Mobile Cloud Ecosystems

Evaluating the feasibility and viability of smartphones as a shared resource pool

Soebhaash Dihal - 1048902
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Delft University of Technology, Faculty of Technology, Policy and Management
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Graduation Supervisors:
Chair: Prof. dr. Yao-Hua Tan - ICT section
Officious Chair: Prof. Harry Bouwman - ICT section
First Supervisor: Dr. Ir. Mark de Reuver - ICT section
Second Supervisor: Dr. Martijn Warnier - Systems Engineering section
External Supervisor: Pieter van Houten RE MSc - KPMG Advisory

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Foreword

This thesis is the final product of my Masters' graduation project at Delft University of Technology. During this project I have enjoyed immersing myself in the world of telecommunication innovations, which have fascinated me ever since my first dial-up modem and mobile phone. Many people have helped me complete this thesis. I would like to thank them for their input.

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Abstract

The increasing ubiquity and capabilities of smartphones provide opportunities to combine their processing power, storage, connectivity and sensors into a shared resource pool for end-users and service providers. This is analogous to the concept of cloud computing, in which cloud computing datacenters provide a shared resource pool. Several technological architectures and prototypes exist in which smartphones themselves serve as such a mobile cloud computing resource pool. However, little guidance is available regarding the possibilities for commercialization of mobile cloud computing.

This study identifies factors influencing the feasibility and viability of the mobile cloud concept in order to provide input for future mobile cloud business models. To this end the opportunities for mobile cloud to deliver multi-sided platforms are explored. Multi-sided platforms serve as matchmakers between supply and demand side customers, while the platform owner can benefit from mediating between different types of customers. Mobile cloud platforms can mediate between end-users of mobile cloud services, individuals providing smartphone resources and service providers. To evaluate the feasibility and viability of mobile cloud platforms, ecosystems theory is used to formulate a set of qualitative criteria for the role divisions, structures and performance of multi-sided platforms. The criteria have been applied in fourteen semi-structured interviews with mobile industry experts, resulting in a range of success factors and inhibitors for mobile cloud ecosystems.

With regards to ecosystem role divisions it is noted that mobile cloud platforms are most likely to succeed when positioned in existing strong ecosystems with large user bases of service providers and service consumers, such as those of the handset operating systems and internet based service providers. Operators lack such ecosystems and innovation capabilities and are therefore less likely mobile cloud platform owners. However, their support may still be required as end-users incur data subscription costs and cause inter-operator traffic handoff when sharing smartphone resources via the operator network. Billing mechanisms between users and between operators may need to be adapted to take this into account.

With regards to ecosystem structure a mobile cloud platform owner can benefit from the revenues obtained by providing third parties and end-users access to a shared mobile resource pool, which may include unique and desired resources such as sensors. However, this coordinating platform ownership position may be difficult to maintain as similar access to mobile resources may be obtained by installing specific-purpose applications on smartphones. Operators and handset OS developers may therefore struggle to maintain platform control as internet-based service providers can use web-based cross-platform applications to gain access to any number of smartphone resources, regardless of geography and hardware.

The performance of mobile cloud ecosystems is currently considered to be hampered due to current technological limitations and market conditions. Scarce and perishable smartphone resources, limited, expensive bandwidth and lack of clear end-user sharing incentives are the most visible hurdles, along with the security, privacy and legal concerns associated with smartphone resource sharing. While some of these issues may be addressed over time with technical and network improvements, these improvements may also disrupt the need for smartphone resource sharing. Faster operator networks diminish the need to share connectivity, while increasing smartphone power and cloud computing datacenters reduce the need to offload computing tasks to other smartphones. This potential performance of mobile cloud platforms is

expected to change when more collaborative services making use of multiple devices are conceived, rather than considering mobile devices as a straightforward resource pool akin to cloud computing datacenters. A shared pool of smartphone sensors is expected to lead to innovations of which both end-users and service providers can benefit. Additionally it is noted that in private or community environments such as homes and offices some of these performance hurdles may not apply, as they provide an environment where trust and cost are less of an issue and appliances are more visible than in a general purpose resource pool.

Follow-up research towards mobile cloud platforms could focus on mechanisms to award smartphones users for opting in to a shared resource pool. Furthermore, operator, device and service provider centric ecosystems could be further specified in terms of role divisions, relations and platform assets shared using the success factors and inhibitors uncovered in this research as a basis. Finally, as mobile cloud can potentially seamlessly integrate with the traditional cloud, future research could explore ways to optimize whether the resources of a traditional cloud datacenter, a local mobile cloud resource or a remote mobile cloud resource are acquired depending on cost and connection properties.

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1 Introduction: Cloud Computing

Cloud computing is a paradigm in which computing resources are placed outside of devices and accessed via the network (Hayes, 2008), tracing back to concepts such as 'the network is the computer'. This broad interpretation of cloud computing includes network access to storage, processing power, development platforms and software. In the cloud computing paradigm such computing resources are acquired as a service rather than purchased or deployed locally. Well known cloud computing services include Software as a Service, Platform as a Service and Infrastructure as a Service (NIST, 2011).

Cloud computing can offer advantages such as ubiquitous access to online resources and cost savings by reducing investments in local computing equipment (Vaquero, Rodero-Merino, Caceres, & Lindner, 2008). This is in part achieved by the principle of multi-tenancy, a software architecture in which multiple customers share a large resource pool but only perceive their own current resource share. For cloud computing service providers, multi-tenancy offers the benefits of increased resource utilization and economies of scale. Idle resources are available to serve any consumer when required and are balanced in real-time amongst active and idle consumers (Bezemer, Zaidman, Platzbeecker, Hurkmans, & 't Hart, 2010). For consumers this provides the appearance of near-infinite computing resources available on demand (Armbrust et al., 2010).

