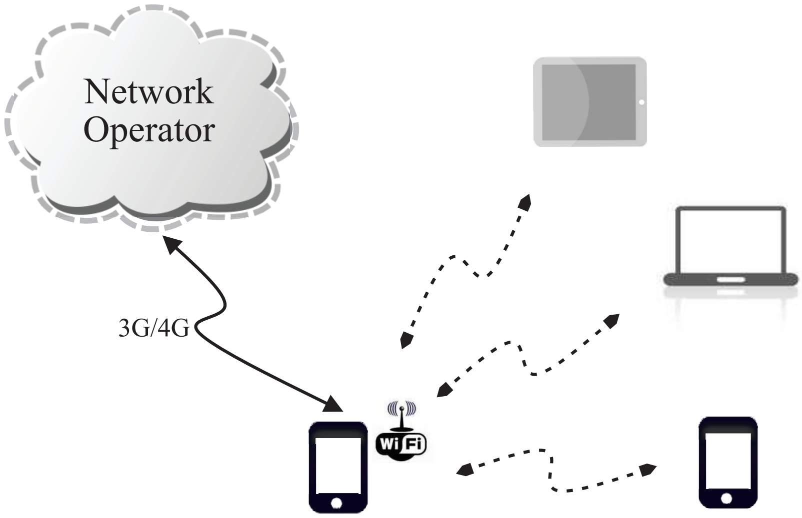


Figure 3-1: Tethering example: connecting multiple types of devices (tablets, laptops, smart-phones or any Wi-Fi capable device), bridging the interfaces of the provider (3G/4G and Wi-Fi) in order to give access to his own data connection

not present then special applications are required for tethering the data connection. These applications might need root access , meaning the user is granted privileged access to the the Android operating system. The term rooting comes from the fact that Android is based on Linux and the most privileged user on the Linux operating system is called *root*.

Rooting allows to bypass some of the software and hardware limitations or the security safety mechanisms for inexperienced users [36]. A user with a rooted phone will typically be able to install custom software (ROMs), increase performance by essentially over clocking the processor, upgrade to a newer version of the Android OS even if the handset is locked to an older version. Essentially, a custom ROM is a version of the OS, including the Kernel, services and applications which make it work, but altered in some way to add extra benefits or with certain functions unlocked or added. However, obtaining root access requires a complex procedure [37] that might discourage inexperienced users.

Another option for tethering is to install an after-market replacement for the firmware (in e.g. CyanogenMod [38]) that allows a variety of enhancements. CyanogenMod is a customized, after-market firmware distribution for several Android devices . Based on the Android Open Source Project, CyanogenMod is designed to increase performance and reliability over Android-based ROMs released by different vendors and carriers. It also offers a variety of features and enhancements that are not currently found in current versions of Android.

But at this moment (Q2 2012), the easiest method is using the built in tethering feature of the latest Android platform version (Android 4.0 ICS - Ice Cream Sandwich [39]). The Tethering and Portable Wi-Fi Hotspots application, simply provides Bluetooth and Wi-Fi tethering without need for any root permission.

A device can supply an Internet connection to five up to eight clients, depending

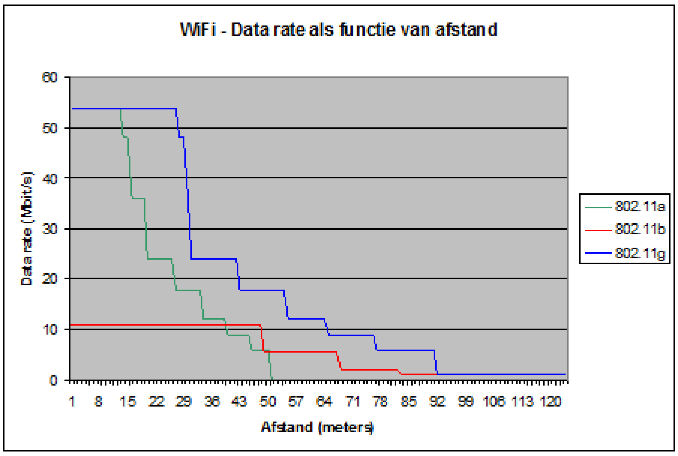


Figure 3-2: Variation of data rates with distance from access point [3]

on the tethering device model and some other variables like network type, coverage or congestion of the network. The performance varies with different scenarios (e.g. urban, indoor or outdoor). Using standard models related to the Wi-Fi signal strength is required for an in-depth analysis. We can make some statements based on personal tests, however, the signal's strength and data rate decline with moving farther from the hotspot as estimated in Figure 3-2.

Important issues concern the usage of the battery, the cost of the 3G/4G data connection, range and coverage of sharing and the data rate of the connection. Some of the telecom operators do not allow tethering because it may reduce their revenues. Even if the operators accept tethering they might demand an extra fee. We can argue on detecting tethering policies and whether the operators can or should do it but this is not the scope of this thesis.

Such a shift in the network topology is expected to be met with hesitation. Concerns regarding an increase in the network operation costs have been raised. But mobile tethering can only utilize the bandwidth which subscribers pay for and are allotted. Providers might realize that new opportunities for revenue might arise.

Current available tethering (sharing the data connection) methods are enumerated below:

1. Android tethering with applications that require root access. There are various free Android market applications that allow Bluetooth or Wi-Fi Tethering. Acquiring root access for these applications requires the following procedure:

    - Unlock boot loader
    - Flash a new recovery image
    - Boot in recovery mode and flash add-on

2. CM 9 (expected) CyanogenMod 9 is based on Android 4.0 (ICS) and the ROM is aimed at maximizing the performance and experience of the Android OS and provide support for Wi-FI, Bluetooth and USB tethering; CM9-capable devices

are being phased out of CM7, but since there's a large amount of devices still on the market that aren't capable of fully running Android 4.0, CyanogenMod 7 exists to support them.

3. CyanogenMod7 (CM7) - CyanogenMod 7 is based on Android 2.3 (Gingerbread) and it only provides support for Wi-FI and USB tethering, Bluetooth tethering is not included.
4. Android 4.0 ICS Tethering and Portable Wi-Fi Hotspots, built in ICS Android firmware - Bluetooth, USB and Wi-Fi tethering abilities (infrastructure mode). Previous Android firmwares like 2.3 (Gingerbread) do also include tethering capabilities, but only based on Wi-Fi interface.

3-1 Market available tethering applications

Android Wi-FI Tether At this moment there are several applications that enable tethering and offer additional features to the existing Android ICS Tethering and Portable Wi-Fi Hotspots application. Applications like Android Wi-Fi-Tether, Wireless Tether for Root Users [40] can be found on Google Market (Play). It enables tethering through the wi-fi interface for rooted handsets running Android. Clients can connect using the wi-fi interface (ad-hoc mode) and get access to the data connection using the 4G, 3G, 2G mobile connection which is established by the handset. This application requires a rooted-device and a custom kernel which supports netfilter (iptables) used in forwarding the traffic from one network interface to another. Most current Android kernels support this feature. Wifi-tethering creates a so called ad-hoc network on the devices. Infrastructure-mode (or Access point/-Master mode) is also supported for a large set of mobile devices. The two concepts, ad-hoc and infrastructure mode, will further be presented in the last chapter of the thesis.

Features of the Android Wi-Fi Tether application:

- Access-control feature. Allow/deny clients to use the mobile-data connection.
- Wifi Encryption. 128-bit WEP in general (ad hoc). WPA/WPA2 on supported devices (infrastructure-mode).
- Settings for Wi-Fi SSID, channel, LAN-network, power and more.

Open Garden Wi-Fi Tethering Another useful application, Open Garden Wi-Fi Tethering [41] is an application that offers wi-fi hotspot tether (ad-hoc mode, infrastructure mode access point where available) and Bluetooth tethering. The application allows sharing 3G/4G Internet connection with different operating systems (Windows, Mac OS etc.) and assumes no tether fees. It requires root access on the device, like the previous application.

The updated version of Open Garden [42] wants to evolve into a mobile mesh network of many interconnected devices pooling their bandwidth for mutual benefit.

Open Garden wishes to interconnect devices to form a wireless peer-to-peer mesh network that provides Internet access. It requires to install Open Garden on personal Android mobile devices or laptop. When more devices running Open Garden are nearby, they all connect into a mesh network.

The created wireless intelligent network would be capable of opportunistic local connections, offering improved bandwidth and coverage while reducing transmission power. Such a mobile mesh network would be highly adaptive and self-optimizing. Of course current issues, like diversity of the mobile devices and their kernel, still need to be resolved.

In addition, all these applications assume and do not yet have an answer to questions like why would users interact and build a mesh network with other unknown people.

3-2 Tethering limitations and issues

Tethering also has a series of limitations or factors that might concern the users like battery, costs, range, bandwidth or security.

Quality of service due to ***bandwidth*** reduction might be an issue. Bandwidth can be best perceived by the users as the average rate of successful data transfer through the communication path (transmission speed). Tethering involves sharing own bandwidth with other users and this means a reduction of it, perceived as a degradation of the device's data performance and quality of the services.

Energy Tethering also has an energy impact and changes the battery lifetime. The impact on the tethering device battery lifetime is dependent on different traffic classes and it might produce a depletion with a higher rate, so a shorter lifetime. In this case battery will deplete sooner, because the device's Wi-Fi is turned on in order to tether and thus consuming energy.

Type of subscription and actual costs for the tethering device are relevant and might come in different forms. It is important if there are higher costs than normal (in e.g. roaming or network extra costs for tethering). Depending on the mobile phone's carrier, tethering may be provided at no extra cost. However, some carriers impose a one-time charge to enable tethering, while others forbid tethering or impose added data charges. Contracts that advertise "unlimited" data usage often have limits detailed in a usage policy.

Security and privacy are important issues in people's view.The motivation for tethering is its ease of use. Mobile devices most usually have a Wi-Fi hotspot mode built in, or can simply download an application with this capability. Tethering is a challenging development for the telecommunication operators. The operator's control is lost and either the user takes care of its own security or the operator should find a way to assure it for all the devices. The underlying problem with wireless networking is that anyone in the vicinity of a device, with the proper knowledge and equipment can watch everything that happens on the network.

If certain security mechanism are not enforced, there is a risk someone may "borrow" the bandwidth, using the wireless connection to access the Internet. Packets might get intercepted or, even worse, someone might gain access to the device, which can get involved in illegal actions. This risk applies to both individual users who connect to a tethering device and to the data connection providers. Other problems may arise around rooted mobile devices, which might lack the same levels of encryption as other devices.

In order to determine if the parameters that we have previously identified as tethering limitations have the same importance in people's general opinion we have designed a prequel questionnaire. The only purpose of this initial questionnaire is to justify the selection of the parameters, in order to further use them in a behavioral analysis.

Following sections will present a detailed description of the above issues.

3-2-1 Security

One of the first important conclusions of the prequel questionnaire was that security is very important. Most of the respondents may not consider tethering due to security reasons.

Even though, initially, it might have been assumed that security can be enforced and it shouldn't be a parameter of this analysis, results show this is in fact critical. Security for tethering can though be improved.

There are basically two primary security issues [43]:

- Access - only authorized people should be capable to use the wireless network. Without proper access control anyone in the vicinity can use the wireless network, and thus get access to restricted information.
- Privacy - no one should be intercepting private communications. Without this, anyone in the vicinity can sniff everything on the wireless network.

Some solutions need to be adopted in order to cover all these issues. There are two approaches commonly used:

- WPA for access control and some level of privacy; supplemented by end to end encryption for privacy
- End to end encryption (typically SSL) for privacy, and special gateway systems for access control

Security between the tethering device and the users can be provided using WPA2 protocol that encrypts each connection separately so that even those connected to same hotspot cannot sniff each other's traffic. For sensitive traffic forwarded through the tethering device, Hypertext Transfer Protocol Secure (HTTPS) provides encrypted communication and secure identification of a network web server. HTTPS signals the browser to use an added encryption layer of SSL/TLS to protect the traffic. The main idea of HTTPS is to create a secure channel over an insecure network. For the tethering device protection distinction between the tethering device and the user can be performed and we assume any illegal action traced to the originating source.

But even though the mechanisms above can be used this does not change the fact that people still feel insecure and most of them don't have the knowledge. The goal of the thesis is not to enforce security but to analyze the impact and in what way it might effect the decision making process.

A practical way that might improve security for tethering is to increase encryption on both ends of a network. Phone carriers are doing more to improve their 3G and 4G networks by adding additional security elements, but users should also consider applying the same security approaches to their mobile or portable devices as they would to their desktops and laptops.

Hopefully in the next few years operators will also improve the policing and packaging of the tethered connections. A key part of this change should involve providers lowering their tethering charges and usage limits to stop people from illegally hacking into connections, or from using rooted devices.

In case an email program is used it should be configured to use SSL/secure connections for sending and downloading email. With these settings, downloading and sending mail using an open WiFi hotspot can be secure.

If a web-based email service used (Gmail, Hotmail, Yahoo) via browser, it has to be checked that it uses an https connection and that it keeps on using that https connection throughout the email session.

HTTPS provides encrypted communication and secure identification of a network web server. It ensures reasonable protection from eavesdroppers and man-in-the-middle attacks, provided that adequate cipher suites are used and that the server certificate is verified and trusted.

The lack of https can be the source of many open Wi-Fi-related hacks. People simply login to their web-based email service without thinking about security and as a result, the username and password are visible to any hackers in range. Web-based services that require login with a username and password should either be used only with https from start to finish, or should be avoided completely while using an open WiFi hotspot.

A VPN, or Virtual Private Network, is a service that sets up a securely encrypted 'tunnel' to the Internet and routes all of the traffic through it. Regardless of https or not, SSL/secure email configuration or not, as all of the traffic is securely tunneled, no one sharing the open Wi-Fi hotspot being able to interfere. This service typically involves a recurring fee.

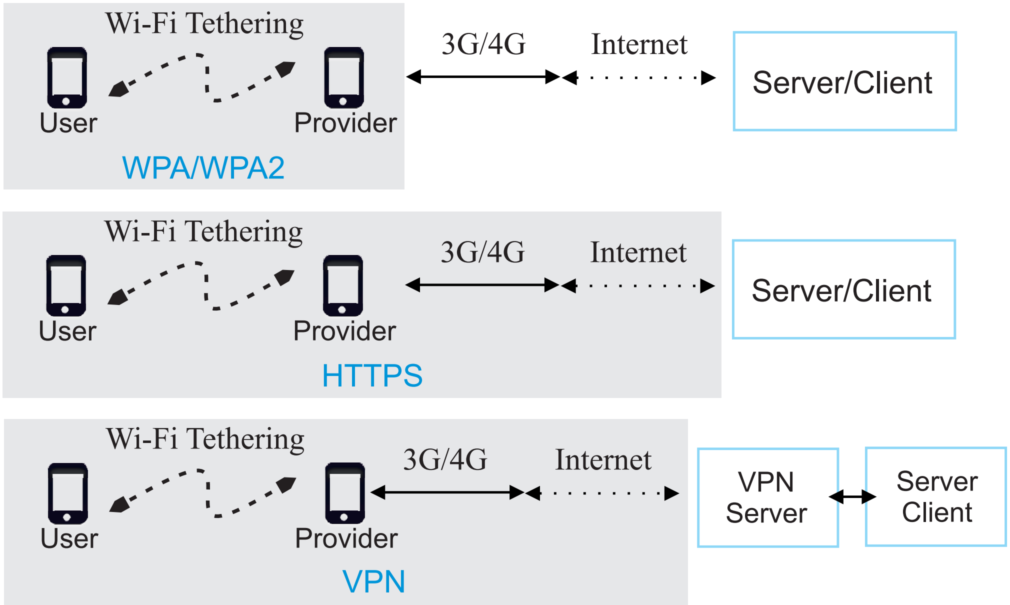


Figure 3-3: Security mechanisms for mobile tethering

It creates another layer of networking on top of the wireless network and this layer is encrypted. Because VPNs are implemented in software (at least on the user's end), they are independent of any weaknesses in the network technology, and they can be used with any vendor's network cards.

There are similarities between SSL/SSH and a VPN: both encrypt the communications. The difference is that SSL and SSH are used for individual connections. With a VPN, all of the traffic goes through a single encrypted connection.

Finally, it's a good idea to keep the passwords of the accounts that are accessed different from each other and, of course, secure.

WPA(2) is a technology that "encrypts" the traffic on the network. That is, it scrambles it so that an attacker can't make any sense of it. To unscramble it at the other end, all systems using it must know a "key" or password. WPA provides both access control and privacy.

Fortunately, with a little knowledge, forethought, and preparation, it's also relatively easy to be safe. As a review figure, 3-3 summarizes the possible security mechanisms for mobile tethering.

3-2-2 Battery lifetime

Another parameter of the analysis is the battery lifetime of the device. Tests performed on devices (Nexus S, Galaxy Nexus) show the depletion time of the device while tethering different types of traffic and their charging cycles. The values are presented in presented in Tables 3-1 and 3-2.

Further investigations on the power consumption while tethering were realized as

Device	No traffic	Video Streaming	Synchronization	Radio Streaming
Galaxy Nexus	20h 30'	5h 47'	19h 15'	6h 7'
Nexus S	17h 20'	4h 30'	15h	4h 39'

Table 3-1: Battery Lifetime (Wifi Tethering)

Device	Charging Cycle
Galaxy Nexus	2h 45'
Nexus S	3h 40'
Samsung tablet	5h 30'

Table 3-2: Charging Cycle

shown in Figure 6-14. The following cases were tested for a device under test (Nexus S):

- Not tethering, normal behavior
- Tethering no device connected
- Tethering 1 device connected, no traffic
- Tethering 2 devices connected, no traffic
- Tethering, 1 device, radio streaming
- Tethering, 2 devices, radio streaming
- Tethering, 1device, video streaming
- Tethering, 2 devices, video streaming

The tests followed the power performance of the device and the impact of tethering on the device's consumption. The same experiments and scenarios were performed on the built Android application and the results and a comparison will be explained in the following chapters.