When extended to mobile devices, cloud computing allows access to services which would otherwise be limited by mobile device constraints (Christensen, 2009). Mobile devices vary in processor capabilities, operating systems, form factors, input methods, display properties, storage and memory capacity as well as in battery lifetime. This restricts the amount of tasks which can be performed on mobile devices and causes fragmentation in the availability of mobile services, as service developers can only support so many devices (Kumar & Lu, 2010). With cloud computing some of these device constraints can be addressed as resource-intensive tasks are left for more capable systems and accessed on the mobile device using standard web interfaces such as browsers (Chun & Maniatis, 2009). For consumers this allows amongst others on-the-move access to documents and services regardless of the device wielded, since storage, processing and service hosting occurs online rather than within the device. A similar device independency advantage applies for service developers, which can suffice with a single version of their services located 'in the cloud' rather than repeatedly tailoring services to heterogeneous devices. Aside from alleviating device limitations cloud computing can also enable new intelligent mobile services, using the context information collected from device sensors in collaboration with the cloud to deliver customized services (Q. Wang & Deters, 2009). An example of this is seen in augmented reality, which matches mobile camera images with product or location information located in the cloud.

Shifting computing tasks to cloud computing can have several drawbacks as well. Privacy, security and trust issues arise when computing resources are handled by third parties and accessed via the network (Pearson & Benameur, 2010). Privacy is an issue as customers have less insight in how their personal information is stored, processed, accessed, deleted etc. Furthermore privacy laws vary per country or continent, while cloud computing can entail cross-border storage of personal information. This complicates compliance for (multinational) organizations. Security is a second issue, including amongst others malicious employees at the cloud computing provider, vulnerabilities in the technology to separate shared resources, data loss or leakage, hijacking of online accounts, interception of data sent via the internet and unsecured application programming interfaces (API's) which facilitate interaction between cloud computing services (Cloud Security Alliance, 2010). Trust is a third issue as customers hand over control of their resources and data to cloud computing service providers. Contractual mechanisms such as service level agreements (SLA's) can offer a degree of trust regarding abuse, availability of service and compensation in case of breaches but questions remain regarding the ability to detect contractual breaches.

1.1 Inverting the Cloud Paradigm

In the traditional cloud computing paradigm mobile devices typically acquire computing resources in a client-server architecture, where mobile devices are resource-light clients and collections of non-mobile servers in datacenters provide computing resources (Shanklin, 2009). The current generation of mobile devices is interwoven with such datacenter-based cloud computing services. This is reflected in the cloud computing services bundled with mobile devices. Apple's iCloud service for example provides large online storage capabilities that allow users access to their data from desktops, smartphones, tablets and portable media players. A drawback of this client-server model is that it creates a large dependency on the mobile network operator (MNO), which may be a bottleneck due to coverage, bandwidth and latency issues. Similarly, the cloud computing provider can be a single point of failure for service availability.

An upward trend in mobile device capabilities could bring changes to the typical client-server model used in cloud computing. Mobile devices -especially smartphones- 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 smartphones themselves. This can diminish the need to offload computing tasks to the cloud, but also provides new opportunities to use the increasingly ubiquitous smartphones themselves as a cloud computing resource.

Whereas current smartphones perform tasks separately or in collaboration with remote cloud computing services, smartphone resources can be combined into a larger mobile cloud construct (Elespuru, Shakya, & Mishra, 2009; Shanklin, 2009; Warner & Karman, 2010). Mobile services could then utilize this mobile cloud for services based on combined smartphone resources, such as using multiple microphones for 3D audio recordings (Wijngaert & Bouwman, 2009). This could also reduce the dependence on a traditional cloud computing provider by allowing computing tasks to be flexibly offloaded to both mobile and non-mobile clouds (Zhang, Schiffman, Gibbs, Kunjithapatham, & Jeong, 2009). Mobile clouds can also aid in avoiding MNO connectivity bottlenecks, by distributing tasks directly between mobile devices (Marinelli, 2009). Furthermore unique mobile resources are added to the cloud computing resource mix, including sensors (Beng, 2009) and connectivity (Ananthanarayanan & Zats, 2009). In practice this could translate to end-users being able to augment the capabilities of their device using other mobile resources, possibly speeding up computation or download speeds. Mobile clouds could also serve third parties, such as a government collecting noise levels in specific geographical areas using smartphone sensors.

Using mobile devices as a cloud computing resource could therefore present several new business opportunities. End-users could be paid for providing their smartphone resources. Collaborative applications based on multiple devices are possible, enabling a new breed of mobile services. Cloud computing vendors could possibly extend their resource mix with sensors. Regardless of these opportunities, mobile cloud computing currently only exists as a number of prototypes and architectures. Business perspectives on the technology are less developed. As the technology is not available in the market yet, our study explores the business considerations enabling actors might have when adopting mobile cloud computing and how mobile cloud computing could impact the creation of services in the mobile domain.

A starting point for this exploration is that mobile cloud architectures generally contain a coordinating role or platform to interconnect multiple smartphones, making these available as resources for other smartphones or developers wanting to deploy services on them. This platform has three types of customers: the service providers that use the functionality of the platform, the end-users of the services delivered by the platform and the end-users providing mobile resources to the platform. Multi-sided market theory provides insight into how such platforms serve as matchmakers and demand coordinators to connect different groups of customers with shared facilities (Evans, Hagiu, & Schmalensee, 2008).

1.2 The Ecosystems around Multi-Sided Platforms

In the mobile domain multi-sided markets are the most visible in app stores, with developers on one side and end-users on the other side of the platform. Developers benefit from a critical mass of mobile phone users, whereas consumers are attracted by a wide range of applications. The environment of such a multi-sided platform can be labeled as an ecosystem. Gawer's (2009) definition of platforms provides more insight in the link between technology platforms and ecosystems: *"platforms serve as technological building blocks (which can be technologies, products, or services) that act as a foundation on top of which an array of firms, organized in a set of interdependent firms (or ecosystem) develop a set of inter-related products, technologies and services"*. Mobile cloud platforms with matchmaking properties can thus be considered as the foundation of ecosystems.

Studies towards ecosystems in the mobile domain are conducted with many different levels of focus, making it unclear what exactly the analysis of an ecosystem entails. Under the label of ecosystems we encounter generic studies towards industry structures or product architectures (Vesa, 2003), market analysis of different geographical areas (Hou, 2011), mapping of industry dynamics (Basole, 2008), product specific studies such as handset ecosystems (Gueguen & Isckia, 2011), service specific studies such as mobile advertising ecosystems (Wong, 2008), analysis of innovation in ecosystems (Adner & Kapoor, 2010) as well as more high-level technology or service ecosystems studies (De Reuver, Bouwman, & Visser, 2010).