The figure is not that easy to interpret in its raw form so further analysis is required. The power and energy consumption and impact of tethering are given in Table 3-3 and Figure 3-5. It can be observed that tethering has an impact on the battery performance of the device and the more users access the provider's data connection the more impact on energy consumption we can see. Energy consumption is also related to different classes of traffic that will deplete the battery sooner than normal. However, the analysis should take in consideration that the energy impact is major only in the case of continuous usage for a longer period of time. In example the battery of a Nexus S device will completely deplete after approximatively 5 hours of continuous radio streaming, which is an extreme situation. For a reduced usage of only a couple of minutes we estimate a minor impact on the energy consumption.

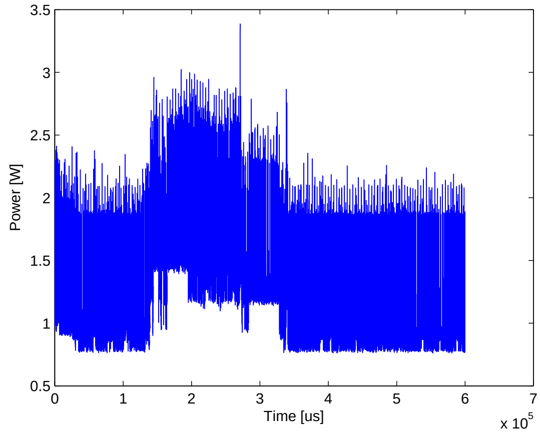


Figure 3-4: Power consumption of the current built in tethering feature; the scenario presented shows the power plot of a device tethering, without any other device connected

Scenario	Average Power	Average Energy
Tethering OFF	1,10 W	67 J
Tethering ON	1,24 W	77.41 J
Tethering ON, device connected	1.29 W	83.06 J
Tethering ON, device connected and radio streaming	1.40 W	84 J
Tethering ON, first device connected, radio streaming and one more device connected	1.53 W	91.78 J
Tethering ON, both devices radio streaming	1.63 W	98 J

Table 3-3: Average power and energy consumption per scenario

Offer	Costs per month	Data limit per month
Internet Basis	9,5 Euros	200Mb
Tethering Extra Option	5 Euros	200 Mb
Standard Tariff Roaming	1,5 Euros/Mb	

Table 3-4: Subscription bundles - extra fees for Internet and tethering [4]

Offer	Costs per month	Data limit per month	Speed
Internet Basis	10 Euros	62,5 Mb	3,6 Mb/s
Internet	20 Euros	200 Mb	3,6 Mb/s

Table 3-5: Prepaid bundles - extra fees for Internet and tethering [4]

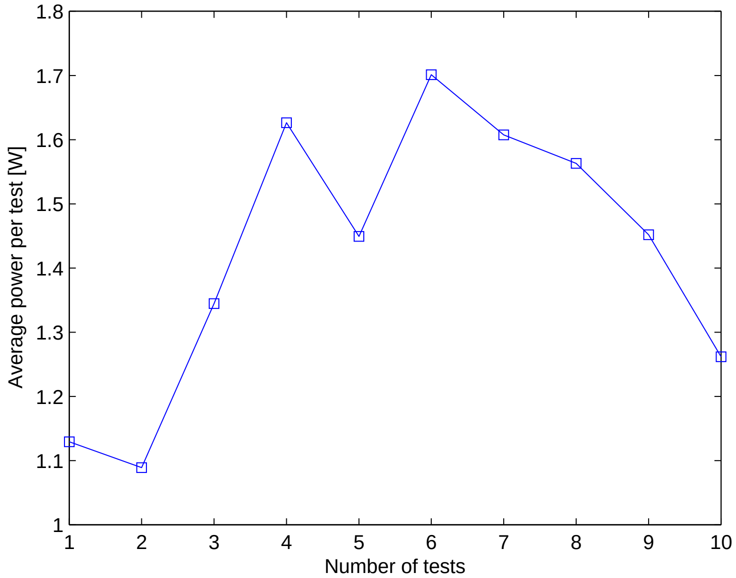


Figure 3-5: Power average consumption per test: 1-2 tethering on, 3. one device connected, 3. device connected and radio streaming, 4. two devices connected (no streaming), 5. both devices radio streaming, 6. one device connected and radio streaming second device just connected, 7. two devices connected, 8. one device connected, 9. tethering, both devices disconnected

3-2-3 Costs

The data connection subscriptions depends on the network operators and their bundles and tariff plans. Mostly, users don't just pay for an Internet monthly subscription and buy an extra option that offers voice, sms, and Internet as a packet. The fees vary with the market and depend on the operators strategies but as an example tables 3-4 and 3-5 provide some values of some specific dutch operators costs. It can be seen that in this particular example the operator does impose a tethering extra cost.

It could be interesting to make a complete market analysis of the state of data connection and worldwide operators' opinion on tethering.

3-2-4 Bandwidth

Bandwidth tests are performed with a traffic measurement tool and verified with the measurement feature of the personal developed application, that gives instantaneous traffic rates. The main purpose of this tests is not to perfectly determine the values of bandwidth. It is to get an impression, an average of experiences, on the impact of tethering on personal bandwidth. The idea is to validate tethering in an open environment with existing conditions and fluctuations, always keeping in mind a certain quality of service threshold. The goal is to test the limits and analyze the limitations of a number of users correlated with different types of traffic.

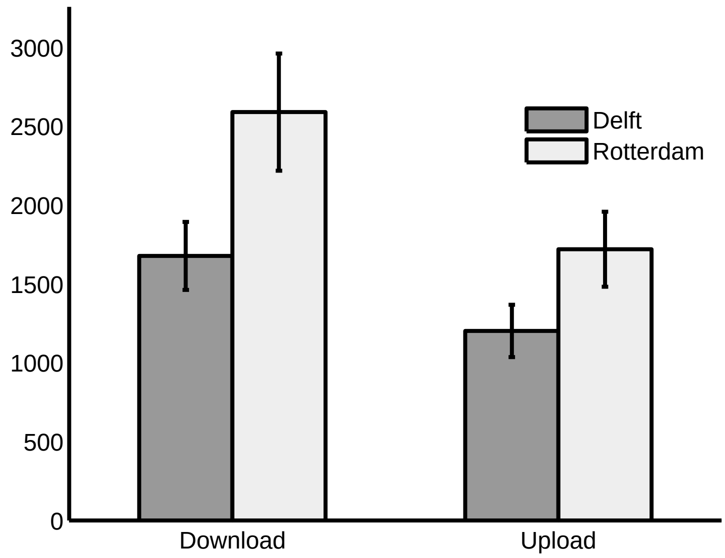


Figure 3-6: Bandwidth (download and upload) comparison of the device under test (Nexus S) tethering in two different locations (Delft, Rotterdam). Values represent the average of the measured download and upload bandwidth (20 samples) with a confidence interval (standard deviation).

Even though the tests were performed in the same location without mobility, the provider's data connection can switch between different mobile telephony communications protocols (i.e. HSDPA to 3G to GPRS) and fluctuates. Changing the location can indeed have an impact on the results of tethering as we can see in Figure 3-6. The visible differences between performances can be put on the network parameters, distance to antennas or levels of usage in the cell.

The cellular network has a huge impact on the tests and can influence the performance of tethering. We are explicitly not interested to determine distances to antennas or the exact reasons for location performance differences. However, the tests have shown that capabilities of a cell are indeed important.

Overall most important conclusion is that tethering has a sufficient quality as a service. However, there is place for improvement, both in the tethering procedures and control of the resources, but also in the network architecture.

As mentioned, the purpose of this section isn't to inspect the standards of the existing telecommunication technologies or try to make any statement regarding them. The idea of this tests was to provide actual results of tethering measurements in an real mobile fluctuating environment. There is no point of simulating or emulating the results if in an actual life interaction the expectations of the provider or the consumer are not satisfied.

Tables 3-6, 3-7, 3-8 and 3-9 give an overview of the average bandwidth of the devices under test and the impact of different types of traffic on tethering. The purpose is to provide details regarding variation and behavior of tethering with multiple devices involved, using different types of traffic. Tables 3-6 and 3-8 analyze the

		(Galaxy Nexus ICS) Average Bandwidth	
		Download	Upload
No Traffic	1 Device	2055 kbps	1515 kbps
	2 Devices	1728 kbps	1417 kbps
Radio Streaming	1 Device	1869 kbps	1579 kbps
	2 Devices	1207 kbps	1161 kbps
Video Streaming	1 Device	1349 kbps	1229 kbps
	2 Devices	1148 kbps	917 kbps
Multiple Browsing	1 Device	1310 kbps	1226 kbps
	2 Devices	1301 kbps	1393 kbps

Table 3-6: Bandwidth statistics (download and upload) of a device (Galaxy Nexus) tethering using the built in feature. The tethering device provides data access to multiple devices (one or two) streaming different types of traffic

		(Tablets) Average Bandwidth			
		Tablet 1		Tablet 2	
		Download	Upload	Download	Upload
No Traffic	1 Device	2146 kbps	1255 kbps	-	-
	2 Devices	1604 kbps	1332 kbps	1743 kbps	1533 kbps
Radio Streaming	1 Device	1847 kbps	1071 kbps	-	-
	2 Devices	1068 kbps	1359 kbps	1275 kbps	1584 kbps

Table 3-7: Bandwidth statistics (download and upload) of the consumer devices (Samsung galaxy tablets 10.1). The tablets are sharing the data connection from a (Galaxy Nexus) provider and they are streaming different types of traffic

performance of the two devices used for the tests, Galaxy Nexus and Nexus S, while Tables 3-7 and 3-9 present the performance of the consumers, two Samsung Galaxy tablets (10.1).

The tests measured the bandwidth values (download and upload) of the tethering (provider) devices (Nexus S, Galaxy Nexus) using the built in feature. The tethering device provides data access to multiple devices (one or two) streaming different types of traffic. The tests examine the impact of different types of streaming and traffic on the performance of the devices under test, both provider and consumers.

We verified the impact of radio and video streaming or browsing traffic compared with normal traffic of the devices. Another interesting measurement focused on the impact in number of consumers and the behavior of the device under intense usage.

The tests were performed using a certain pattern (same location, interval of time, a large amount of samples) that made the variety of scenarios comparable and reliable.

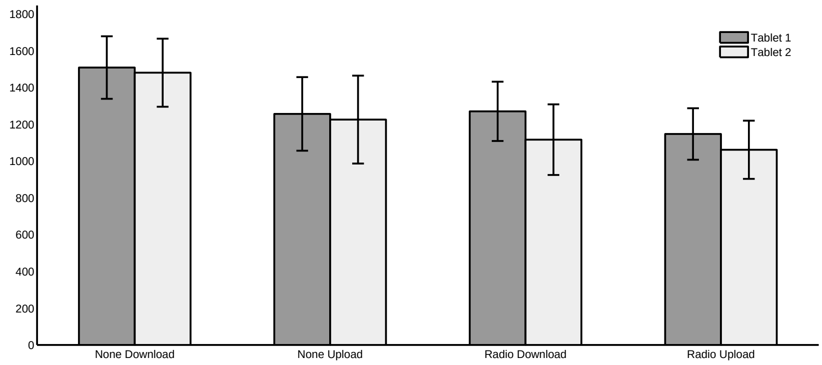


Figure 3-7: Bandwidth (download, upload) comparison of the two consumer devices under test (two Samsung tablets 10.1). Comparison of different types of traffic (no traffic, radio streaming) taking in consideration both devices are connect to the provider. Values represent the average of the measured download bandwidth (20 samples) and a confidence interval is also given using the standard deviation function.

Their validity is certified by the number of the samples and their repeatability over a very long period of time. The results also show a sample of a specific network operator metrics.

It was important to know if sharing the data connection is indeed feasible or contrary to the general knowledge simultaneous usage restricts the bandwidth and lowers the performance of the device beyond a certain threshold level. General knowledge states that depending on the device type, up to eight devices might be connected. However, the tests performed have shown that more than four or five devices connected might have an important impact on the data connection. Connection is still possible but insurmountable limitations and delays are to be expected.

For a complete analysis, we also measured the performance of the connecting devices (tablets), simultaneously connected to the provider. As it can be observed from the results in Figure 3-7, the performances of the devices are similar, but variations do exist. Based on the fact that the consuming devices and the tethering conditions are identical we can conclude that usually their behavior is the same. However, the results represent an average of samples over an interval of time, and during this interval, fluctuations do exists.

The small differences between results can only be assumed. Even though same model of devices (tablets) were used for the tests, same type of traffic was consumed and bandwidth performance was derived simultaneously they might not have been served equally due to a best effort scheme. Even in the case of introducing a delay in between the tests, the results of the bandwidth measurement won't be perfectly the same. Individual results will vary based on network, service or traffic fluctuations, however we can estimate the general behavior.

Bandwidth measurement comparisons on the provider devices under test (Galaxy Nexus and Nexus S) are shown in Figures 3-8 and 3-9, for both the download and upload scenarios. The purpose of this tests was to check if the performance might

		(Nexus S ICS) Average Bandwidth	
		Download	Upload
No Traffic	1 Device	1678 kbps	1202 kbps
	2 Devices	1463 kbps	1014 kbps
Radio Streaming	1 Device	1228 kbps	1158 kbps
	2 Devices	1070 kbps	831 kbps
Video Streaming	1 Device	1114 kbps	1113 kbps
	2 Devices	925 kbps	662 kbps
Multiple Browsing	1 Device	1353 kbps	1051 kbps
	2 Devices	1290 kbps	1076 kbps

Table 3-8: Bandwidth statistics (download and upload) of a different device (Nexus S) tethering using the built in feature. The tethering device provides data access to multiple devices (one or two) streaming different types of traffic

		(Tablets) Average Bandwidth			
		Tablet 1		Tablet 2	
		Download	Upload	Download	Upload
No Traffic	1 Device	1670kbps	1075 kbps	-	-
	2 Devices	1480 kbps	1325 kbps	1508 kbps	1356 kbps
Radio Streaming	1 Device	1105 kbps	1094 kbps	-	-
	2 Devices	1116 kbps	1061 kbps	1270 kbps	1247 kbps

Table 3-9: Bandwidth statistics (download and upload) of the consumer devices (Samsung Galaxy tablets 10.1). The tablets are sharing the data connection from a (Nexus S) provider and they are streaming different types of traffic

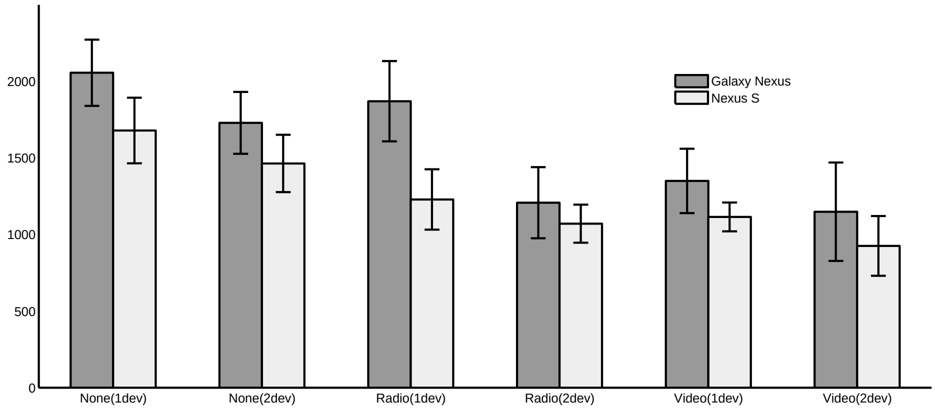


Figure 3-8: Bandwidth (download) comparison of the two devices under test (Nexus S and Galaxy Nexus) while tethering. Comparison of different types of traffic (no traffic, radio streaming and video streaming) taking in consideration multiple devices connect to the provider (one or two devices connected). Values represent the average of the measured download bandwidth (20 samples) and a confidence interval is also given using the standard deviation function.

be also device specific. The two devices were tested while tethering with multiple device, streaming different types of traffic.

We can observe that, even though the average performances are similar, one of the devices (Galaxy Nexus) performs slightly better. Fluctuations in the measurement exist and we can also observe from the plots that the variance and fluctuation of the results (standard deviation and confidence interval) are quite high.

We can conclude however, after intensive measurement and comparisons of different current mobile devices that in general we can say that they can produce similar performances connected to the same network operator. At least we can assume that without analysis of actual values, the general perception of users regarding tethering is similar and it is influenced more by the network rather than the device model or brand.

The results also confirm that the more devices connected to the provider's data connection the higher the impact impact on its own bandwidth. However, the impact is not dramatic. The influence of different types of traffic is also notable. The exception can be put again on the network performance fluctuations or the unpredictability of the Internet services and further tests should be taken in consideration.