Our mobile cloud study joins the ranks of research towards technology and service specific mobile ecosystems. This focus is of interest as we are dealing with (potentially) emerging mobile cloud platforms, while the emergence of platforms is traditionally accompanied with competition for platform leadership as well as competition between open and closed business models around platforms (Chesbrough, 2003; De Reuver, Bouwman, Prieto, & Visser, 2011). Platform competition in the mobile domain is increasingly on the level of ecosystems rather than on the level of firms. Recent examples include the rivalry between HD DVD and the Blu-Ray consortium (Den Hartigh, Ortt, Van de Kaa, & Stolwijk, 2009) and Windows versus Apple's Mac OS. In the mobile world we see similar increasing platform-plus-ecosystem competition between supporters of mobile operating systems, e.g. the Nokia and Microsoft alliance versus Android, Android versus iOS.

Mobile cloud could reinforce existing platform competition, or trigger new competition between emerging mobile cloud platforms. According to Gawer's (2009) definition of platforms mobile cloud platforms could bring together an array of firms with inter-related products, technologies or services. However it is unclear what products, technologies or services are common to mobile cloud as mobile cloud approaches strongly vary in literature.

1.3 Research Focus

Summarizing the previous sections, the owner of a mobile cloud platform can be a central hub in connecting individual owners of mobile device resources with developers of mobile services and end-users consuming these services. However, many different combinations of technology and collaboration models for mobile cloud can be conceived, with unknown value and likelihood of success. We now discuss the knowledge gaps around mobile cloud and the relevance of addressing these knowledge gaps.

1.3.1 Knowledge Gaps

From the discussion of mobile cloud and ecosystems three categories of knowledge gaps are identified. First, the concept of mobile cloud computing is not clearly delineated. This is in part due to a lack of consensus in research and practice on what cloud computing itself entails. The mobile cloud concept however also appears similar to technologies such as peer-to-peer networks, mobile grids, mobile clusters and mobile ad-hoc networks. It is unclear how mobile cloud relates to these technologies.

Secondly, knowledge gaps are noted around business models for mobile cloud computing and the possible impact of mobile cloud on the proliferation of mobile services. Business models are a blueprint to describe how organizations can co-operate to create and capture value from technical innovations (Faber et al., 2003). Business models around mobile cloud platforms may be unique as unlike traditional cloud computing datacenters, a shared smartphone resource pool may have many individual resource owners which could be compensated for using their device. Currently it is unknown who coordinates these mobile resources, how this is technically arranged and whether different coordination models have diverging chances of success. De Reuver et al (2011) state that platforms can be operator centric, device centric or service provider centric. No specific indications exist on how mobile cloud platforms would be arranged at these positions. Similarly the position of the individuals providing smartphone resources is unclear as they may need to be compensated or provided other incentives to share. Though some researchers have explored the factors influencing the willingness of smartphone owners to share their device (Wijngaert & Bouwman, 2009) such research is often focused on ad hoc resource sharing on the level of individuals, rather than making a smartphone available in a general purpose resource pool.

The third knowledge gap is regarding ecosystems. Interactions between platform enablers and platform customers can also be labeled as an ecosystem (Basole, 2009; Gawer, 2009). While the ecosystems approach provides insight in the properties of multi-sided platforms we require a further understanding of ecosystems as an analytical approach to be able to evaluate mobile cloud ecosystems. Though there are many different approaches to studying ecosystems in the mobile domain, there appears to be a limited amount of tools providing guidance for designing or evaluating new ecosystems (Adomavicius, J., Gupta, & Kauffman, 2006).

1.3.2 Practical and Scientific Relevance

Addressing the knowledge gap regarding the definition of mobile cloud is of scientific interest as technical papers aside there is limited literature available which consistently translates the concept of cloud computing to mobile resources. This gap can be closed in two ways. First, by applying formal definitions of cloud computing to the concept of mobile devices as a shared resources pool. Secondly, by seeking common grounds between mobile resource sharing concepts.

The mobile cloud business knowledge gap is of practical interest as closing this gap can provide industry players insight in their possible roles in provisioning mobile cloud services or platforms and new business models involving mobile end-user resources, as well as factors which could influence the success of mobile cloud services. Consequently, industry players may learn how to align their strategies to emerging mobile cloud computing platforms. During this research we take a neutral perspective on the mobile industry, looking at mobile cloud from a helicopter perspective rather than that of a specific industry actor. The results of this study may therefore be relevant for a large number of actors in the industry.

Addressing the third knowledge gap is of practical and scientific interest. Practitioners may learn about the dynamics of interactions around new mobile cloud platforms. From an academic perspective this research may contribute to a further understanding of ecosystems as an analytical tool and the relation between business models and ecosystems.

1.4 Research Objective and Questions

While existing prototypes lead us to assume that it is technically feasible to bring mobile cloud platforms to market, there are uncertainties regarding the feasibility of the ecosystem around these platforms. This includes issues such as the various possible arrangements for the role of mobile cloud platform owner, resource compensation and the relation with mobile service providers. Similarly, the subsequent chances of success of mobile cloud platforms in various arrangements are unknown. This can be expressed as a question of viability, which stands for to the potential value delivered for customers and enabling networks (H. Bouwman, Haarker, & De Vos, 2005).

Based on the stated knowledge gaps the objective of this research is formulated as follows:

Identify factors influencing the feasibility and viability of mobile cloud platforms within their ecosystem to provide input for defining mobile cloud business models.

This leads to the following main research question:

What is the feasibility and viability of mobile cloud computing platforms from an ecosystems perspective with regards to their positioning, enabling networks and ability to deliver streams of mobile services?

To structure the research we split this research question into three parts.

1. *What is mobile cloud computing and how is it related to cloud computing?*
   Cloud computing definitions vary and appear to change over time. We set a working definition for cloud computing as a basis to define mobile cloud computing. Using this definition possible variants of mobile cloud computing can be categorized. This separates the traits of mobile cloud from related

approaches such as peer-to-peer networks, mesh networks, ad-hoc networks and mobile grids and identify multi-sided mobile cloud platforms.