We can propose a series of explanations for the above observed fluctuations in the measurements. Possible reasons for the existing high fluctuations in measurement are given below:

- cellular network performances (coverage, type, technology, distribution of base stations (BTSs) and distance to base station, congestions)
- number and utilization of users inside the cell
- environment (indoor/outdoor shapes, with characteristic infrastructure and obstructions)

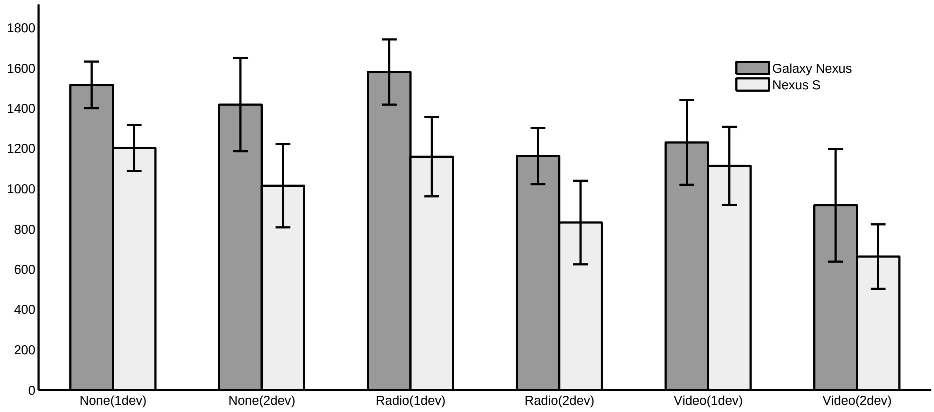


Figure 3-9: Bandwidth (upload) comparison of the two devices under test (Nexus S and Galaxy Nexus) while tethering. Comparison of different types of traffic (no traffic, radio streaming and video streaming) taking in consideration multiple devices connect to the provider (one or two devices connected). Values represent the average of the measured upload bandwidth (20 samples) and a confidence interval is also given using the standard deviation function.

- time slot of tests

In order to exclude the incidental occurrences and increase precision and confidence in the results, the tests have been repeated for a multiple number of time during a large range of time, increasing the number of samples and repeating the assumptions and conditions. Furthermore, using a higher number of samples that lowered the probability of measurement errors, didn't change the fact that network fluctuations and other reasons from the above determine our variation in the results.

Further work might be needed and a possible integration with cellular network knowledge and radiation patterns would bring valuable new information. More devices could be tested, in different multiple locations and synchronous testing.

As a main conclusion, with all the existing variations, there is no overwhelming impact on the quality of the service. The quality of the audio and video reception is most of the times constant and even though the rates might suffer some fluctuations the are are no serious disturbances or interruptions of the stream.

We can conclude based on presented tests and personal prolonged experience with tethering, that even though limitations exist and there is still place for improvement (starting with the cellular networks), tethering is a current valuable service.

Chapter 4

The mobile tethering game

4-1 A game theoretical approach

Game theory is a distinct and interdisciplinary approach to the study of human behavior, based on the fact that conflicts and choices of strategy, as in war, deception, and economic competition, can be treated as if they were games [44] [45]. Game theory is a method of studying strategic decision making. More formally, it is the study of mathematical models of conflict and cooperation between intelligent rational decision-makers.

Game theory is an essential tool of behavioral sciences and understanding human behavior, thus a relevant method of our research. Sharing the mobile data connection by tethering involves strategic decision making, so we can analyze it applying game-theoretical concepts.

The mobile tethering game has a set of players, represented by the connection provider of the data connection and the consumer using the offered connection.

We assumes people have a certain behavior related to sharing their own data connection, so they adopt a best response strategy from the set of available actions. Each combination of actions from the strategy profile produces an outcome with a certain payoff and people try to maximize their various subjective benefits. Game theory often assumes that people act rationally when they act as though they are maximizing something: profits, wining in a game, subjective benefits, or perhaps minimizing a penalty.

The connection provider has the option to *cooperate* and share his 3G/4G data connection or he can choose to *defect* and hence not share. The consumer may connect to the offered connection , or reject, thus defect. The decision depends on a series of parameters, proposed terms of tethering and user subjective requirements. We are further going to identify and analyze the above factors. If the provider decides to share his connection, he might not get any "reward" in return, and in

		Player 2 (Consumer)	
		Cooperate	Defect
Player 1 (Provider)	Cooperate	p^1_{cc}, p^2_{cc}	p^1_{cd}, p^2_{cd}
	Defect	p^1_{dc}, p^2_{dc}	p^1_{dd}, p^2_{dd}

Table 4-1: The normal form of the mobile tethering game

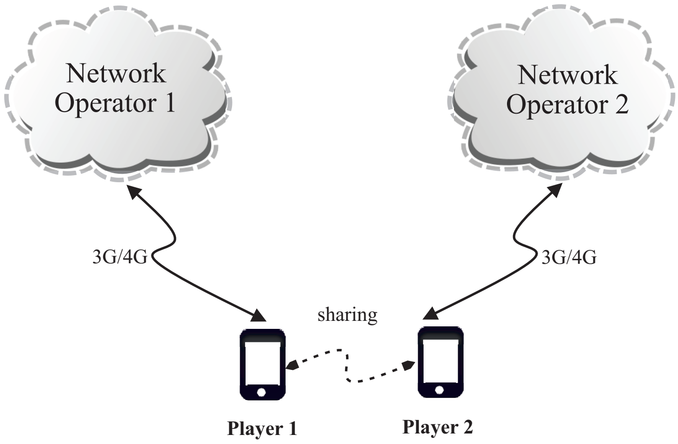


Figure 4-1: Different operators scenario: both of the players have data connection subscriptions, but one of the users pays more than the other. The users might use for this scenario a commune strategy in order to both reduce their costs

effect only to reduce his bandwidth and energy. Cooperators provide a benefit to other individuals at some cost, while defecting consumers exploit the resources without bringing any benefit. Defection in the mobile tethering game represents the consumer's decision to take advantage of the shared connection, without "payment" or offering the same service in future interactions (might offer the service to other players of the game).

The mobile tethering game is presented in Table 4-1 in the normal form and the payoffs of the game represent the benefits and the costs of the cooperation and defection strategies. To determine the Nash equilibrium of the game, we have to quantify the payoffs (p_{cc}, p_{cd}, p_{dc}, p_{dd} where c and d represent cooperation and defection, respectively) and determine the preference relationships.

The mobile tethering game in its simplest form, presents a couple of two-player scenarios. We assume either only one of the players has a data connection subscription as in Figure 4-3, or both of the players have data connection subscriptions but one of the players pays more than the other player as in Figure 4-1. A reasonable situation is the international roaming case (Figure 4-2) with overwhelmingly high roaming fees. In this case the players may be willing to cooperate to reduce their costs.

The complexity of the game can be increased by the number of users involved in the game and the frequency of their interactions.

There are various well known games in game theory such as ultimatum games, dictator games, gift exchange games or public good games. However, the famous

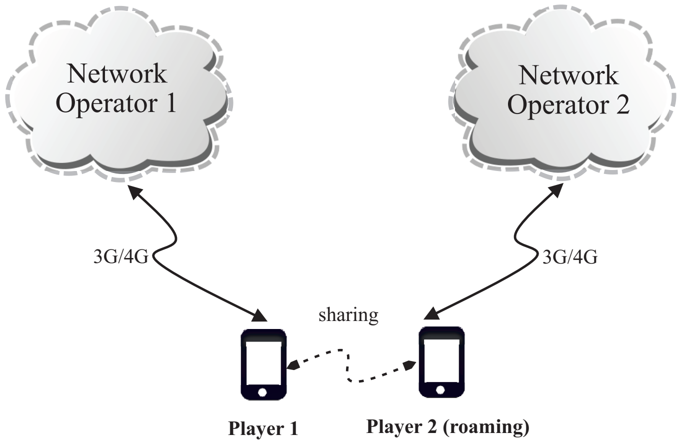


Figure 4-2: Roaming scenario: one of the players is roaming in a foreign country and considers his roaming fees overwhelming. In this scenario he might want to reduce his costs and this can also bring benefits (financial or subjective) to the other player that is sharing his connection

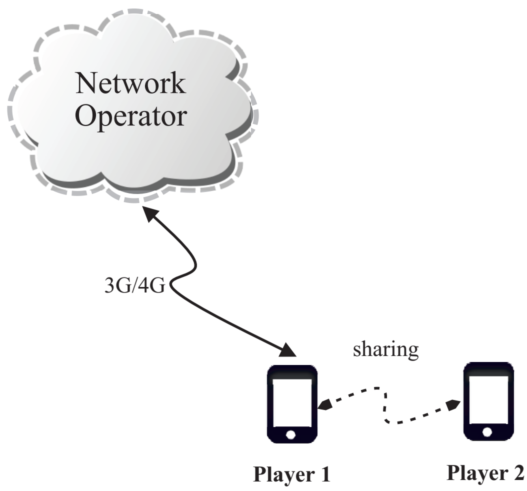


Figure 4-3: Unidirectional scenario: only one of the players has a data connection subscription, while the other doesn't and he is willing to "pay" for one

prisoner's dilemma or the snow drift game [46] [47] [48] [49] fit the best to our mobile tethering analysis. The expected assumed payoff values of mobile tethering fall in the category of the above mentioned games. However, in order to exactly determine the payoff values of the game, we need to quantize the costs and benefits that define the matrix payoffs. If they can be determined, then we can have a better understanding on the model and set of mechanism that have to be employed for cooperation success.

For a complete description of the theoretical concepts, a list of terms [13] is present in the glossary section of the thesis.

4-2 Computational appliance of the tethering game

Mobile tethering is a strategic game and although we are not sure regarding the type of the game, defection seems to be the dominant strategy. Although people can be forced to pay for the connection, we know that cooperation may evolve without any external enforcement as observed in nature. Rules of cooperation given in previous chapters show how cooperation may evolve in an open environment.

In order to analyze the game, firstly, the factors that effect the payoffs of the game should be determined with their significance among others.

Then, considering the payoff values in the game, the explanations of the evolution of cooperations should be incorporated to see whether we can see natural cooperation among the users. We can change the game if we employ those systems. Even if cooperation turns out to be impossible with the above explanations, the price of the connection sharing can be determined by the payoff values.

4-2-1 Determining the payoff matrix: costs and benefits

A game consists of a set of players, a set of moves (or strategies) available to those players, and a specification of payoffs for each combination of strategies. Most non-cooperative games are presented in the extensive or the normal form.

In our case as previously mentioned we also have a set of players, two or more, a set of strategies available, cooperate/defect and of course some payoffs for each combination of the strategies set.

Assuming two individuals with strategies x and y, the payoff of x interacting with y could then be written as $P(x, y) = B(x) - C(x)$ where $B(x)$ function represents the benefit, while $C(x)$ represents the incurring costs, obviously depend on the investment x.

The cost function is dependent on a series of variables (price, energy consumption, data rate etc.) and can be presented in the form of the following linear equation:

$$C(x, t) = (w_1 c_1 + w_2 c_2 + ... w_n c_n) \tag{4-1}$$

		Thief 2	
		Silent	Implicate
Thief 1 (Provider)	Silent	1year, 1year	20 years, free
	Implicate	free, 20 years	10 years, 10 years

Table 4-2: Prisoner's Dilemma payoff matrix

where w_1, ... w_n represent the behavioral weight of the importance of this variables.

So our final payoff is a measure of our received satisfaction, depending on the normalized costs and benefits. However the number of players involved, the frequency of their interactions and their structure, has important implications on the results. Moreover, each individual has a randomly distributed number of interactions with other individuals.

4-2-2 The Prisoner's Dilemma model

As mentioned before the Prisoners Dilemma [20] is one of the most famous games and we can start our theoretical analysis from it: Two thieves have been caught by the police and they are being interrogated in separate rooms. They are both offered the same deal so they only have two options, to remain silent or to betray their partner and only implicate him. If both refuse to confess, then both will serve 1 year in prison. If both betray and sell the other, both will go to prison for 10 years. However, if one remains silent, but the other does confess the other did it, then the one who has collaborated will go free, while the other will go to prison for 20 years. The payoffs matrix of the prisoner's dilemma can be seen in Table 4-2.

The interesting result of this game is that the logical decision leads each to betray the other, even though their individual benefit would be greater if they cooperated.

Prisoner's Dilemma is a two-person game, and many of the applications involve many person interactions. If each player tries to consider the strategies chosen by every other player, as we have assumed in the Prisoner's Dilemma, the number of combinations of players and strategies increases more rapidly than the number of the players, and of course this is a big problem for the game analysis.

Applying the Prisoner's dilemma form to the mobile tethering game a possible scenario can be as in Table 4-3. We can assume a value of 2 for p_{cc} if both users decide to share and have common payoffs. For p_{cd} and p_{dc} a symmetrical payoff of 3 and -1 can be assumed, and in case of both users decide not to cooperate, $p_{dd} = 0$. So it can be assumed there are no costs, but neither benefits.

In this case, as p^1_{cc} (2), p^1_{cd} (-1) are smaller than p^1_{dc} (3) respectively p^1_{dd} (0) and p^2_{cd} (3), p^2_{dd} (0) are bigger than p^2_{cc} (2), respectively p^2_{dc} (-1), then the Defect strategy strictly dominates the Cooperation one for both players. Defection strategy (Defect, Defect) represents for this scenario the dominant equilibrium.

So in our case (Defect, Defect) is a dominant strategy equilibrium, but repeated interaction can lead to cooperation. If there is no promise of future reward then this strategy will be the only choice, if rationality assumed. Non-cooperative games

		Player 2 (Consumer)	
		Cooperate	Defect
Player 1 (Provider)	Cooperate	2, 2	-1, 3
	Defect	3, -1	0, 0

Table 4-3: Prisoner's Dilemma model applied to the mobile tethering game, an example of an expected payoffs matrix

played repeatedly may often have cooperative equilibria. Repeated play does make a difference, but does so primarily when the game continues for an indefinite period, and even then there might be more equilibria, and there are many trigger strategies with payoffs in between cooperative and non-cooperative level. So long as there is an end point cooperative play cannot be an equilibrium in a repeated social dilemma. Intuition can be very misleading when repeated play has an end point.

Successful mechanism design may require that people be given incentives. Games are defined by their rules, which, in turn, influence the non-cooperative equilibria or rational players of the game. In mechanism design, we turn this around, first identifying the target non-cooperative equilibrium, and then adjusting the rules (so far as possible) to achieve equilibrium.

Temptation (t) to defect "now" should be smaller than the difference between the reward (r) and the applied punishment (p) "in the future":

$$t_{now} \leq r - p_{future} \tag{4-2}$$

If a repeated game has more than one Nash Equilibrium then we may be able to use the prospect of playing different equilibrium in the future to provide incentives (reward and punishments) for cooperation now. If chances of meeting again are lower than we can expect less cooperation. One possible trigger strategy is to play Cooperate and then play Cooperate again, if no one has played Defect, and play Defect otherwise.

For this form of the tethering game if the probability that they will meet again is high enough and in this case the threshhold value is 1/3 (30% chances to meet again), the Defection strategy is not the dominant one anymore.

4-2-3 Mixed strategies for tethering, Snowdrift and similar models

Another type of game that can be used as a model for the mobile tethering analysis is the Snowdrift game (Table 4-4) also known as the Hawk-Dove game or Chicken. It is basically a game in which two drivers drive towards each other on a collision course: one must swerve, or both may die in the crash, but if one driver swerves and the other does not, the one who swerved will be called a coward (chicken). The different names of the game come from parallel development of the basic principles in different research areas.

Because the loss of swerving is so trivial compared to the crash that occurs if nobody swerves, the reasonable strategy would seem to be to swerve before a crash

		Player 2 (Consumer)	
		Cooperate	Defect
Player 1 (Provider)	Cooperate	2, 2	-1, 3
	Defect	3, -1	-2, -2

Table 4-4: Snowdrift game model applied to the mobile tethering game, an example of an expected payoffs matrix

		Player 2 (Consumer)	
		Cooperate	Defect
Player 1 (Provider)	Cooperate	5, 5	-1, 3
	Defect	3, -1	0,0

Table 4-5: Example of a different game model derived from the snowdrift model, better describing the mobile tethering game, defining the multiple Nash equilibria of the game

is likely. Yet, knowing this, if one believes one's opponent to be reasonable, one may well decide not to swerve at all, in the belief that he will be reasonable and decide to swerve, leaving the other player the winner. This unstable situation can be formalized by saying there is more than one Nash equilibrium, which is a pair of strategies for which neither player gains by changing his own strategy while the other stays the same. In this case, the pure strategy equilibria are the two situations wherein one player swerves while the other does not.

This mixed strategy equilibrium is often sub-optimal, both players would do better if they could coordinate their actions in some way.

The essential difference between the two types of game is that in the Prisoner's Dilemma the benefits of cooperation increase exclusively to the other individuals whereas in the Snowdrift game the act of cooperation also provides some benefits to the cooperator itself. The snowdrift game occurs whenever not only the recipient but also the cooperator draws some benefit from the act of cooperation [46].

Using a form of the snowdrift game applied to mobile tethering, the matrix has payoffs as in Table 4-5, and there is no dominant equilibrium anymore. In a game that does not have a dominant strategy equilibrium, the strategy choices of all the players can be stable, predictable, and rational if every player is playing his best response to the strategies the other players play (Nash equilibrium). The dominant strategy equilibrium is a Nash equilibrium, but there are (there might be) other Nash equilibrium that are not dominant strategy equilibrium. A Nash equilibrium is a non-cooperative equilibrium, and therefore may or not agree with a cooperative equilibrium for the game.

If player one decides a Cooperation strategy, the best response of player two is to also Cooperate (because p^2_{cc} (5) $>$ p^2_{cd} (3)). For player one's Defect strategy the best response is to Defect (because p^2_{dd} (0) $>$ p^2_{cd} (-1)), and reciprocal for player two's Cooperate strategy the best response of player one is to Cooperate (5) and in case of Defection, to also Defect (0). So (Defect, Defect) and (Cooperate, Cooperate) are both Nash equilibriums of the game.