2. *What are the ecosystems around platforms and how can these be analyzed?*
   Ecosystems theory includes a wide range of theoretical domains related to mobile platforms such as inter-firm relations, emergent behavior, innovation and platform competition. We seek clarity in ecosystems as an analytical approach to evaluate the potential of conceptual mobile cloud platforms.

3. *What are success factors and inhibitors which determine the real-world feasibility and viability of mobile cloud platform?*
   Mobile cloud appears to be feasible from a technical perspective as witnessed in various prototypes. However, little is known regarding the feasibility of the organizational arrangements around mobile cloud and the business viability of the mobile cloud service proposition in a real-world setting. We seek perspectives from practitioners to determine strengths and flaws in current mobile cloud concepts.

We answer the research questions using two research methods: literature review and interviews.

1.4.1 Literature Review

The first two research questions are answered with the aid of scientific literature on cloud computing and ecosystems. Several authors have previously structured the definition of cloud computing (Armbrust, et al., 2010; Geelan, 2008; Vaquero, et al., 2008e.g.). Their definitions provide a starting point for defining mobile cloud. On the topic of ecosystems as an analytical approach Iansiti & Richards (2005) provide measures of ecosystem health and performance, which may provide a starting point to define feasible and viable ecosystems. Aside from scientific literature, grey literature will be consulted to study mobile industry trends which may influence mobile cloud computing. Literature sources to be consulted include:

- Scientific publications, journals and conference proceedings:
    - Initial keywords: mobile platforms, mobile ecosystems, multi-sided platforms, multi-sided markets, mobile cloud, mobile distributed computing, mobile grids, wireless grids, cloud computing
    - Databases: Elsevier Science Direct, Emerald, Scopus, Google Scholar, Safari, IEEE Xplore, SpringerLink, Scopus, Web of Science
- Consultancy publications
- Industry white papers
- Various websites:
    - Hardware and infrastructure providers (Qualcomm, Nokia-Siemens, Alcatel)
    - Network operator publications (KPN, Vodafone, T-Mobile, AT&T)
    - Industry alliances (JIL, WAC, Digital Living Network Alliance, Universal Plug and Play forum, Internet Home Alliance, Ambient Network project)
    - Research projects and research institutions (IAMSR, MAGNET, Freeband, TNO)

1.4.2 Interviews

Studying the real-world feasibility of mobile cloud platforms requires insight beyond that of scientific and grey literature. We therefore turn to interviews to support the explorative nature of this study. Interviews are suitable for this qualitative research as broad range and depth in relevant factors influencing mobile cloud are sought (Verschuren & Doorewaard, 2005). Interviews will complement the literature review with tacit knowledge and multiple perspectives from experts and stakeholders in the industry. The interviews will be semi-structured in nature to allow respondents room for their own input while maintaining a structured flow of analysis. The interview results will be interpreted in a qualitative way, using the ATLAS.ti software tool to process interview transcripts. ATLAS.ti aids in constructing visual relations between concepts in textual data and evaluating the strength of these relations. To obtain a broad amount of perspectives 10-15 interview candidates from different backgrounds and roles will be consulted, including:

- Consultancies
- Researchers
- Mobile (Virtual) Network Operators
- Application developers
- Content and Service Providers
- Messaging Service Providers
- Device Manufacturers
- Infrastructure Providers

A more extensive description of the respondent selection and interview setup will follow in chapter 4.

1.5 Thesis Outline

Each sub question is focused on in one chapter of the thesis. Chapter 2 clarifies the concept of cloud computing and mobile cloud computing. Chapter 3 discusses ecosystems theory and seeks analytical tools for mobile cloud ecosystems. Chapter 4 presents the interview setup and the methodology of processing interview results. Chapter 5 presents the interview results: success factors and inhibitors for the real-world feasibility and viability of mobile cloud platforms (Figure 1). Chapter 6 discusses conclusions, limitations of this research and presents recommendations for follow-up research.

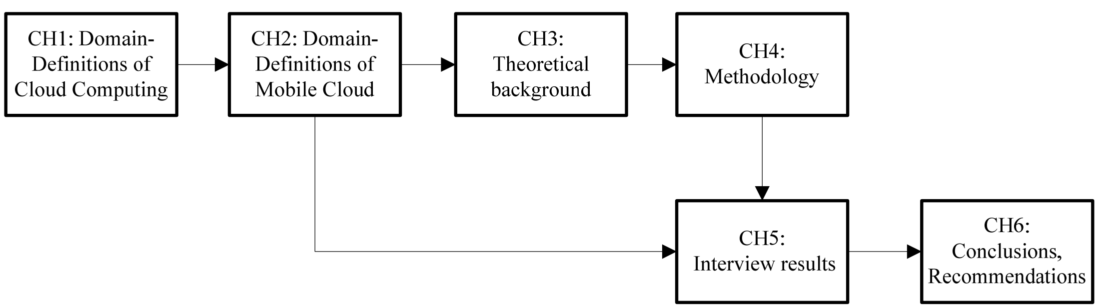

Figure 1 - Thesis outline

2 Mobile Cloud Computing

The introductory chapter briefly addressed the different possible interpretations of mobile cloud computing used in literature and practice. The definition of cloud computing (or 'cloud') itself is a topic which has been extensively debated both in industry and science. Cloud computing definitions appear to be constantly changing under the influence of both technology and industry marketing practices, providing little guidance in extending these definitions to the mobile domain. This chapter therefore focuses on the question: *What is mobile cloud computing and how is it related to cloud computing?*

To gain an understanding of how to define mobile cloud computing we first compare cloud computing compared with the wider range of computing concepts it is associated with in section 2.1. From here we seek formal definitions of cloud computing in literature and practice in section 2.2. With the selected working definition we fine-tune our understanding of cloud computing in section 2.3, by studying its component parts and discussing use cases and associated technology. This provides us with the means to present a breakdown and definition of mobile cloud computing in section 2.4. The chapter is concluded in section 2.5.