Without cooperation, the probability that both players will coordinate and choose

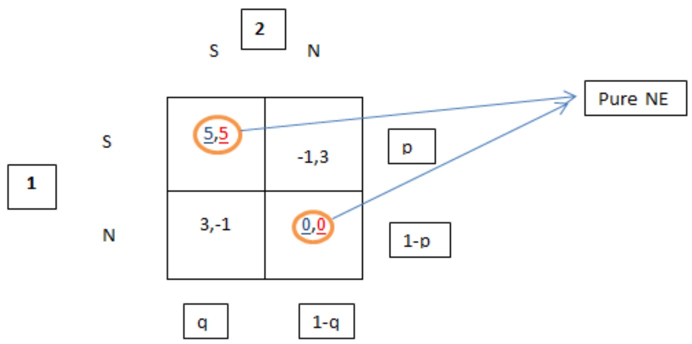


Figure 4-4: Pure Nash Equilibria of the game

at the same time the (Cooperate, Cooperate) equilibrium or the (Defect, Defect) one is very small and mixed or randomized strategies should be considered. A player who chooses among the list of pure strategies according to given probabilities is said to choose a mixed strategy and if the Nash equilibrium is one in which the players choose a mixed strategy then it is a mixed strategy equilibrium.

Uncertainty may come from the human players involved in the game. Playing in one pure strategy might make the player vulnerable to exploitation by an opponent. In this case the rational player might attempt to be unpredictable, choosing among the pure strategies with probabilities carefully adjusted to neutralize the opponents opportunities for exploitation (mixed strategies).

Since the payoffs to a mixed strategy are uncertain, we can evaluate them using the concept of expected value. The best response is the strategy (or probabilities for choosing among strategies) that maximizes the expected value of the payoff. For best responses defined in this way all two person games have Nash equilibria, including those that have no equilibria in pure strategies.

If a mixed strategy is a best response then each of the pure strategies in the mix must themselves be best response, in particular, each must yield the same expected payoff.

In the analysis of the snowdrift game with its equilibria, we consider p, *1*-p, q and *1*-q the probabilities that the players will use in choosing one of their strategies, as presented in Figure 4-4. We want to determine p, q and the mixed Nash Equilibrium. To do this we have to compute the payoffs of the players in this situation. In order to compute the payoffs of player two, we have to check the payoffs of player one, taking in consideration that player two will apply probabilities q and *1*-q. This also applies in player one's case.

The mixed Nash equilibria of the mobile tethering game in this form is:

$$NE = \left[\left(\frac{1}{3}, \frac{2}{3} \right) \left(\frac{1}{3}, \frac{2}{3} \right) \right] \tag{4-3}$$

And the expected payoffs are:

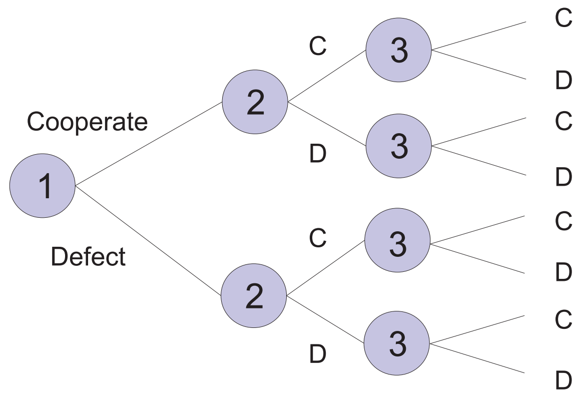


Figure 4-5: The sequential form of the mobile tethering game, 3 players involved are represented by the nodes of the tree and its branches the decisions based on previous player strategies

$$Eu_1(Cooperate, q) = \frac{1}{3}[5] + \frac{2}{3}[-1] = \frac{5}{3} - \frac{2}{3} = 1 \tag{4-4}$$

$$Eu_1(Defect, q) = \frac{1}{3}[3] + \frac{2}{3}[0] = \frac{3}{3} + 0 = 1 \tag{4-5}$$

$$Eu_1(p, q) = \frac{1}{3}[1] + \frac{2}{3}[1] = \frac{1}{3} + \frac{2}{3} = 1 \tag{4-6}$$

Compared with the non mixed strategies the expected payoff of player one is:

$$E_1 = \frac{1}{9}[5] + \frac{4}{9}[0] = \frac{5}{9} < 1 \tag{4-7}$$

And the probability of coordination and taking at same time the (Cooperate, Cooperate) or (Defect, Defect) decision is:

$$prob = \frac{1}{3}\frac{1}{3} + \frac{2}{3}\frac{2}{3} = \frac{5}{9} \tag{4-8}$$

4-2-4 Sequential form of the tethering game

The extensive or sequential form of the mobile tethering game, involving multiple players ($n = 3$) is presented in Figure 4-5. We assume the decisions and payoffs of the users depend on their previous encounters and choices to cooperate and share or not to. Using backwards induction we can estimate the equilibrium of this complex interactions.

In this simplified scenario we have a three players game, and their sequential decision, dependent on previous player choice to cooperate or defect. Each branch of choices contains as a consequence of the player's interaction, different payoffs. Scenarios might depend and vary with parameters like memory, reputation and reciprocity of interaction.

The cases based on previous assumptions are:

Case #1	Case #2	Case #3	Case #4
$[10, 10, 10]$	$[5, 10, 5]$	$[5, 5, 5]$	$[10, 10, 10]$
$[4, 4, 6]$	$[5, 4, 3]$	$[5, -1, 3]$	$[4, 4, 6]$
$[4, 6, 4]$	$[-1, 6, -1]$	$[-1, 3, 1]$	$[4, 6, 4]$
$[-2, 3, 3]$	$[-1, 3, 0]$	$[-1, 0, 0]$	$[-2, 3, 3]$
$[6, 4, 4]$	$[3, 4, 5]$	$[3, 5, 5]$	$[6, 4, 4]$
$[3, -2, 3]$	$[3, -2, 3]$	$[3, -1, 3]$	$[3, -2, 3]$
$[3, 3, -2]$	$[0, 3, -1]$	$[0, 3, -1]$	$[3, 3, -2]$
$[0, 0, 0]$	$[0, 0, 0]$	$[0, 0, 0]$	$[0, 0, 0]$

Table 4-6: Payoff values (vectors of values) for the four cases with eight branches each

- Case 1: Encounter memory and with direct reciprocity - players remember previous interactions and defection, and the interactions with all other users (previous and current) are reciprocal.
- Case 2: Memory, without reciprocity - players remember interactions but don't have the chance to punish or don't want do it.
- Case 3: No memory, reciprocal - players don't know what happened before, have no memory of previous encounters, and they interact with the other players reciprocally sharing resources back.
- Case 4: No memory, without reciprocity - everybody interacts with everybody without considering last outcomes, finding out in last round what happened and what was the outcome. However, we have to assume players should know what happened in their own previous interactions.

Using backwards induction for the specified cases (trees) the equilibrium can be derived. For these case the the equilibrium is achieved for a maximum payoff vector and a (Cooperate, Cooperate, Cooperate) strategy. The vector of equilibrium values is constructed by summing up the branches of the tree shown in Figure 4-6.

We can add a weight on our choices, to cooperate or to Defect, p and *1-p* and depending on the trust or reputation of the other players or other parameters we can lower or raise this value. Probability p can be raised for example when trust in the other users is higher or if the reputation of the other users is high enough as in Table 4-7.

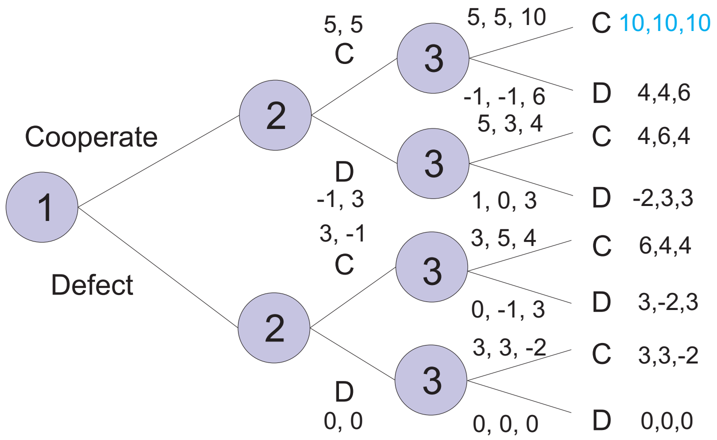


Figure 4-6: Sequential form of the mobile tethering game assuming payoffs as in Case1 example

Branches	Player 1	Player 2	Player 3	Average 1	Average 2	Average 3	Weight
Branch Cooperation	5	10	5	2	5,75	1,75	p
	5	4	3				
	-1	6	-1				
	-1	3	0				
Branch Defection	3	4	5	1,5	1,25	1,75	1-p
	3	-2	3				
	0	3	-1				
	0	0	0				

Table 4-7: Weighted tree decision (applied to Case 2), a weight can be added to the choices of the players, choices represented by the two halves of the tree (upper and lower branches of the tree); an average per semi half is computed and depending on its value different weights can determine different decisions

4-3 Economic perspective of the scenarios

We can suppose that the tethering experience is dependent on the device used and it's performances, therefore further investigation is needed. But let us consider only the economic aspects and assume that the players only care about the fees.

Let p_1 and p_2 represent the subscription fees of the players 1 and 2, respectively where player 2 is roaming and is subject to a larger fee, $p_2 > p_1$, as in Figure 4-7. The producer (player 1) sells the connection service to the consumer (player 2) with a fee of p_s units. When $p_s < p_2 - p_1$, player 2 will rationally prefer buying the connection service from player 1 since it will pay less amount of money. Player 1 will provide the service since it earns money.

We can also consider the two mobile subscribers connected to different network operators with different price rates (p_1 and p_2) per Mb used. We assume for the two players different usage consumptions, data rate d_1 and d_2. Table 4-8 offers an average data usage per activity. We consider a linear pricing scheme and assume the provider did not exceed its data connection limit.

So the total data connection cost of the users is

$$p = d_1 p_1 + d_2 p_2 \tag{4-9}$$

In the case that this two users compare their network operator's pricing scheme and decide to cooperate in order to reduce their costs then their combined new cost will be described by the following equation:

$$p' = d_1 p_1 + d_2 p_s \tag{4-10}$$

where p_s represents the price required for sharing and can be established through a negotiation process.

As long as $p < p'$ and $p_2 > p_s$ cooperation is possible. As mentioned, p_s can be established through a negotiation scheme, and as long as p_s asked is less than the price of the operator, cooperation is possible.

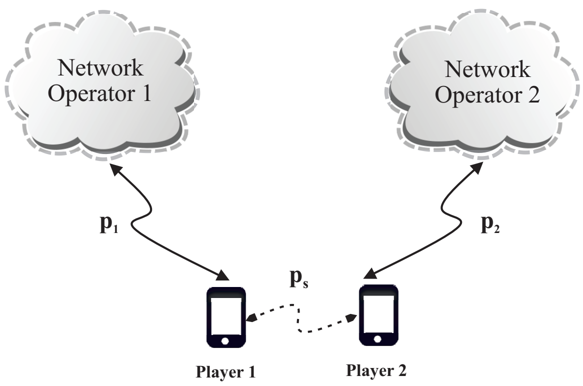


Figure 4-7: A mobile tethering scenario involving one of the players in roaming and respectively the prices involved and the sharing condition

Activity	Data usage
Email	0,1 MB
Email with attached file	1,1 MB
Web mobile page surf	0,2 MB
Web surf normal page	0,5 MB
Social network message	0,06 MB
Photo social network	0,2 MB
Radio streaming (1 min, 128 Kbps)	0,9 MB
Video streaming (1 min, good quality)	2,1 MB

Table 4-8: Average data usage per activity [4]

The interaction can be reciprocal and in the case the subscription is increasing for the current provider, the other player or someone else can start tethering. The usage d can also increase and this can also influence the scheme. Changes in the pricing scheme are also possible and the operators might impose a tethering fee.

The general condition for sharing sharing is:

$$p_c + p_s \leq p_i \tag{4-11}$$

Where p_c is the cost of the cooperator; p_s the sharing cost, required by the provide in order to tether and p_i the initial cost of the users, sum of network operators fees.

Depending on the regularity of the interactions, usage and different tariff plans, the price can vary and can be established using a negotiation procedure. Conditions on amount of traffic must/can be imposed in order not to exceed the initial costs.

4-4 Complementary methods to game theory

However, game theory alone cannot fully explain human behavior and should be complemented by other tools of the behavioral disciplines. "Just as game theory without broader social theory is merely technical bravado, so social theory without game theory is a handicapped enterprise". (Herbert Gintis)

Rather than construct a social understanding or reasoning process that reflects the real world, our game theoretical analysis may use unwarranted assumptions which imply that rational players enjoy a commonality of beliefs. But, as previously mentioned, people have a unique form of reasoning and understanding, which complexly combines rationality with our social needs. For a better understanding of human behavior, we need a unified approach.

In real life, players do not always play the dominant-strategy equilibrium. Often they do play the cooperative strategy pair depending on a series of parameters such as the repeatability of the game. So they are not really as rational as game theory assumes, or may not always base their actions on self-interests. Altruism can prevail, but players do not spontaneously choose the rational solutions of the game and rather tend to employ heuristic rules.

People have different motivations as well as different approaches to solving the problem, but often find their way to the solutions of simple games, especially with some opportunity to learn through trial and error. Human beings follow bounded rationality [13] and game theory is only partly a theory of human behavior, it is also partly a "normative" theory, that is, a theory that explains how people would behave if they were rational.

Thus, this is why we are further going to use for our analysis a questionnaire on mobile tethering and sharing the data connection.

Chapter 5

Survey on people's choices

As presented in the previous chapter, game theory needs a complementary analysis in order to overpass the missing details. This is where a customized questionnaire steps in and brings new information and weight to the rationality of the game theoretical approach.

In order to analyze the mobile tethering game, firstly, the factors that effect the payoffs of the game should be determined with their significance among others. The questionnaire can be used to get a response from the people on these factors. Then with the payoff matrix, we can find out the exact game type.

We are also interested in finding out if people might be willing to share their connection for an incentive (not necessarily real money) or are they just expecting to receive the same treatment (service) in another situation, at another time (roaming).

In this questionnaire, we can also investigate which one of the rules of cooperation appeals more to human behavior or is more prominent. Cooperative behavior of the existing mobile users is crucial and they should be motivated to share their connection with others. This questionnaire intends to inquire the significance and order among the costs and possible motivations of sharing of the data connection. We are interested in finding out the key drivers that determine the user's satisfaction and an order of importance of each parameter that determines it.

The purpose of the survey is to investigate if people are willing to use this technology and what would make them use it. It is also useful in predicting the potential use of an Android application, developed for improving tethering.

The thesis also analyzes what is the relationship between the most important parameters and user's satisfaction and how is the normalization of parameters performed.

5-1 Conjoint analysis

Conjoint Analysis [50] [51] is an advanced market research technique that investigates how people make decisions and what they really value in products and services. It is a technique that allows us to work out the hidden rules people use to make trade-offs between different values they place on different features. By understanding precisely how people make decisions and what they value, it can work out the optimum level of features and services. Thus, conjoint analysis seems to fit perfectly to our goal and provides the required results for our previous analysis.

The principle behind conjoint analysis is to break a product or service down into its constituent parameters then to test combinations of these parameters to look at what customers prefer. By designing the study appropriately it is then possible to use statistical analysis to work out the value of each parameter in the decision process. Users give their opinion on a series of products with differing features and then applying regression analysis to compute mathematical values that explain consumer behavior.

Developing a conjoint analysis involves the following steps:

- Choosing product attributes.
- Choosing the values or options for each attribute. The higher the number of options used for each attribute, the more burden that is placed on the respondents.
- Defining cases as a combination of attribute options. The set of combinations of attributes that will be used will be a subset of the possible cases.
- Choosing the form in which the combinations of attributes are to be presented to the respondents.
- Deciding how responses will be aggregated.
- Selecting the technique to be used to analyze the collected data. The part-worth model is one of the simpler models used to express the utilities of the various attributes.

First, we need to select what attributes to test, and what the possibilities are for each attribute. Consumers are unable to accurately determine the relative importance that they place on each attribute. The response may be that they all are important and individual attributes in isolation are perceived differently than in the combinations found in a product. The task is easier if the respondent is presented with combinations of attributes that can be visualized as different product offerings. However, such a survey becomes impractical when there are several attributes that result in a very large number of possible combinations.

The scientific way, is to test each of the attributes in the context of the others. To do that, we take each of these descriptors and create a series of cases. Given the consumers' ratings of all diverse combinations, we compute a mathematical regression to tell us how important each of the factors is to the individual responding consumer, and to the group of responding consumers as a whole.

Conjoint analysis is a tool that allows a subset of the possible combinations of product features to be used to determine the relative importance of each feature in the decision. It is based on the fact that the relative values of attributes considered jointly can better be measured than when considered in isolation. The utilities can be determined using a subset of possible attribute combinations. The end result is a quantitative analysis of what consumers really want, with each attribute evaluated in the context of the others, incorporating the trade-offs that ultimately project the greatest influence on consumer behavior.

5-2 Attributes and levels

In conjoint analysis, attributes and levels have to behave in certain ways so that the conjoint analysis is valid, and in certain other ways to make the conjoint useful. Firstly, each attribute has to be independent, that is it should not overlap with other attributes. Independent and readable levels are important from an analysis point of view, but for the conjoint to be useful it also needs to ensure that the range of attributes cover all the areas that are important to the customer, and that the range of levels cover all.

These attributes and levels can be used to define different cases and profiles. The first stage in conjoint analysis is to create a set of profiles which respondents are then asked to compare and choose from. The number of potential profiles increases rapid for every new attribute, so there are techniques to simplify both the number of profiles to be tested and the way in which preferences are discovered.

By analyzing which items are chosen or preferred from the product profiles offered to the customer it is possible to work out statistically both what is driving the preference from the attributes and levels shown, but more importantly, give an implicit numerical evaluation for each attribute and level.

The goal of conjoint analysis is to determine how much each feature contributes to overall preference. This contribution is called the "part-worth" of the feature. The part-worths are the regression coefficients. These part-worths are approximate rather than exact numbers because there is measurement error when the consumer provides his or her preferences on the questionnaire.

Utilities are 'unit less' so can be rescaled without losing accuracy. However, each set of utilities is unique to the study in question - cannot compare utilities across studies. Nonetheless, if we asked enough consumers to complete a conjoint analysis exercise, we could gain greater statistical power and obtain estimates of the part-worths that are more accurate.

5-3 Orthogonal design

A core challenge in using conjoint analysis is in minimizing the number of choices per respondent, yet still getting good estimates of utilities. This is most commonly achieved using what are known as orthogonal designs.

In a conjoint analysis with 4 attributes each of 4 levels for instance there would be 4^4 possible combinations of products to show to a respondent. By using an orthogonal design a minimal set of profiles is needed (typically 12-24) by choosing the profile designs so that levels are shown in combination in such a way that the effect of each level can be estimated without needing to show all combinations. This is a key part of any large scale experimental design seeking to examine underlying factors.

To reduce the consumers' task, we select profiles more efficiently. One of the most common experimental designs is known as an orthogonal fractional factorial design - an "orthogonal design" for short. In an orthogonal design, the levels of the features are chosen such that, for each pair of features, say a and b, the high level a appears equally often in profiles that have a high level b as in profiles that have a low level of b, and vice versa.

Such experimental designs are extremely efficient for estimating part-worths for features. These designs do not come without a cost. Without all possible combinations of attribute levels (complete factorials), information is lost. Also information lost might be confounded with the one obtained, where confounded means that some effects are correlated with other effects.

If the sample of consumers is representative, the consumer tasks are designed carefully, and the appropriate statistical methods are used to estimate part-worths, conjoint analysis accurately represents how consumers will behave when faced with new products.

A practical consideration is that a fully crossed design can be unwieldy for the research and exhausting for the respondent. Fully crossing all of the parameters results in a situation in which the number of scenarios grows dramatically if either more variables are added to the scenarios or the number of values per parameter is increased. For a study with four parameters, each with three levels, a completely crossed design would require $3^4 = 81$ scenarios. Adding a fifth parameter would increase the required number of scenarios to $3^5 = 243$. Similarly, if the original design was changed from three parameters to four (still with four values each), then the number of scenarios required would be $4^4 = 256$. In both of these examples, the number of scenarios required is at least tripled.

Thus, there is a critical trade-off between the number of parameters per scenario and the total number of scenarios that will be required. Effective design requires enough scenarios and parameters to yield realistic and stable estimates; having too many scenarios will result eventually in respondent boredom or fatigue.

Standardized weights are often used to deal with this problem. With standardized weights, all variables are measured in standard deviation (SD) units. Hence, a standardized regression coefficient indicates the expected change, in SD units, in

Case	Costs	QoS	Battery Lifetime	People involved	Subscription Type
1.	Normal	Lower	Longer	Familiar	Unlimited
2.	Higher	Lower	Shorter	Familiar	Unlimited
3.	Higher	Normal	Longer	Familiar	Limited
4.	Higher	Normal	Shorter	Not Familiar	Unlimited
5.	Higher	Lower	Longer	Not Familiar	Limited
6.	Normal	Normal	Shorter	Familiar	Limited
7.	Normal	Lower	Shorter	Not Familiar	Limited
8.	Normal	Normal	Longer	Not Familiar	Unlimited

Table 5-1: Orthogonal design *Provider*

Case	Costs	QoS	Battery Lifetime	People involved	Subscription Type
1.	Higher	Lower	Longer	Familiar	Limited
2.	No connection	Lower	Shorter	Familiar	Limited
3.	No connection	Normal	Longer	Familiar	Unlimited
4.	No connection	Normal	Shorter	Not Familiar	Limited
5.	No connection	Lower	Longer	Not Familiar	Unlimited
6.	Higher	Normal	Shorter	Familiar	Unlimited
7.	Higher	Lower	Shorter	Not Familiar	Unlimited
8.	Higher	Normal	Longer	Not Familiar	Limited

Table 5-2: Orthogonal design *Consumer*

the outcome variable that is associated with a change of one SD in the parameter, with the values of all other parameters held constant. Placing all variables on the same metric (i.e., SD units) improves the comparability of regression coefficients across variables.

The weights are still not directly comparable, however, unless the parameters are uncorrelated (orthogonal). If the parameters are uncorrelated, then the variance in the dependent variable that is associated with or explained by each parameter is unique to that particular parameter. Hence, the importance of each parameter is reflected in the magnitude of its regression coefficient. This, of course, is the reason for the attractiveness of the fully crossed designs discussed earlier.

5-4 Core concepts and levels of the mobile tethering conjoint analysis

In order to proceed with the development of our questionnaire, we first need to determine what are the core elements of the factorial design. To determine the parameters that will be used in the questionnaire we have to analyze what are the most important factors in process of decision making and we can start by analyzing the costs, motivations and benefits of tethering. We then compare the assumed key attributes with a prequel questionnaire designed specifically to confirm our options.

We can first start be determining the possible costs of sharing. One of the questions regarding the costs of sharing is if some attributes have a higher degree of importance than others or we should consider all to be equal by their possible influence on the output. Assumed costs are listed below:

1. **Bandwidth**: The provider has to give up some of the bandwidth and this might be perceived as a lose of quality of service. Depending on the situation, the provider might choose to limit the priority of the sharing and the bandwidth used to a certain percentage.
2. **Energy**: The providers' mobile device might consume much more energy than normal, which the case will degrade the battery lifetime. Depending on the differences between her normal activities and different classes of tethering traffic consumption, might also want to reserve a certain amount of battery for personal business. We would like to know what is the percentage of battery perceived as a limit (min) for tethering and how is tethering dependent on actual battery level.
3. **Subscription Costs (Money)**: The monthly subscription costs are dependent on the network operator's policies and/or amount of data used. The user may have to pay for the provider's connection:
   - Unlimited monthly subscription. The provider and user can *negotiate* how they will split the subscription and no limits are imposed on the traffic (or per traffic classes: web, sync, video).
   - Limited monthly subscription. The user has a limited amount of data that he can use and when he exceeds it has to pay more/or cannot use the connection anymore.
   - Payment per MB. The user pays a standard amount of money for every MB that he uses.
4. **Privacy**: We may assume that encryption techniques can guarantee the privacy and security of the traffic, but we have to check if the participants of the survey have the same perception.

We continued with assumed motivation and benefits of sharing the data connection. Since the provider has some costs while sharing it should have a motivation for sharing. We can only assume the following factors have a certain influence and we would like to find out the weight on the decision:

1. **Credit Exchange**-*(external incentive)*: the user pays money for the connection.
2. **Reputation/virtual currency**-*(Indirect Reciprocity)*: the provider earns reputation or virtual currency that it can use afterwards to get a connection when needed, from others.
3. **Family** -*(Kin Selection)*: the provider may want to share connection with family or related users/nodes (PAN).

4. **Acquaintances** -*(Direct Reciprocity)*: the provider may want to share the data connection with acquaintances. These people are the ones that the provider meets in daily life: work colleagues / friends. The main point is that the provider may require some help from these other people in the future.

Virtual currency is a counter of the reputation of a person. You earn virtual currency (reputation) by sharing your connection with others and spend it while getting connection from others. Virtual currency does not represent real money and can only be used again for getting the same tethering service.

5-4-1 Independent variables

After the previous analysis of core concepts, we can afterwards continue by selecting the independent parameters to be used in the orthogonal design of the conjoint analysis. These independent parameters are the result of a personal analysis of the possible factors that influence tethering and confirmed by a prequel questionnaire. The main purpose of this prequel survey was to confirm whether our assumptions were correct and if are backed by general opinion.

The selected parameters are enumerated below:

1. Perspective of tethering:
   - Provider (Tetherer): tethering device willing or not to share the connection
   - Consumer (User of the shared connection): device without a data plan or higher expenses willing to use someone else's connection
2. Quality of Service due to bandwidth reduction - Data Bandwidth refers to the bit-rate measures, representing the available or consumed data communication resources expressed in bits/second or multiples of it. Bandwidth can be best perceived by the users as the average rate of successful data transfer (or speed) through the communication path. Tethering involves sharing own bandwidth with other users and this means a reduction of own bandwidth, perceived as a degrade of device data performance and quality of the services):
   - Lower perceived QoS due to bandwidth reduction, meaning sharing the connection reduces the performances of the provider's device and its data connection; or in the case of the consumer using the offered connection has an impact and reduces performance and the consumer will have a restricted data connection
   - No perceived difference in QoS, bandwidth reduction is minor. So sharing or using the connection has a minor impact on the performances and data connection.
3. Energy impact - continuous impact on the tethering device battery, dependent on different traffic classes

- No impact on the battery
- High impact on the battery, depletion with a high rate

4. Battery Status (Level of battery can influence the decision of sharing)

   - Depleting or Low battery level
   - Medium or Full battery

5. Persons to share with/use from: the familiarity and level of acquaintance with different people might be important for sharing from both perspectives User or the person with the tethering device):

   - Private: family members or friends
   - Familiar: familiar persons (acquaintances or colleagues)
   - Public: not familiar(unknown) persons

6. Type of subscription for/with tethering device (tethering device - network operator and user - tethering device): the type of subscription with the data provider and also if sharing with the tethering device are relevant and might come in different forms:

   - Unlimited data usage
   - Limited data usage
   - Pay per use (MB)

7. Actual costs - cost (money) perceived for the subscription:

   - higher costs than normal (example roaming or network extra costs for tethering)
   - normal or no connection

8. Security

Due to different parameters of interest and incompatibility of the two perspectives, Consumer and Provider, it has been decided that the questionnaire should be split in two different conjoint analyses. This is why the questionnaire has two parts, one in which participants would be the person sharing the connectivity and the other in which they would be the person receiving the connectivity. Tables 5-1 and 5-2 present the previous mentioned designs.

Due to volume limitations imposed on the maximum parameters, the analysis focuses on an aggregated battery lifetime parameter:

- Minor impact on the battery and its lifetime, battery won't deplete soon
- High impact on the battery, depletion with a high rate, shorter lifetime - battery will deplete soon

Due to limitations imposed on the maximum levels of the parameters, in order to reduce the cases number (for both the Provider and Consumer perspectives) the Type of subscription and Persons involved have a reduced number of levels in the final version of the questionnaire. The type of subscription parameter will focus on the limited and unlimited levels. Only the familiar(family, friends acquaintances) and not familiar (unknown, public) persons involved will be taken in consideration.

5-4-2 Dependent variables

1. Willingness to share
2. Credit exchange:
   - monetary value
   - virtual currency, to be exchanged for services
3. User satisfaction: scale

Based on this selection the questionnaire has in its final version 32 cases per perspective so 64 cases in total. Reducing the number of levels (2) per parameter was required in order to make the questionnaire attractive and understandable for the participants. Using the Orthogonal design we have a reduction to 16 cards, 8 card for the Provider Perspective and 8 for the Consumer.

According to conjoint methodology, filling in a questionnaire with too many stimuli can be tiresome for the respondents and we needed to reduce them in an appropriate way. The orthogonal method minimized the number of profiles in a way that all level of attributes are independent from each other and still calculation of utilities remains accurate. The reduced profiles were obtained using the SPSS software. SPSS is among the most widely used programs for statistical analysis in social science. SPSS is a computer program used for survey authoring and deployment, statistical analysis, and collaboration and deployment (batch and automated scoring services).

We are going to present a number of cases related to sharing and using a mobile data connection with/from others. We will first give a short description of the scenario using key parameters like costs of sharing, perceived Quality of Service due to restricted bandwidth or energy consumption. Then we are going to ask if participants will be willing to use such a service, and the way you would pay for this service (or not), and if you would consider this service satisfactory.

The survey consists of two parts. In the first part, participants are asked to answer eight situations in which would be the person sharing the connectivity (provider perspective). In the second part, eight situations are displayed in which they would be the person receiving the connectivity.

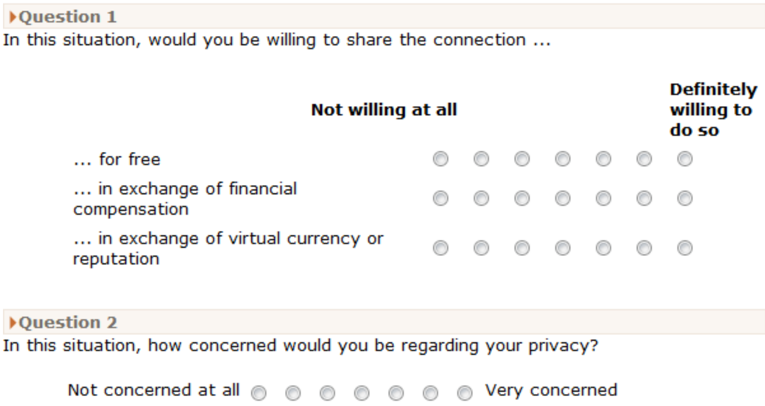


Figure 5-1: Participant questions (Case 1)

5-4-3 Questionnaire cases examples

Provider Perspective (Cases 1 - 8) is presented below:

You are in a situation in which you are willing to share your mobile data connection with somebody else, so you are the connection provider:

Case 1

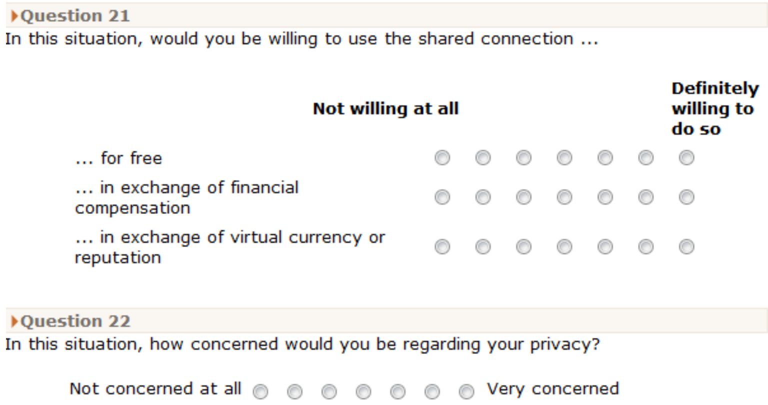
- Normal network costs: sharing doesn't incur extra costs
- Sharing your connection reduces the performance of your device and data connection
- Minor impact on the battery and its lifetime, battery won't deplete soon
- Share the connection with familiar persons (family, friends or colleagues)
- You offer unlimited amount of Mbs to the person(s) using the connection

Consumer Perspective (Cases 9 - 16) is presented below:

You are in a situation in which you would like to use someone else's mobile data connection, so you are the consumer, using the mobile connection of others:

Case 11

- You do not have a data connection currently
- Using the offered connection has minor impact on the performance of your device and provides a sufficient data connection
- Minor impact on the battery and its lifetime, battery won't deplete soon
- Use the connection from familiar persons (family, friends or colleagues)
- Offered unlimited data access


Question 21
In this situation, would you be willing to use the shared connection ...

	Not willing at all						Definitely willing to do so
... for free	○	○	○	○	○	○	○
... in exchange of financial compensation	○	○	○	○	○	○	○
... in exchange of virtual currency or reputation	○	○	○	○	○	○	○

Question 22
In this situation, how concerned would you be regarding your privacy?

Not concerned at all ○ ○ ○ ○ ○ ○ ○ Very concerned

Figure 5-2: Participant questions (Case 9)

5-5 Results of the conjoint analysis and integration with game theory

The survey had in total 80 respondents that participated to the study. Initial results of the questionnaire indicate on a scale of 7 the rate (willingness) of the users per scenario reported to the Consumer/Provider perspective, as it can be seen in Figures 5-3 and 5-4.

After further conjoint interpretation of the results, the weights ("part-worths") are derived. There are interesting results as it can be seen in Figures 5-5 and 5-6.

From both perspectives, either consumer or provider, the persons involved parameter is perceived as the most important criterion upon which respondents make decisions. Sharing with familiar people i.e., family, friend and co-workers has a positive utility value. In consumer's perspective the value is 0.338 and in provider perspective the value is 0.763. Sharing with non-familiar people in both perspectives has, of course, the same values but negative, due to the fact that the parameter had two levels.