2.1 Cloud Related Computing Paradigms

In 1984 several employees from Sun Microsystems coined the phrase "The network is the computer" (Oracle Labs, 2004). Cloud computing is an effectuation of this concept, shifting the location of computing infrastructure to the network (Hayes, 2008). Cloud computing touches upon many related computing concepts in which consumers can obtain computing resources without being bound to a specific location or device, such as ubiquitous computing, pervasive computing and ambient intelligence. The (dis)similarities of cloud computing with such earlier established computing concepts are an often discussed topic, where comparisons with utility computing, grid computing and cluster computing repeatedly emerge (Armbrust, et al., 2010; Buyya, 2009; Vaquero, et al., 2008; L. Wang & von Laszweski, 2008). As with cloud computing, scientists and practitioners have struggled to clearly define these paradigms, making the distinction between clouds, grids, utilities and clusters somewhat unclear. (Vaquero, et al., 2008). As many of these computing concepts also have mobile counterparts, e.g. mobile grids (McKnight, Howison, & Bradner, 2004) we briefly explore their main characteristics.

We start off exploring the link between *cloud and utility computing*. Some researchers expect computing to join the other utility services of water, electricity, gas and telephony (Armbrust, et al., 2010). With computing as a utility service consumers would only pay when accessing the computing service, without infrastructure or maintenance expenditures (Buyya, 2009). Most authors agree that cloud computing does in fact have these pay per use and expenditure saving properties of utility computing (Armbrust, et al., 2010; Buyya, 2009; Vaquero, et al., 2008; L. Wang & von Laszweski, 2008). Cloud computing as a true utility service has yet to mature however, as different vendors use proprietary interfaces for their services. This hampers the possibility to connect different cloud computing services and with that the ability to ubiquitously provide access to computing services. This ubiquitous access is a prime trait of utility services (Armbrust, et al., 2010; Buyya, 2009). Research towards connecting cloud computing services from different vendors is however ongoing. The vision is held that at some point in time a combined, global market for trading computing services should be available, much like energy is currently traded (Buyya, 2009).

Continuing with the energy source analogy we move to *grid computing*. According to Chetty and Buyya (2002) grid computing is inspired by the electric power grid's properties of pervasiveness, ease of use and reliability. The most commonly cited definition of Grid computing appears to stem from the work of Ian Foster (2002; 2001, p. 1) *"A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities"*. Foster (2001) further specifies his definition by stating that a grid is a system that coordinates resources which are not subject to centralized control, using standard, open, general-purpose protocols and interfaces to deliver nontrivial qualities of service. Grids combine the computing resources of different organizations and dynamically allocate and share these resources to solve large-scale resource intensive applications, providing more horsepower than a single (super)computer or computer cluster would be able to provide (Buyya, 2009). Resource management and computing prioritization across multiple organizations are a challenge in grid computing as multiple organizations have different budgets and priorities and central control is lacking (Vaquero, et al., 2008).

Cluster computing entails groups of computers combining their resources to perform computing tasks. Buyya (2009, p. 2) defines clusters as: *"A cluster is a type of parallel and distributed system, which consists of a collection of inter-connected stand-alone computers working together as a single integrated computing resource"*. Unlike grids, clusters are often managed by a single organization (Buyya, 2009). Clusters can be used for redundancy purposes to ensure that a single computer failure does not affect computing availability, for load balancing to ensure proper handling of large numbers of requests and for high performance computing such as weather simulations. Practical examples of cluster computing can be seen in projects such as folding@home or seti@home. In these projects processing workloads are distributed across a large network of commodity computers and combined by a research organization, such as Stanford University in the case of folding@home. Another example is found in Google's search engine, which is powered by large clusters of computers to meet the huge amounts of search engine requests Google receives at any time (Yeo et al., 2006).

The common characteristic of utility, grid and cluster computing is that they combine a multitude of dispersed computing resources via networks. The differences between these concepts are in the number of owners of the combined computing resource and the audience which is allowed to tap into the combined resources (Table 1). Cloud computing in the current market differs from all three concepts as it consists of dedicated data centers in which multiple computers are combined using virtualization, while computing capacity is dynamically allocated according to client-specific service level agreements. This combined computing pool is then shared across a number of consumers (Armbrust, et al., 2010; Buyya, 2009). This combined computing pool could perhaps consist of mobile devices owned by individuals. Before elaborating on that subject in section 2.4 the next sections will focus on further defining cloud computing.

Table 1 - Differences in ownership and consumption audiences in computing paradigms

Computing concept	Ownership over computing resources	Consumers of computing resources
Utility Computing	Heterogeneous computing suppliers	Global market
Grid Computing	Multiple organizations	Grid member organizations
Cluster Computing	Single managing organization	Managing organization
Cloud Computing	Single computing supplier	Multiple consumers, shared

2.2 Cloud Computing Definitions

The confusion regarding the definition of cloud computing can be attributed to both the diversity of technologies and concepts associated with cloud computing as well as hype from the media and IT industry. The generic cloud interpretation of 'shifting the location of computing infrastructure to the network' (Hayes, 2008) could include any kind of computing capacity delivered via network facilities. Many older computing concepts have therefore been relabeled under cloud computing as they fit this interpretation, but also as they fit the marketing purposes of computing vendors. According to Gartner (2008) this is in line with the first phase of a 'Hype Cycle', which describes how technology hype goes from overenthusiasm through a period of disillusionment to an eventual understanding of the technology relevance and a role in a market or domain. We currently witness a lack of consensus as researchers, vendors, consultancies and others parties all provide their own interpretations of cloud computing. Research initiatives such as those of Vaquero (2008) and Geelan (2008) collect cloud computing definitions to obtain common denominators, but typically also arrive at inconclusive and diverging definitions. Table 2 presents several of such attempts to arrive at a comprehensive definition.