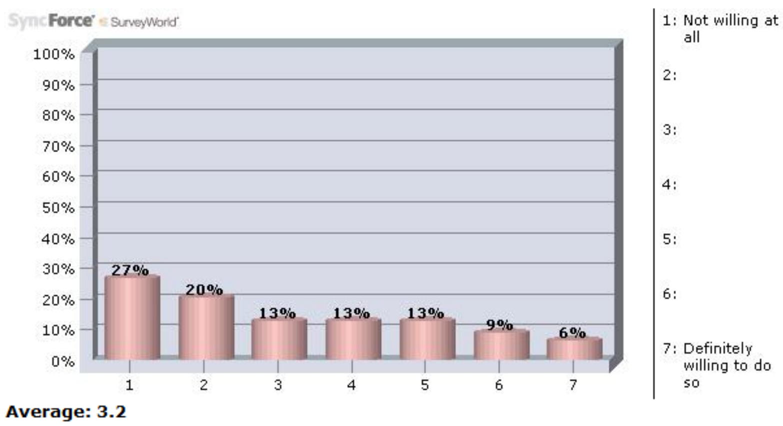


Figure 5-3: Results conjoint analysis: willingness to provide data connection for free

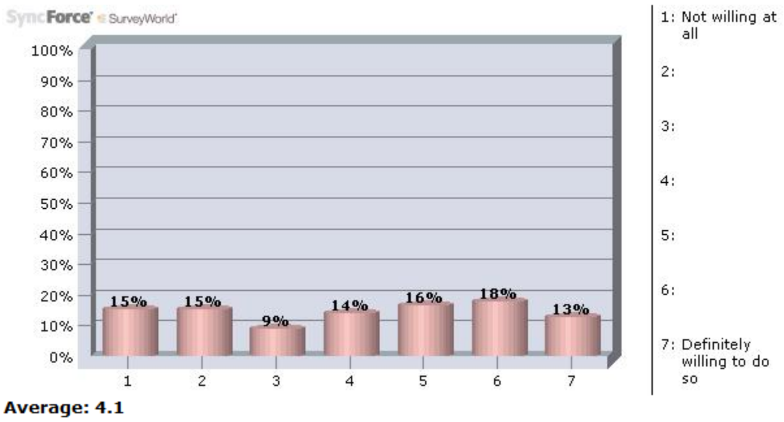


Figure 5-4: Results conjoint analysis: willingness to provide data connection in exchange of financial compensation

Consumer:

Attributes	Levels	Q1: Sharing for free		Q2: In exchange of financial compensation		Q3: In exchange of virtual currency or reputation		Q4: how concerned would you be regarding your privacy?	
		Utility	Importance	Utility	Importance	Utility	Importance	Utility	Importance
Costs	No Connection	0.276	36%	0.046	12%	0.108	19%	0.186	13%
	Higher	-0.276		-0.046		-0.108		-0.186	
Quality of Service	Normal	0.022	3%	-0.038	10%	-0.004	1%	0.203	14%
	Lower	-0.022		0.038		0.004		-0.203	
Battery Lifetime	Longer	-0.004	1%	0.029	8%	0.050	9%	0.225	16%
	Shorter	0.004		-0.029		-0.050		-0.225	
Persons involved	Familiar	0.338	44%	0.154	40%	0.246	44%	-0.647	45%
	Not Familiar	-0.338		-0.154		-0.246		0.647	
Subscription Type	Unlimited	0.123	16%	0.117	30%	0.154	27%	-0.175	12%
	Limited	-0.123		-0.117		-0.154		0.175	
Pearson's r		.904 p< .001		.916 p< .001		.952 p< .000		.927 p< .000	
Kendall's tau		.764 p< .004		.643 p< .015		.857 p< .001		.593 p< .022	

Figure 5-5: Results conjoint analysis: Consumer's utilities based on the influence of analyzed parameters and attribute levels

Provider:

Attributes	Levels	Q1: Sharing for free		Q2: In exchange of financial compensation		Q3: In exchange of virtual currency or reputation		Q4: how concerned would you be regarding your privacy?	
		Utility	Importance	Utility	Importance	Utility	Importance	Utility	Importance
Costs	Higher	-0.608	37%	-0.043	9%	-0.416	36%	0.019	3%
	Normal	0.608		0.043		0.416		-0.019	
Quality of Service	Normal	0.040	2%	0.059	12%	0.029	2%	-0.019	2%
	Lower	-0.040		-0.059		-0.029		0.019	
Battery Lifetime	Longer	0.176	11%	0.158	33%	0.213	19%	0.019	3%
	Shorter	-0.176		-0.158		-0.213		-0.019	
Persons involved	Familiar	0.763	47%	0.186	39%	0.416	37%	-0.625	89%
	Not Familiar	-0.763		-0.186		-0.416		0.625	
Subscription Type	Limited	-0.047	3%	-0.035	7%	-0.072	6%	-0.019	3%
	Unlimited	0.047		0.035		0.072		0.019	
Pearson's r		.981 p< .000		.974 p< .000		.966 p< .000		.999 p< .000	
Kendall's tau		1.000 p< .000		.929 p< .001		.786 p< .003		.964 p< .001	

Figure 5-6: Results conjoint analysis: Provider's utilities based on the influence of analyzed parameters and attribute levels

The sign of the utilities shows whether their effect is negative or a positive one, if the availability of that specific criterion encourage the respondents to rate a high score or discourage them. Logically being available and not being available should have the same weight with different signs. However, if more than two levels per parameter used, for example 3 levels, then the sign varies according to all levels. Two can be positive and one negative or vice versa, but at the end the sum should always be zero.

From provider's perspective, the quality of service is the least important criterion and has received the lowest importance rates in *Q1: Sharing for free*, in *Q3: In exchange of virtual currency or reputation* and in *Q4: how concerned would you be regarding your privacy?*. In *Q2: In exchange of financial compensation* subscription type is considered to be the least important criterion though. In the provider's perspective, battery lifetime has a higher importance in *Q2: In exchange of financial compensation*.

From consumer's perspective, battery lifetime is the least important criterion in Q1 and Q2, while for Q3, service quality and for Q4, subscription type are the least important criteria.

Testing the models: Kendall's τ and Pearson's r values are all above the benchmark values (">.70" and ">.80" respectively) in provider perspective, however these values in consumer perspective are a bit lower than the benchmark values -like in Q2 (Kendall's τ is ".643") and in Q4 (Kendall's τ is ".593").

Kendall rank correlation coefficient, commonly referred to as Kendall's τ coefficient, is a statistic used to measure the association between two measured quantities. A τ test is a non-parametric hypothesis test which uses the coefficient to test for statistical dependence. It is used to establish whether two variables may be regarded as statistically dependent. This test is non-parametric, as it does not rely on any assumptions on the distributions. Specifically, it is a measure of rank correlation: that is, the similarity of the orderings of the data when ranked by each of the quantities.

Pearson product-moment correlation coefficient, or Pearson's r, is a measure of the correlation (linear dependence) between two variables. It is widely used as a measure of the strength of linear dependence between two variables. Pearson's correlation coefficient between two variables is defined as the covariance of the two variables divided by the product of their standard deviations.

From conjoint analysis results, what it can be concluded is that, sharing the connection with people is the most important attribute and respondents are really concerned regarding people they share the connection with.

So besides price, only the social issues matter and the technical issues do not. The results appear to be consistent with previous work [27] on why do users share mobile resources.

Also interesting for the debate regarding the power consumption implications of mobile cloud computing: apparently, consumers do not care about this anyway.

We can state that most important parameters that influence the mobile tethering game and the payoff matrix are the costs and the people involved in the game.

Reducing the scenarios we can now construct a couple of simple games with simplified payoffs. For example in the case of interacting with familiar people we can claim that the overall payoff will conduct to a snowdrift model. The utility of the Peoples involved parameter (0.763) is higher than the utility (0.608) of the cost, meaning in this situation the fact that the Provider is interacting with a familiar person is more important than the fact that this is going to have a cost.

The "benefit" of this situation, the fact that he is helping a friend or a family member overpasses the costs involved, so that our final payoff will lead us to a situation in which the cooperate strategy is not dominated.

The opposite case is where we are interacting with a non familiar person, case that can be considered a Prisoners dilemma, thus based on the costs of sharing schemes like financial compensation, need to "reward" the provider.

In the case where we consider a financial compensation for the service provided it might be actually possible to compute numerically the value of the payoffs. If we consider the costs functions only dependent on the money involved in the exchange, and assume that the technical parameters are not that important as the questionnaire states, then in example let's assume $C(x, y) = 1Euro$ the cost of the transaction and $B(x) = 1,5Euro$ the financial compensation. Thus we have a positive payoff of $0,5Euro$.

Payment should be in a way certified. So if real money is involved in the process it should be verified there are no defectors. Or if virtual money is used for example we still need a reputation system to keep track of the defectors from the cooperative network.

Another way to analyze the results and to integrate them with the previous game theoretical approach is to construct the total utility of the possible combinations of parameters and afterwards to extract and select only the games that have the higher probability of success.

Higher chances of success will have the games with a total sum of the parameter's combination utility value as higher as possible compared with the zero value. There are 32 possible cases, as presented in Table 5-3, based on the possible combinations of the five questionnaire parameters, each parameters having 2 different levels.

We constructed the table of total utilities for both of the provider and consumer perspectives and taking in consideration all the possible mechanism (free, financial compensation or virtual currency). Mostly for the three mechanisms only half of the cases have utility values higher than zero, however some of them are much more probable with higher differences in values. The only exception is the case of sharing in exchange of financial compensation where only 15 cases are valid.

In all the possible mechanism the best scenarios are the ones of course with normal quality of service, longer battery lifetime, unlimited subscription and familiar persons involved. As we have seen the persons involved and the costs of sharing have the most important role and values of the utilities, however feasible combinations exist when of the previous two attributes are negative but the positive influence of the others sum up in positive value.

Further research on human behavior and integration of current work with other questionnaires related to the mobile tethering might give better understanding to our game theoretical approach. The designed questionnaire gives a very broad perspective of the topic and provides important results for our analysis. However, due to the limits of the questionnaire's complexity, levels and factors had to be neglected. This can be overpass by future analysis and design of related surveys that will bring new details.

Combination	Cost	QoS	Battery Lifetime	Familiarity	Subscription Type	Total utility
1.	43	59	158	186	35	481
2.	-43	59	158	186	35	395
3.	43	-59	158	186	35	363
4.	-43	-59	158	186	35	277
5.	43	59	-158	186	35	165
6.	-43	59	-158	186	35	79
7.	43	-59	-158	186	35	47
8.	-43	-59	-158	186	35	-39
9.	43	59	158	-186	35	109
10.	-43	59	158	-186	35	23
11.	43	-59	158	-186	35	-9
12.	-43	-59	158	-186	35	-95
13.	43	59	-158	-186	35	-207
14.	-43	59	-158	-186	35	-293
15.	43	-59	-158	-186	35	-325
16.	-43	-59	-158	-186	35	-411
17.	43	59	158	186	-35	411
18.	-43	59	158	186	-35	325
19.	43	-59	158	186	-35	293
20.	-43	-59	158	186	-35	207
21.	43	59	-158	186	-35	95
22.	-43	59	-158	186	-35	9
23.	43	-59	-158	186	-35	-23
24.	-43	-59	-158	186	-35	-109
25.	43	59	158	-186	-35	39
26.	-43	59	158	-186	-35	-47
27.	43	-59	158	-186	-35	-79
28.	-43	-59	158	-186	-35	-165
29.	43	59	-158	-186	-35	-277
30.	-43	59	-158	-186	-35	-363
31.	43	-59	-158	-186	-35	-395
32.	-43	-59	-158	-186	-35	-481

Table 5-3: Cases of utilities combinations

Chapter 6

Cooperative tethering application

6-1 Application design

Based on existing open source code [52] [53] and on the android stack 6-1 we developed a personal tethering application. Starting from current features of tethering state of the art, this new application follows to add some new capabilities. The purpose of this application would be to allow building a cooperative network of users, that not just tether their data connection with own devices, but share it with others. Mobile users that do not have a data connection or have current expensive rates may take advantage of this application. They can track friends or other users that are willing to share their connection.

The application might either have a centralized or distributed architecture. It can have a centralized entity that deals with coordination and security, a distributed method of interaction between mobile devices or a hybrid. We can either have a central server that contains the details of all the devices and keep track of them or each device can store individually the necessary information. In the case of a distributed architecture a database with the profiles of users might be stored on every other device.

This research focused on the features that can invoke cooperation and testing their functionality, rather than implementing a certain architecture. Thus, implementing one of the above architectures requires further work that can include setting a server and actually deploy this application on the market.

In the case of a centralized architecture, the application is supposed to have a central server and a number of users clients that have the application installed. A way to obtain cooperation is making the game voluntary rather than obligatory, so applying this game theoretical concept, if players willingly choose to download the application then cooperation has higher chances.

In order to influence users decisions and reduce the doubts and chances of defection, the application might also show some statistics regarding the battery or energy tests

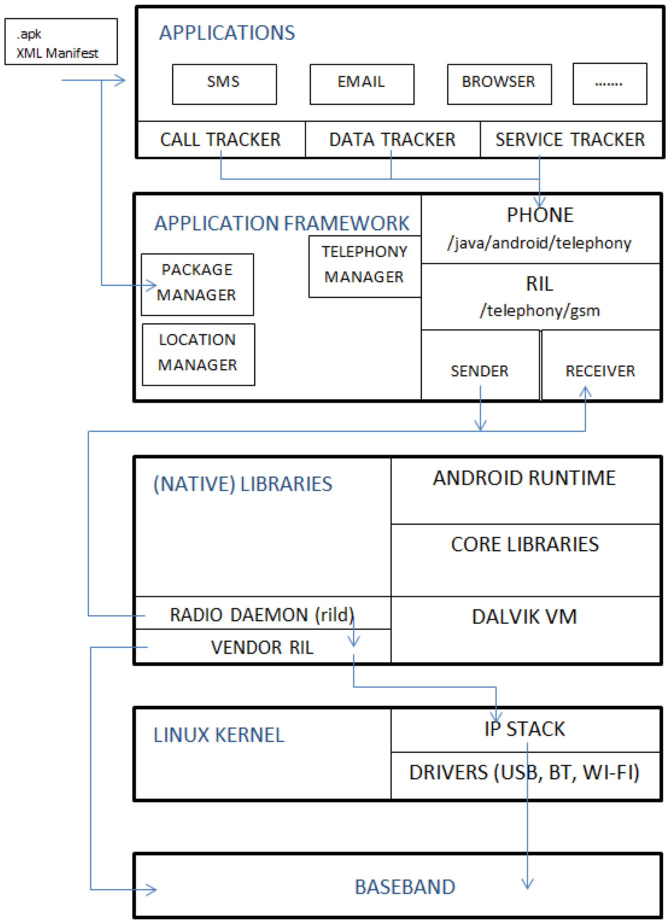


Figure 6-1: Android stack

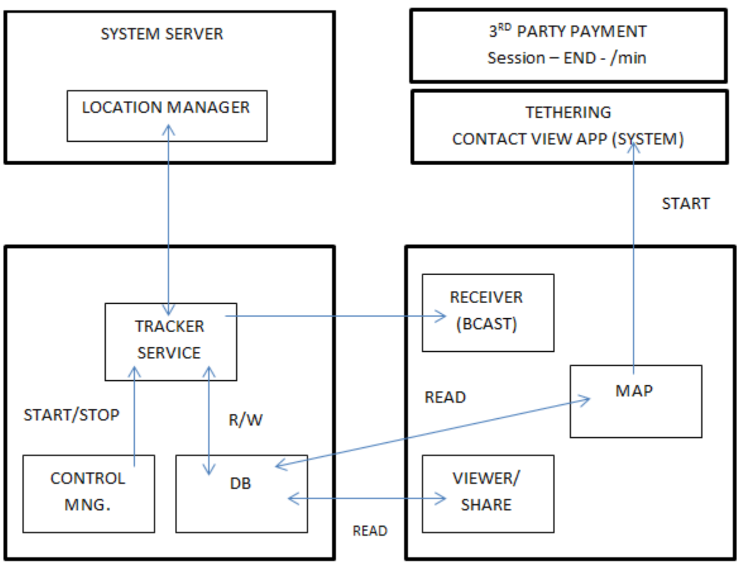


Figure 6-2: Android application design

performed. Even though results of the questionnaire show that people are mostly not interested in the technical details, making them aware of the sharing costs might be an useful extra information. At this moment the application has the capability to send some tethering statistics of the mobile device (i.e. duration of tethering, rate, device details), but a server needs to be configured in order to receive this information and analyze it.

Some of the functionalities and features of the application are manually emulated on the devices. In a large scale deployed system, a centralized scheme might be used as in Figure 6-2, where the server should contain a tracking functionality to poll users location (most recent), a database for storing locations, profiles, costs, content and a control service for authentications and security checks. Our work started from the premises that information has been received or already exists on the device. The client application is supposed to first of all allow tethering, display a list of users locations, provides a map that shows registered users with their "known" location and a receiver to display on proximity, message notifications (groups, content etc.).

The application's logic involves downloading the application and register (upload personal profile, details to database) and of course download a map of current user's position. If without Internet access, based on current map user's position an Wi-Fi scan can be performed and inquire a provider.

One of the most powerful methods for inducing cooperation in the games is to permit the players to talk to one another. So as further work for the application maybe introducing a feature that enables communication and a negotiation system.

The application is developed in Eclipse using JAVA programming code [54], android specific plug-ins for Eclipse like ADT and the Android Development Kit. The application is supposed to work for a broad range of device models that come with different versions of android firmware. This can be a very difficult task. So the target level (the version of API and firmware) of the executable (.apk) file can be selected.

However, we can expect some issues regarding deprecation of code or integration of the code for different types of devices. This is why pretesting using and emulator (Eclipse AVD) might be very useful in emulating different Android kernels and behavior. Finally when the .apk installment file is put on actual mobile devices the application can be actually be seen in action and unwanted bugs and gaps can be fixed.

6-2 Tethering modes

Devices in a wireless network are set up to either communicate indirectly through a central node - an access point - or directly, one to the other. The first is called *Infrastructure Mode* and the other is called *Ad Hoc mode* (or peer-to-peer). Either of them selected, for the wireless network, all devices communicating directly with each other must use the same mode.

In an ad-hoc network, no node acts as a relay, all traffic is direct and broadcasts are direct. In an infrastructure (or soft access point) network, the access point relays all traffic: even broadcast packets will be sent to the access point which then broadcasts them to all. Ad Hoc, or IBSS, mode is a legacy protocol for Wi-Fi devices.

In infrastructure mode, a single access point (AP) together with all associated stations (STAs) is called a BSS. An access point acts as a master to control the stations within that BSS. In ad hoc mode a set of synchronized stations, one of which acts as master, forms a BSS. Each BSS is identified by a BSSID. The simplest BSS consists of one access point and one station.

It is possible to create an ad-hoc network of client devices without a controlling access point called an independent basic service set (IBSS), in which case the SSID is chosen by the client device that starts the network, and broadcasting of the SSID is performed in a pseudo-random order by all devices that are members of the network.

Because the network topology in ad hoc mode might change regularly, system resources may be taken just to maintain the connectivity. As the ad hoc topology changes, throughput and range will change, sometimes in unanticipated ways. New users will have an easier time learning wireless strengths and weaknesses with Infrastructure Mode. In an ad hoc network with many devices, the amount of interference for all will go up, since each is trying to use the same frequency channel. Infrastructure takes advantage of the power of the access point to cover an area. Ad hoc mode connections are limited to the power available in the devices.

For an access point/infrastructure mode the phone's drivers has to support it. Unfortunately for the android case the wifi-drivers of some of the mobile devices do not support master mode (infrastructure) and they might have to be rewritten to support it. If it's not supported by the driver it cannot be set with iwconfig, usually used to display and change the parameters of the network interface which are specific to the wireless operation (e.g. interface name, frequency, SSID). Personal knowledge on kernel-modules is limited and it is not sure if the hardware could support infrastructure at all for some of the devices.

Infrastructure mode might be more useful in some scenarios. It could permit a wider range of devices and operating system support for the clients. The ad hoc mode only allows WEP encryption which is weak. But with AP mode the WPA_Supplican can be used to get WPA2 AES encryption working. Wpa_supplicant is a free software implementation of an IEEE 802.11i supplicant for Linux. In addition to being a full-featured WPA2 supplicant, it also implements WPA and older wireless LAN security protocols.

Android devices can't connect without infrastructure by default. It is required to to either allow infrastructure in the wifi hotspot application or enable connection to ad-hoc networks. A wpa_supplicant mode that will work on all android devices is needed.

At this time, unfortunately, the WifiManager current Android class ignores ad-hoc networks so android also does not support ad-hoc networks. That is, ad-hoc (IBSS) entries are filtered out from the scan results reported by the wpa_supplicant.There are a couple methods to bypass this issue.

One is to modify the android framework to support ad-hoc networks. To add ad-hoc network support one could augment the WifiStateTracker to not filter IBSS entries out and set the wpa_supplicant in AP_SCAN 2 mode to establish new IBSS instead of associating with a scanned one. That would require fiddling with the Java framework on the phone.

Another is to manually configure the wpa_supplicant to connect to an ad-hoc network. Yet another one is to patch the wpa_supplicant to pretend that ad-hoc networks are regular access points. The wpa_supplicant can be augmented to masquerade ad-hoc networks as regular infrastructure access points (APs). This makes changes only to the wpa_supplicant and allows a drop in replacement on rooted phones. The patch modifies the wpa_supplicant code in the external/wpa_supplicant AOSP repo to make ad-hoc networks appear as regular APs with a (*) prefix:

- removes the [IBSS] flag from scan results,
- masquerades and demasquerades ad-hoc ssid with (*) prefix
- sets mode 1 (ad-hoc) if the ssid is for IBSS
- permits the supplicant to select an IBSS when associating to a given SSID

It seems Android engineers prefer Wi-Fi Direct over ad-hoc. Ad-hoc has slipped in priority in favor of other solutions keeping power constraints and security in mind. So wi-fi direct might be a better solution in the future, even though ad-hoc is a well known technology supported by many many devices and used for a couple of years. Also Wifi Direct is not yet available on all devices.

Wifi direct is a layer that auto configures one of the devices as a soft application. The benefits are the same as with wifi direct, wpa2 and power management. There is though a very good reason to use ad-hoc, the compatibility with devices that only support ad-hoc. It is expected to see both direct and ad-hoc support in the future.

Wi-Fi Direct brings important security features, ease of setup, and higher performance that is not currently available in Ad Hoc mode. With Wi-Fi Direct, a device can maintain a simultaneous connection to an infrastructure network. this is not possible with Ad Hoc.

6-3 Application features

In case a user would like to share his data connection and act as a provider the application offers this feature in its main view. Further work needs to be done in order to also inform when it should start tethering. At this moment the application warns the users if someone else using the application is in their proximity but a communication and negotiation scheme should be implemented in the future.

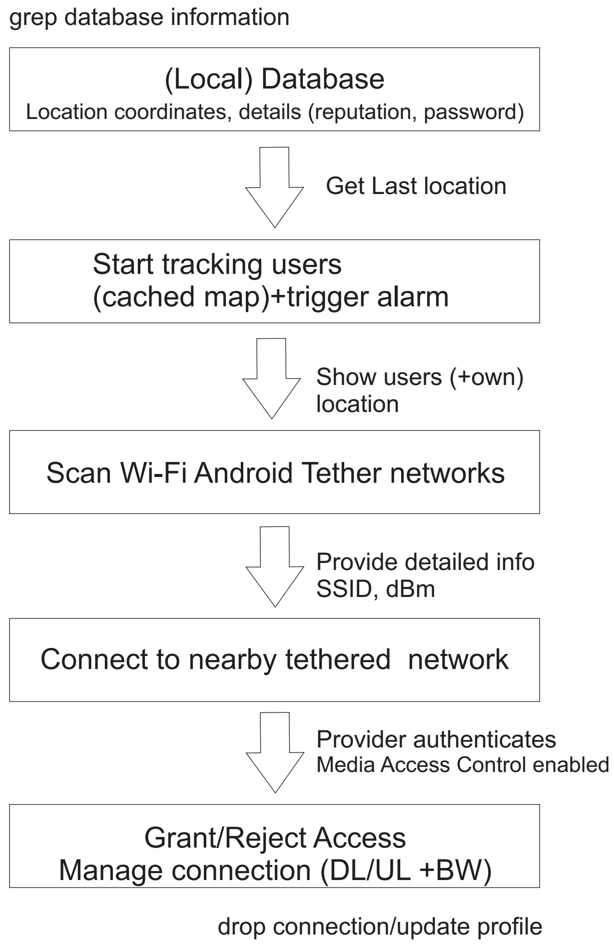


Figure 6-3: Android application flow chart

The flowchart of the application for the case of a consumer is presented in Figure 6-3. Basically the user looking for a data connection is gathering information from a database either stored locally on the devices in a decentralized manner or grabs them from a central server. The user gets in this way information about user names(nickname), location coordinates (last known coordinates), reputation of other users, their SSIDs or even passwords if they share for free.

Users can be tracked and their position relative to own is shown on a map. In case of proximity an alarm is generated, and a user can also scan the Wi-Fi networks available. If available it has the option to either try to negotiate and connect manually to the provider or to connect automatically if the connection is free. Information about the SSIDs and strength of the available networks. The provider also has an access control feature that allows him to grant or reject the incoming connection.

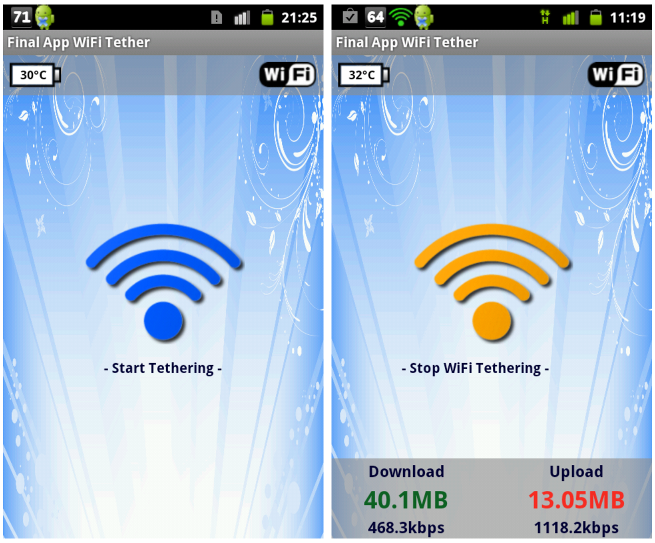


Figure 6-4: Application outlook and statistics - download/upload; bandwidth

6-3-1 Tethering

A main focus of the application is to provide data connection to other users and allow tethering. The application offers both Bluetooth and Wi-Fi tethering. Figure 6-4 presents the outlook of the own built application. It shows the user if tethering is enable or not and if enabled it it also shows the instant download and upload data rate. Plus it show the the battery temperature and current method used for tethering, in its main application screen (main view). Based on the shown data rates statistics a policy management can be implemented in order to control and restrict the usage of personal resources.

The application also logs the details of the activities performed as presented in Figure 6-5.

6-3-2 Database

A key element of the application is a use of a Database as shown in Figure 6-6. The database can be kept on a centralized server that communicates with the other devices or can be distributed on all the nodes of the network. In the case of the current application the database is manually built on the phone and contains the profile of a series of users.

The profile contains details regarding the name of the user (nickname if anonymity wanted), position of the user (last position of the node, known by the server), its reputation and password of the tethering device. The chosen details of the profile can be changed depending on strategy that we want to use. For example based on strategies as in [55] we can create different classes of profiles dependent on the trust in the users, the probability of meeting with them again or the grade of acquaintance maybe.

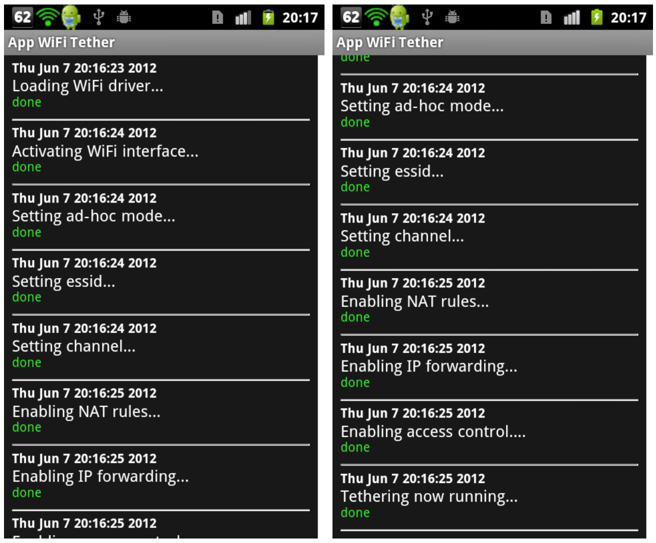


Figure 6-5: Application logging

The database contains a series of values representing each user's reputation. Based on a reputation mechanism the developed application can allow or deny consumer's requests for a data connection.

6-3-3 Media access control

Access control means limiting who can use the data connection. If there is no way to limit access to the data connection, then there is no way to know who might have used and in what way, nor any way to prevent re-occurrence of any security breach. The application has a media access control feature, presented in Figure 6-7 that can be activated or not. If it is enabled then it gives the opportunity to chose if the the users that want to use the connection are indeed granted access. Using this feature extra protection is assured and a track of the devices and users that connected before and might not be trustworthy is kept.

6-3-4 Security

As previously mentioned for the infrastructure capable devices WPA2 is provided, in the case of Ad-Hoc mode only WEP is available in this might be an issue. The media access control feature can help, but further work in this direction still needs to be done.

6-3-5 WiFi scan

Another important feature of the application (Figure 6-8) is for a user that needs a data connection to scan the wifi area for a tethering device from it's stored database and in case he finds one to automatically try connect to it (if he knows the password).

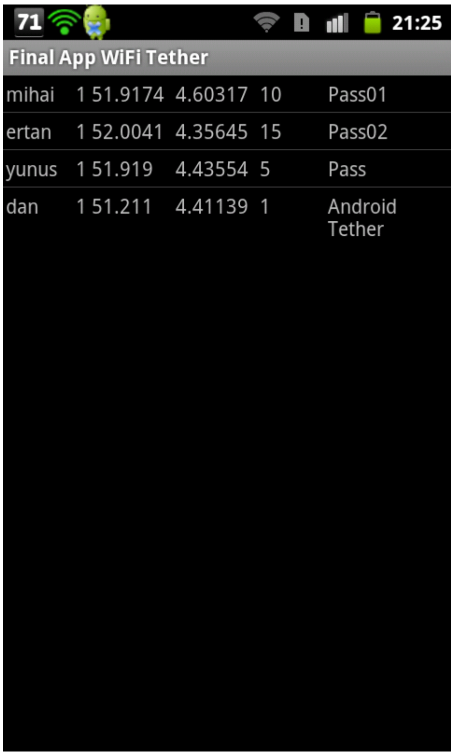


Figure 6-6: Application (local) database

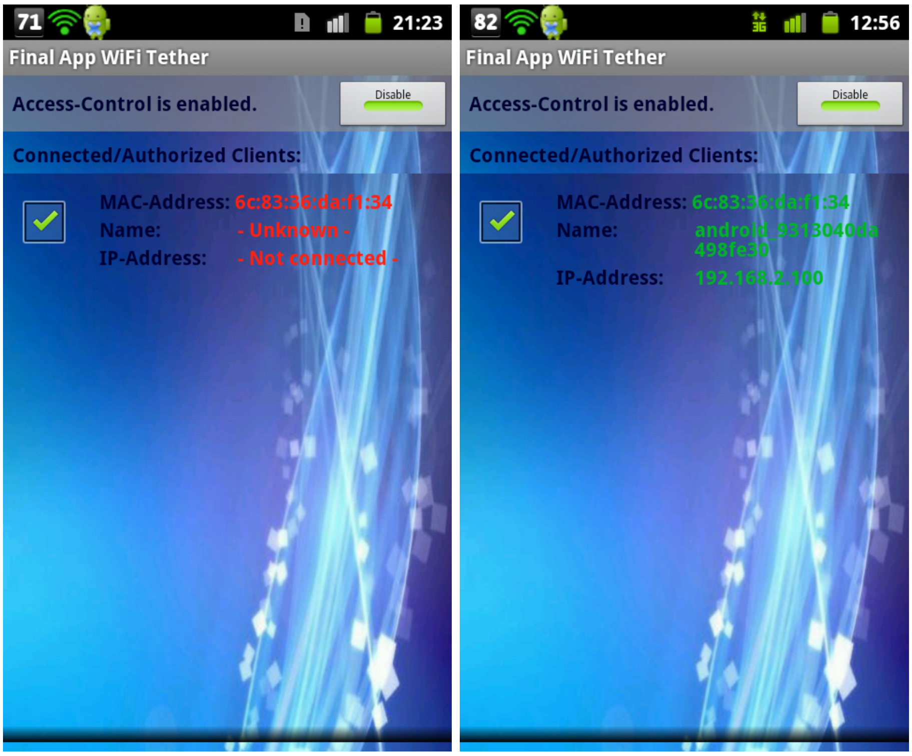


Figure 6-7: Application media access control

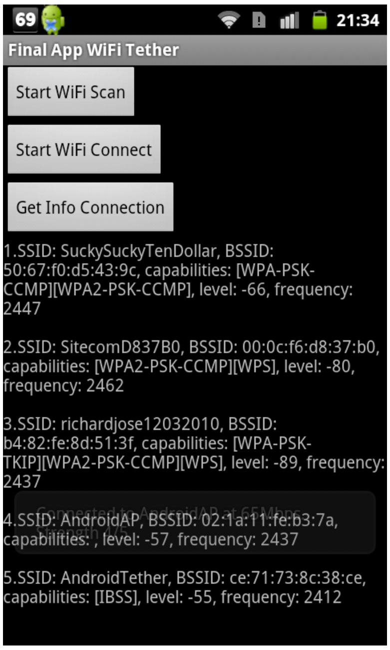


Figure 6-8: Application scan and connect Wi-Fi networks

Details regarding the surrounding Wi-Fi networks, including the present ad hoc networks (if the phone permits it) are available.

A related field is the basic service set identification (BSSID), which uniquely identifies each BSS (the SSID however, can be used in multiple, possibly overlapping, BSSs). In an infrastructure BSS, the BSSID is the MAC address of the wireless access point (WAP). In an IBSS, the BSSID is a locally administered MAC address. The bssid seems to be unique since it is assigned according to the mac address of the AP. May be we can change some part of it and say that such BSSID owners are possible tethering devices. Later on with authentication involved with our main server, we will be sure that it is a true tethering device.

6-3-6 Map

Before scanning the vicinity for any tethering known device using the application we can track the last known position of the other registered users and show it on a map as in Figure 6-9. Of course if no current Internet connection exist then the map is based only on the previous cached information. The application also has a feature that allows the consumer to receive an alarm every time he is in a closer range from a provider. Another issue might be the fact that maybe not all the users might want to provide their location due to privacy reasons. In this case they might allow this kind of information only to friends or not at all.

Figure 6-9: Application map

6-4 Methods of payment

Based on the results of the questionnaire we can infer that the level of acquaintance and familiarity between users has a very important influence on their interactions and willingness to cooperate for free or for a renumeration. This is why we propose different approaches and classes of profiles for the users.

If in the case of family and close friend we might not consider our costs at all and we are willing to share for free, this is not the case with other people. As we have seen from our previous analysis interacting with unknown people has a negative impact on willingness to share our resources and this is why a different scheme is needed to sustain the cooperative network.

For example for a users having the profile of colleagues or someone that we might know, a reputation-based mechanisms can be used. The decision to interact with them can be based on its reputation or degree of social likeliness.

Finally a remuneration based mechanism that comprises a negotiation process can be decided for unknown users. The two peers may negotiate the terms of the interaction. The remuneration can consist in virtual currency units or real money and if their interaction become more often then with the gained trust a profile change can also come.

If real money or virtual currency used, a payment scheme has to be designed and this a very interesting work for further research. This solution assumes integration

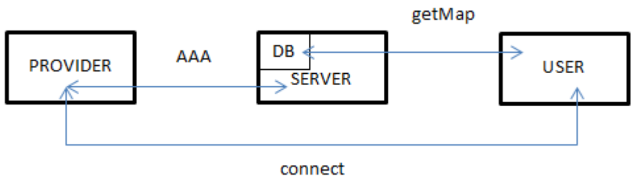


Figure 6-10: Application logic

with banks and a bank account, which might be serious problem. Not only technical issues might arise but also users might not agree with using such a system and they might not trust it. Using systems like Bitcoin can be a solution, but further research needs to conclude what might be the best option.

6-5 Test results

A series of tests were performed with the developed application in order to ensure that its performance is at least as good as the current capabilities. The goal was to improve tethering usage and create a cooperative network keeping the costs of sharing the resources in the same parameters, if reducing them is not possible.

6-5-1 Bandwidth

Table 6-1 offers an average bandwidth measurements overview (download and upload) of the device under test (Nexus S) using the developed tethering application. The tethering device provides data access to multiple devices streaming different types of traffic. The performance of the two consumers (Samsung Galaxy tablets) using the tethered data connection is shown in Table 6-2.