Table 2 - Overview of cloud computing definitions in literature

Author	Definitions
(Vaquero, et al., 2008, p. 51)	"Clouds are a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically re-configured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized SLAs."
(L. Wang & von Laszweski, 2008, p. 3)	"A computing Cloud is a set of network enabled services, providing scalable, QoS guaranteed, normally personalized, inexpensive computing platforms on demand, which could be accessed in a simple and pervasive way."
(Buyya, 2009, p. 2)	"A Cloud is a type of parallel and distributed system consisting of a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resource(s) based on service-level agreements established through negotiation between the service provider and consumers."
(Armbrust, et al., 2010, p. 1)	"Cloud Computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the datacenters that provide those services. The services themselves have long been referred to as Software as a Service (SaaS), so we use that term. The datacenter hardware and software is what we will call a Cloud. When a Cloud is made available in a pay-as-you-go manner to the public, we call it a Public Cloud; the service being sold is Utility Computing. We use the term Private Cloud to refer to internal datacenters of a business or other organization that are not made available to the public. Thus, Cloud Computing is the sum of SaaS and Utility Computing, but does not normally include Private Clouds."
(NIST, 2011, p. 6) Short extract from full 676 word definition	"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models[1]."

[1] Further discussed in section 2.3

Looking at these definitions we notice their length diversity, which suggests that cloud computing is a very multi-facetted notion. Table 3 presents which elements are common in these cloud definitions.

Table 3 - Presence of common elements in cloud computing definitions

Element / Author(s)	Vaquero (2008)	Buyya (2009)	Wang&von Laszweski (2008)	Armbrust et al (2010)	NIST (2011)
Virtualization of resources	Yes	Yes	-	-	Yes
Variety of resources	Yes	-	-	-	Yes
Shared resource pool	-	-	-	-	Yes
Scalability (automatic/dynamic)	Yes	Yes	Yes	-	Yes
Convenience in use and access	Yes	-	Yes	-	Yes
Network enabled	-	-	Yes	Yes	Yes
Service Level Agreements (SLA's)	Yes	Yes	Yes	-	Yes
Pay-per-use	Yes	-	-	Yes	Yes

We derive two conclusions from Table 3. The first conclusion is that none of the eight elements are common to all five definitions, illustrating a lack of consensus. The second conclusion is that with the exception of virtualization, none of the common elements explicitly refer to a specific type of technology. The common elements instead appear to refer to the conditions under which cloud computing resources are acquired (network access, pay-per-use, SLA's, convenience) and the properties of the resources acquired with cloud computing (virtualized, varied, shared, scalable). Cloud computing is therefore often considered a paradigm (e.g. Hayes, 2008) or a paradigm shift – a change in the way we observe contemporary phenomena in computing. As noted in the common elements, virtualization is an enabler of this paradigm. Virtualization is a technique which hides the physical characteristics of computing resources from the way in which other systems, applications or end users interact with those resources. Virtualization of both hardware (data, storage, memory, processors, network) and software is possible, such as operating systems (OS). An example could be that a Windows mobile OS device runs a *virtual machine* with the Android OS. The user of the mobile device can then run Android applications on a Windows based mobile phone. A more typical example is that multiple virtual machines are deployed on a single physical server, running multiple instances of the same software or completely independent types of software. The users of this software are unaware of the properties of the server underneath and the other virtual machines running on the server. An example of this is found in webhosting, where multiple website owners perceive only their own share of web space, even though their websites are hosted on the same server.

With the selected cloud definitions and their common elements we have deepened our understanding of cloud computing. It is not our intention to extract a new definition of cloud computing from these common elements. Rather than this we seek guidance in pinpointing what is meant by cloud computing to capture what mobile cloud computing entails. For this purpose we select to work with the cloud definition wielded by the U.S. National Institute of Standards and Technology (NIST) as cited in Table 2. The NIST (2011) definition is chosen to work with for three reasons. First, the NIST definition is the most comprehensive, covering all of the common elements encountered in other definitions and beyond (Table 3). Second, at the time of writing it is the most well-known definition to have been recently updated -in

January 2011- which we consider important due to evolving nature of cloud computing. Third, the NIST definition breaks down different aspects of cloud computing into three broadly acknowledged components: characteristics, service models and deployment models. This breakdown provides guidance in uncovering the multiple facets of cloud computing and applying these to the mobile domain. In the next sections we will discuss this breakdown of the NIST definition.

2.3 The Three Components of Cloud Computing

Figure 2 summarizes the three components of cloud computing as defined by NIST (2011). Cloud Computing services have five essential characteristics as shown in the third dimension. Service models make up the vertical dimension depicting the type of resource delivered. Deployment models provide a horizontal dimension showing the level of resource sharing. Cloud computing according to NIST thus enables a range of services in combinations of service models and deployment models, with a range of essential characteristics. In the next sections we will discuss each of these components in more detail to gain a better understanding of what cloud entails. The results of this discussion will subsequently be used in section 2.4 to provide a breakdown of mobile cloud computing.