The goal of this tests was to compare the performance (download and upload bandwidth) of the developed application with the current Android ICS tethering feature. Our goal was a bandwidth comparison of the device under test (Nexus S) while tethering using the developed application and the built in feature. We compared different types of traffic (no traffic, radio streaming and video streaming) taking in consideration multiple devices connect to the provider. Values represent the average of the measured bandwidth with confidence interval (standard deviation) integrated.

We can observe similar behavior, thus it can be stated that the developed application performs as good as the built in feature.

Based on our experience and results presented in Figure 6-11, we can confirm that the performances of the devices (Nexus S) while tethering via the ICS internal application or our personal one are comparable.

Testing the consumer's (Samsung tablet) quality of data connection while connected to the provider through Application tethering and ICS hotspot feature, we reached

		(Nexus S ICS) Average Bandwidth	
		Download	Upload
No Traffic	1 Device	1718 kbps	1192 kbps
	2 Devices	1507 kbps	1036 kbps
Radio Streaming	1 Device	1427 kbps	1058 kbps
	2 Devices	1215 kbps	916 kbps
Video Streaming	1 Device	1090 kbps	913 kbps
	2 Devices	902 kbps	723 kbps
Multiple Browsing	1 Device	1431 kbps	1117 kbps
	2 Devices	1390 kbps	1148 kbps

Table 6-1: Bandwidth statistics (download and upload) of a device under test (Nexus S) tethering using the developed application. The tethering device provides data access to multiple devices (one or two) streaming different types of traffic

		(Tablets) Average Bandwidth			
		Tablet 1		Tablet 2	
		Download	Upload	Download	Upload
No Traffic	1 Device	1502 kbps	1035 kbps	-	-
	2 Devices	1470 kbps	1012 kbps	1530 kbps	1034 kbps
Radio Streaming	1 Device	1202 kbps	1001 kbps	-	-
	2 Devices	1173 kbps	991 kbps	1205 kbps	1047 kbps

Table 6-2: Bandwidth statistics (download and upload) of the consumer devices (Samsung Galaxy tablets 10.1). The tablets are sharing the data connection from a (Nexus S) provider and they are streaming different types of traffic

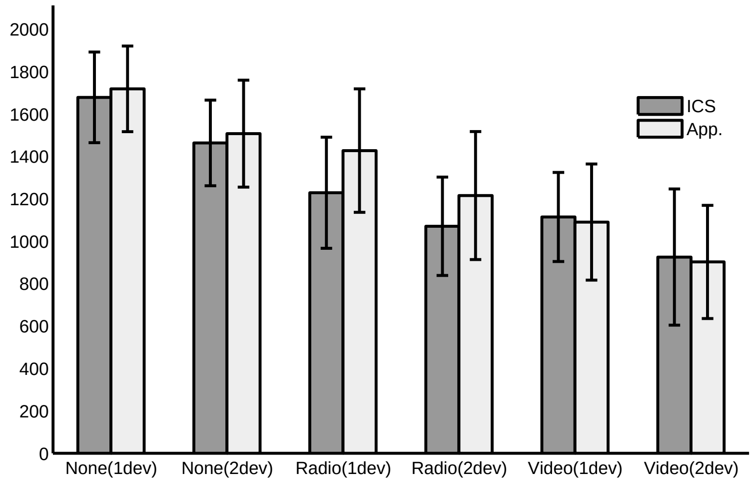


Figure 6-11: Bandwidth (download) comparison of the device under test (Nexus S) while tethering using the developed application. Comparison of different types of traffic (no traffic, radio streaming and video streaming) taking in consideration multiple devices connect to the provider (one or two devices connected). Values represent the average of the measured download bandwidth (20 samples) and a confidence interval is also given using the errorbar function.

the same conclusion. The devices have similar performances if connected using both methods and Figure 6-12 shows the average results of our tests.

It was important also to know what might be the range limitation and what is the impact on tethering, so this is why tests were performed in this direction. A comparison between the firmware tethering feature and the developed application was performed. The tests were performed placing devices at multiple distances from the data connection provider and observing what are the limits of the devices and tethering in each situation. The tests have shown that for different indoor, outdoor scenarios and locations the limit for tethering varies. In order to analyze the influence and restrictions of distance for tethering, we need to compare our results with different location based models and different ranges in order to draw a clear conclusion.

The developed application performs differently in an indoor or outdoor environment and at different distances from the provider. We present the results in Figure 6-13. Tethering indoor (in our specific scenario) reaches its range limits at around 30 meters. For the tested outdoor scenarios, tethering reaches its boundary at around 20-25 meters. However this tests were performed in a vary specific location, thus further work and analysis of existing models of propagation need to be used in order to generalized the results. Our measurement are again very specific and might only apply to the tested area, with its specific multi-path or shadowing effects.

Due to network hazard, slightly different results can be observed and this is also why we have higher standard deviation values.

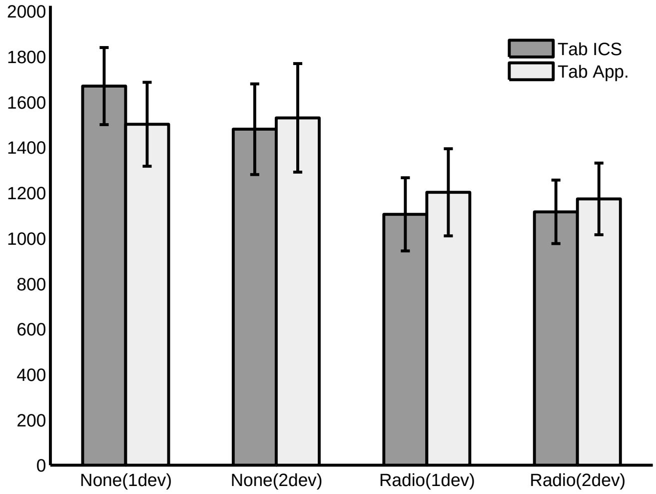


Figure 6-12: Bandwidth (download) comparison of the device under test (Nexus S) while tethering using the developed application and the built in feature. Comparison of different types of traffic (no traffic, radio streaming and video streaming) taking in consideration multiple devices connect to the provider (one or two devices connected). Values represent the average of the measured download bandwidth (20 samples) and a confidence interval is also given using the standard deviation function.

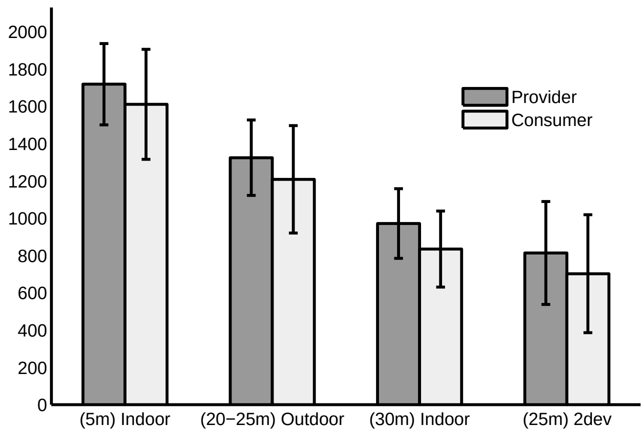


Figure 6-13: Bandwidth (download) dependency on distance between the provider (Nexus S) and the consumer (Samsung tablet). Comparison of different Indoor and Outdoor scenarios. Values represent the average of the measured download bandwidth (20 samples) with a confidence interval (standard deviation).

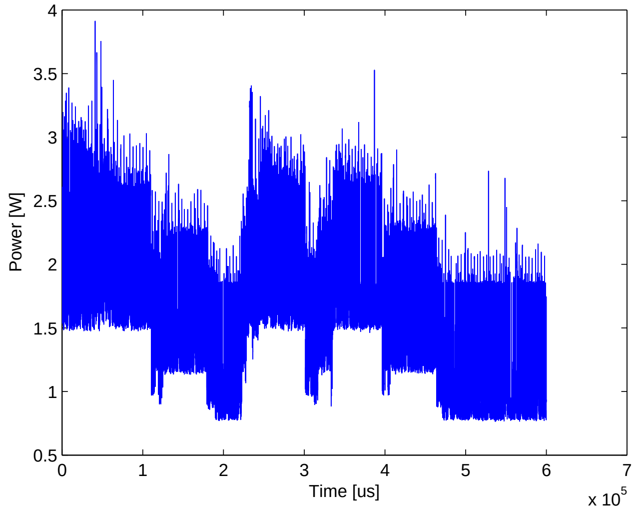


Figure 6-14: Power consumption of the developed tethering application; the scenario presented shows the power plot of a device tethering, without any other device connected

6-5-2 Battery lifetime

Another parameter of the analysis is the battery lifetime of the device. Tests performed on the device under test (Nexus S) aim a comparison with the previous performed tests on the ICS tethering application.

Further investigations on the power consumption while tethering were realized as shown in Figure 6-14. The following cases were tested for a device under test (Nexus S):

- Not tethering, normal behavior
- Tethering no device connected
- Tethering 1 device connected, no traffic
- Tethering, 1 device, radio streaming

The tests followed the power performance of the device and the impact of tethering on the device's consumption.

The power and energy consumption and impact of tethering using the developed application are shown in Table 6-3 and Figure 6-15.

It can be observed that tethering using the developed application has a similar impact on the battery with the current firmware implementation.

Thus, the developed tethering application, with its implemented features and current architecture and mode, do not have an impact on the technical performances and costs of sharing the data connection.

Scenario	Average Power	Average Energy
Tethering OFF	1,09 W	65.56 J
Tethering ON	1,28 W	77.07 J
Tethering ON, device connected	1.30 W	78.49 J
Tethering ON, device connected and radio streaming	1.49 W	88.30 J

Table 6-3: Average power and energy consumption per scenario

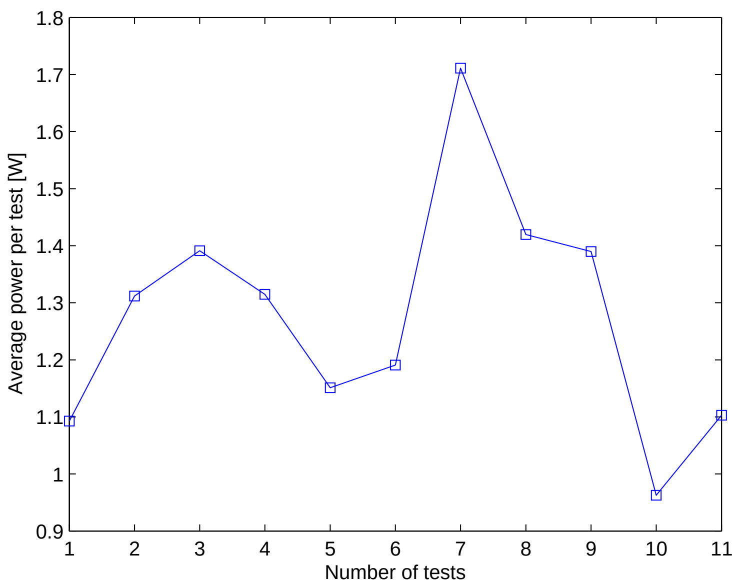


Figure 6-15: Power average consumption per test: 1. normal (tetherin not turned on), 2.tethering on, 3. device connected, radio streaming 4. device connected, 5. tethering, no device connected 6.tethering, device connected, 7. tethering, device connected and radio streaming, 8. radio off, 9. radio on, 10.radio off, 11. device disconnected

Chapter 7

Conclusions

The thesis proposed to make a complete analysis of sharing mobile data connection and building a cooperative network by using a tethering application. Thus, in order to achieve this purpose we have used a variety of methods and knowledge from various fields. The thesis represents a broad analysis that integrated technical research, with market and behavioral studies.

The thesis was looking to find out why and how do people share their mobile data connections or if not willing to how to make them share with others in order to build a cooperation network. We investigated possible rules for the evolution of cooperation, gave some answers and offer possible mechanisms.

We studied ways to share resources and tested the mechanisms proposed for the mobile tethering game. As a solution for the cooperative network proposed, we developed an application that allows users to find peers that are looking for a connection or are willing to sell or give for free their data connections.

The main conclusion is that an application as the one developed by us is necessary and people are willing to use such an application. There are a series of recommendations that might improve tethering as a cooperative service. Depending on the people involved in the exchange, there should be different profiles and we might use different mechanisms. The reward should be greater for an interaction with an unknown users. There are also optimum combinations of parameters that might influence the willingness to share. If the costs of sharing are too high or higher than the moral benefits than the exchange needs to be rewarded differently.

The learnings of this work are that a cooperative tethering network is viable technically and based on people's choice. It can bring added value to the users and to the mobile telecommunications industry. Even though tethering is dependent on the performances of the telecommunication infrastructure and on the network operators per ensemble the quality of tethering as a service is good and we estimate an increase of usage. Of course, it needs some help and it has to be backed up by further research and technological development.

Thus, based on the analysis and results of this work it can be stated that the thesis represents a broad research providing valuable ideas.

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Glossary

Best response is the strategy that gives a player a maximum payoff, given the strategies the other player has chosen or can be expected to choose.

Payoff Table is a table with the strategies of two or more players along the margins and the payoffs to the players (strategies) in the cell. Each strategy corresponds to a column or row and so the payoffs in a cell are the payoffs for the strategies that correspond to the column and row.

Extensive form The game is represented as a tree diagram in which each strategic decision is shown as a branch point.

Normal form A game is represented in normal form when it is shown as a table of numbers with the strategies listed along the margins of the table and the payoffs for the participants in the cell of the table.

Any game can be represented in both forms (extensive or normal) but for some games one of the forms can be more intuitive (sequential games - extensive form)

Dominant strategy whenever one strategy yields a higher payoff than a second strategy, regardless of which strategies the other player chooses, the first strategy dominates the second. If one strategy dominates all other strategies (for a particular player in the game), it is said to be a dominant strategy (for that player).

Dominant Strategy equilibrium if in a game, each player has a dominant strategy, and each player plays the dominant strategy, then that combination of (dominant) strategies and the corresponding payoffs are said to constitute the dominant strategy equilibrium for that game.

Cooperative and Non-cooperative solutions - The *cooperative solution* of a game is the list of strategies and payoffs that the participants would choose if they could commit themselves to a coordinated choice of strategies; for example, by signing an enforceable contract. The strategies and payoffs they would choose if there are no enforceable agreements is the *non-cooperative solution.*

Social Dilemma - if the game has a dominant strategy solution that is different from the cooperative solution to the game, the game is a social dilemma.

Nash Equilibrium (NE) - in any non-cooperative game, when each player chooses the strategy that is the best response to the strategies that the other players choose that is a Nash equilibrium. For any game in normal form, if there is a list of strategies, with one strategy per player, such that each strategy on the list is the best response to the other strategies on the list, that list of strategies is a Nash equilibrium.

Coordination Game - A game with two or more Nash equilibria may present a coordination problem, in that the players could have difficulty deciding which equilibrium will occur and thus in coordinating their strategies.

Payoff Dominant and Risk Dominant Equilibrium - if there are more than one equilibria, and one of them yields a higher payoff to each player than the others do, it is said to be the payoff dominant equilibrium. If one of them gives the smallest maximum loss to each player, it is said to be the risk dominant equilibrium.

Utility - a numerical measure of the subjective benefits an individual derives from a particular good, service, income, or payoff.

Pure Strategies - every game in normal form is defined by a list of strategies with their payoffs. These are the pure strategies in the game.

Mixed or randomized strategies - in a game in normal form, a player who chooses among the list of normal form pure strategies according to given probabilities (2 or more which are positive) is said to choose a mixed strategy.

Mixed strategy equilibrium - a Nash equilibrium in which one or more of the players chooses a mixed strategy is called a mixed a strategy equilibrium.

Strongly and weakly dominated strategies - whenever one strategy yields a payoff strictly greater than that of a second strategy, regardless of which strategies the other players choose, the second strategy is strongly dominated by the first. If the first strategy yields a payoff that is not less than the second strategy, and sometime more, then the second strategy is weakly dominated by the first.

Cooperative and Non-cooperative games and solutions - if the participants in a game can make credible and binding commitments to coordinate their strategies, then the game is cooperative, and otherwise it is non-cooperative.

Sequential games - a game is represented in extensive form when it is shown as a sequence of decisions. The game in extensive form is commonly shown as a tree diagram. A subgame of any game consists off all nodes and payoffs that follow a complete information node. If the subgame is only part of the game it is called a proper subgame.

Subgame perfect equilibrium - a Nash equilibrium in a game in extensive form is a subgame perfect if it is an equilibrium for every subgame. A subgame in a game in extensive form is basic if it contains no other proper subgames (otherwise complex subgame).

Backward Induction - is a method of finding subgame perfect equilibria by solving the basic subgames, substituting the payoffs back into the complex ones, solving those, and working back to the beginning of the game.

Repeated games - when a game is played repeatedly, we must analyze the sequence as a whole, and the subgame perfect equilibrium of the sequence is the equilibrium of the game. The widely held intuition that non-cooperative games played repeatedly may often have cooperative equilibria is called the folk theorem of game theory.

Indefinitely repeated games - when a game is played repeatedly, but with no definite end point, we treat the game as if it were repeated infinitely many times, and the subgame perfect equilibrium of the sentence is the equilibrium of the game.

Trigger strategy (Tit-for-Tat, Grimm) - a rule for choosing strategies in individual repetitions in an indefinitely repeated game is called a trigger strategy if the rule is that non-cooperative play triggers one or more rounds of non-cooperative play by the victim in retaliation.

Reciprocity - when people deviate from self-interested rationality to return favors or wrongs, they act with reciprocity.

Evolutionarily stable strategy - A Nash equilibrium that is stable under the replicator dynamics is an evolutionarily stable strategy equilibrium.