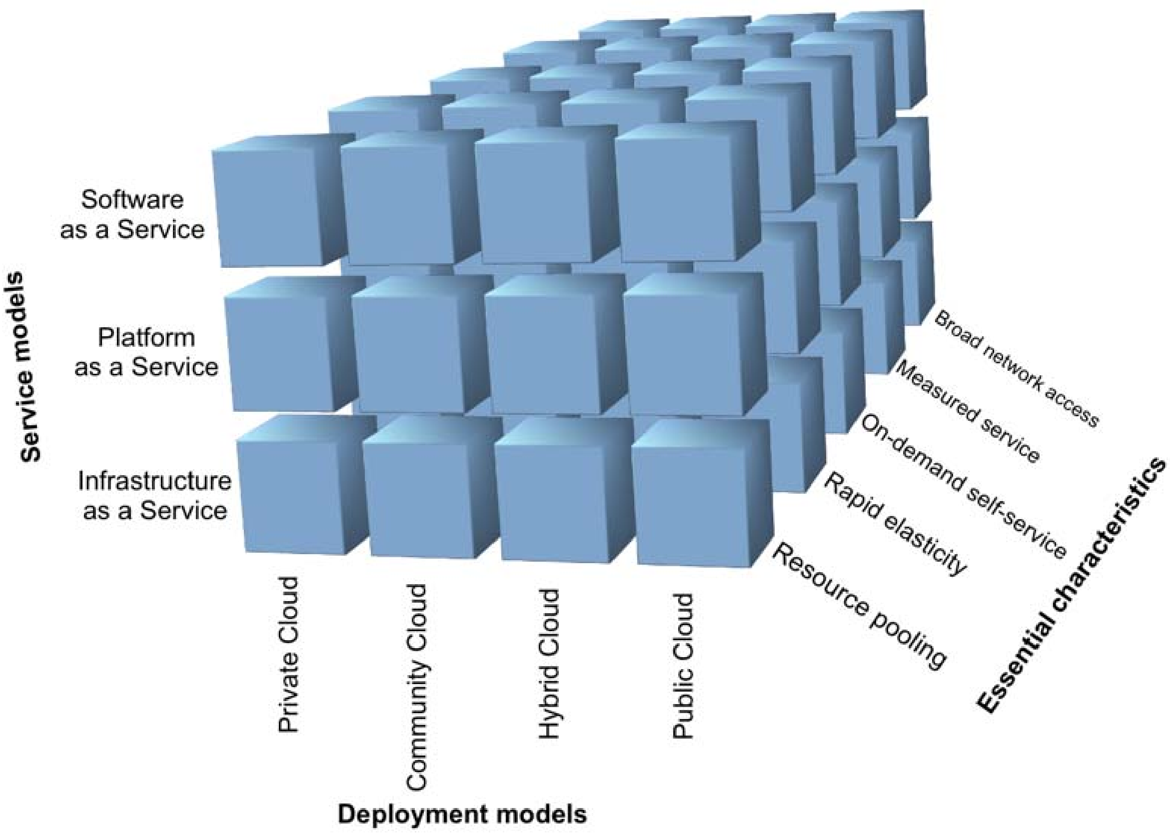

Figure 2 - The three cloud computing components as defined by NIST (Craig, 2010)

2.3.1 Essential Characteristics

NIST defines five 'essential' characteristics of cloud computing. These characteristics refer to both the properties of the resources obtained with cloud computing as well as the way resources are obtained via cloud computing.

1. *On-demand self-service.* This characteristic entails that consumers can obtain computing capabilities without requiring human interaction with providers of computing services (NIST, 2011). In practice this means that consumers can instantly obtain resources such as storage or processing power via several clicks on a web interface, much like products would be purchased in a web shop. The self-service characteristic presents a step forward in convenience compared to the cost and complexity of physically rolling out computing infrastructure with system integrators and IT consultants.

2. *Broad network access.* Cloud computing capabilities are obtained via the network and can be accessed through capabilities which are standard in client platforms such as phones, PC's, laptops and tablets (NIST, 2011). Browser access often suffices to obtain cloud services. In practice this means that computing resources do not have to be available locally and that resources can be accessed via the internet regardless of the device used. A picture database can for example be accessed from any home PC, at work or on the move on a mobile device. It is unclear why the NIST definition speaks of *broad* network access. Broad could refer to the scope of devices capable of accessing resources via the network, to the large variety in wired and wireless network access methods or perhaps even to geographically broad network access to resources.

3. *Resource pooling.* Cloud computing service providers combine their computing resources into large pools to serve multiple customers. These resources include storage, processing, memory, network bandwidth, and virtual machines (NIST, 2011). Using a multi-tenant model, customers -the tenants- are assigned resources from pools of interconnected servers (Bezemer, et al., 2010). Interconnection ensures that computing loads may be intelligently distributed across the server pool depending on consumer demand. This differs from older client-server or datacenter concepts where 'rack space' with a set number of servers and fixed capacity was bought according to consumer estimations of their current and future computing requirements (Figure 4). This leads to unutilized capacity, reducing efficiency for both computing providers and customers. With resource pooling instead, the minimum, average and peak usage of each customer can be met without upfront commitments.

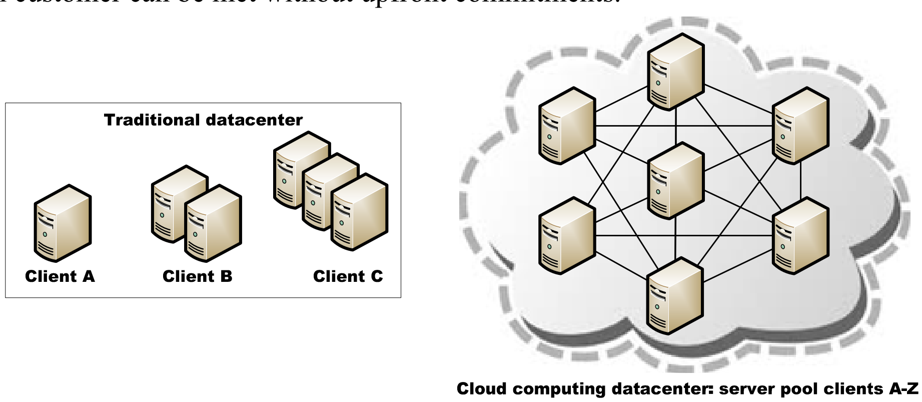

Figure 3 - Traditional dedicated server capacity versus a common resource pool

A cloud computing provider could also maintain multiple resource pools to separate power-hungry customers, preventing them from exhausting a common resource pool with high demand. Historical resource usage statistics are used as a predictive tool to find the proper ratio of demanding and less demanding customers per resource pool. The advantage of provisioning pooled computing infrastructure via the network can be summarized as that it reduces hardware expenses (capital expenditure, CAPEX) and maintenance costs (operational expenditure, OPEX) for both users and computing vendors. The consumer requires less powerful on-premise hardware, while at the same time maintenance and governance costs are shifted to the cloud computing provider. The cloud computing provider in turn profits from economies of scale and high resource utilization as resources are shared across multiple customers.

According to NIST (2011, p. 2), resource pooling entails a degree of location independence: *"the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter)."* An example of location independence is seen in Google's cloud offerings, which fragments and disperses files not only across servers in one datacenter but also across geographically separated data centers. The concept of location independency could thus entail a multitude of dispersed computing resources, possibly including mobile devices.

4. *Rapid elasticity.* Cloud computing creates the illusion of unlimited computing resources available on demand by rapidly and automatically scaling resource availability according to usage, eliminating the need for users to plan capacity requirements ahead. Resources 'elastically' scale in or out, making use of shared idle resources as required (Armbrust, et al., 2010; NIST, 2011). The elasticity characteristic of cloud computing is advantageous for users which cannot plan their capacity requirements up ahead. Examples of where this would apply could be the introduction of new online businesses with unknown demand or environments where computing requirements strongly fluctuate due to the likes of seasonal or day- and nighttime influences.

5. *Measured service.* This characteristic of cloud computing is in line with the notion of pay-per-use often encountered in cloud computing definitions, as seen in Table 3 of section 2.2. NIST (2011, p. 2) defines measured services as follows: *"Cloud systems automatically control and optimize resource use by leveraging a metering capability, Typically through a pay-per-use business model, at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported providing transparency for both the provider and consumer of the utilized service."* Pay-per-use thus entails the ability to pay for computing resources only when needed, for example to meet peak demands. Example of where this would apply would be:

- running large-scale password cracking algorithms;
- peak demands in online event ticket sales;
- online gamers requiring server capacity at once after their favorite game has been released.

In such cases the user would only pay for added capacity until the peak demand has perished.

Reflecting on the five essential characteristics we conclude that they provide us with a number of ways to separate cloud computing from traditional data centre or client-server based computing models. Though not explicitly stated as such by NIST the 'essential' prefix suggests that all five characteristics should apply to allow for the label of cloud computing. It is debatable whether this applies in all scenarios. In the case of a flat fee computing subscription model for example the pay-per-use nature of the measured service characteristic does not apply. Translating the essential characteristics to mobile devices as the cloud resource we can conclude that mobile cloud resources should also be shared, pooled and scalable according to demand. We further apply the essential characteristics to the mobile domain in section 2.4.

2.3.2 Service Models

The essential characteristics described above have taught us how cloud computing resources are obtained and what the properties of these resources are. According to NIST (2011) the essential characteristic apply to three service models (Figure 4) which express the type of resources provided via 'the cloud': software (SaaS), platforms (PaaS) and infrastructures (IaaS).

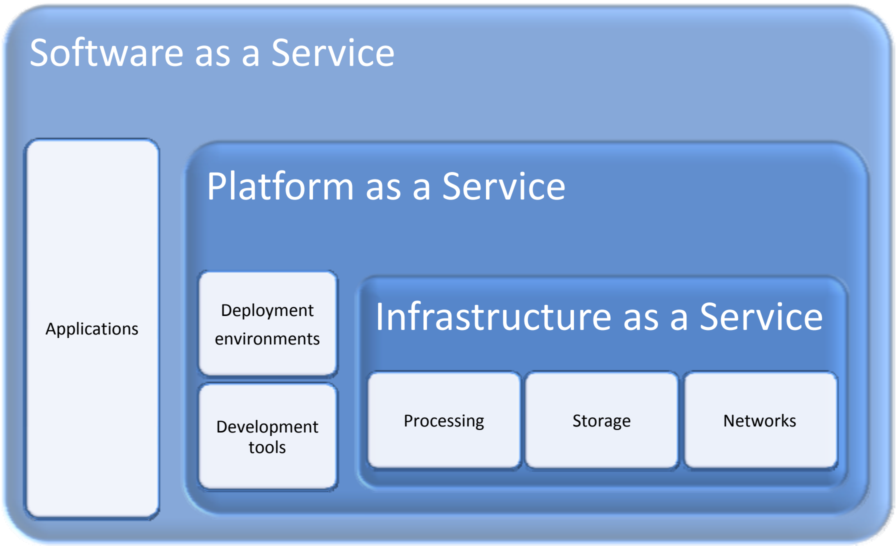

Figure 4 - Cloud Computing service models according to NIST definition (NIST, 2011)

1. *Software as a Service (SaaS).* SaaS entails providing applications which run on the cloud computing resources of service providers rather than locally (NIST, 2011). Examples of this could be the online counterparts of office applications such as mail clients or word processors, e.g. Gmail and Office 365 (Vaquero, et al., 2008). Consumers can access their applications through a web browser or other kind of web interface using any device at any time or place, leaving management worries about the underlying infrastructure of operating systems, network, servers, storage etcetera to the SaaS provider (NIST, 2011). As an added advantage SaaS makes it easier for consumers to collaborate or share services (Armbrust, et al., 2010). Consumers of SaaS can be both businesses (e.g. salesforce.com) and end-users (e.g. iCloud, Dropbox) (Gonçalves & Ballon, 2011).

The definition of SaaS is somewhat susceptible to discussion as potentially anything running online fits the SaaS paradigm, e.g. online flash games, Hotmail, Twitter, RSS feeds etcetera. This is partly because the 'essential characteristics' as defined by NIST do not always visibly apply to SaaS, such as pay per use. We take a straightforward approach to demarcating SaaS *applications* by considering them as local on-device or on-premise applications translated to their online hosted counterparts, e.g. local Outlook mail to Outlook web access mail, and local word processors to online word processors. This 'hosting online' property of SaaS provides specific advantages for both SaaS consumers and providers.

The advantages of SaaS for consumers can be illustrated with the case of replacing purchased or licensed applications by SaaS (Forrester, 2010). Traditionally organizations purchased and locally deployed long-running software and support licenses, paying in bulk for the estimated number of licenses required. With

SaaS the organization can now access the applications they require online at any time and only pay for the actual amount of users, which may fluctuate over time. A university for example could offer students engineering software online rather than paying for local bulk campus licenses. The university would then only pay for the students actually making use of the software, rather than estimating the number of licenses required upfront. At the same time, the university requires less local storage and processing capacity as this task is offloaded to the SaaS provider. Students enjoy access the software on any device, at any time and from any location with a web browser rather than being bound to the campus computers and opening hours.

For cloud service providers offering SaaS three advantages apply (Armbrust, et al., 2010): simplified software installation and maintenance, centralized control over versioning and the choice of deploying the product as SaaS without provisioning a datacenter. The last advantage is interesting as not only can consumers offload computing requirements to a SaaS provider, SaaS providers can offload their own computing requirements to other cloud computing providers as well (Figure 5). This allows them to scale their services as required by running them on PaaS or IaaS resources (Armbrust, et al., 2010). As an example, internet radio service provider Soundtrckr -SaaS for consumers- runs from Amazon's PaaS/IaaS cloud computing solutions. In the upcoming sections we will discuss the concepts of PaaS and IaaS in more detail.

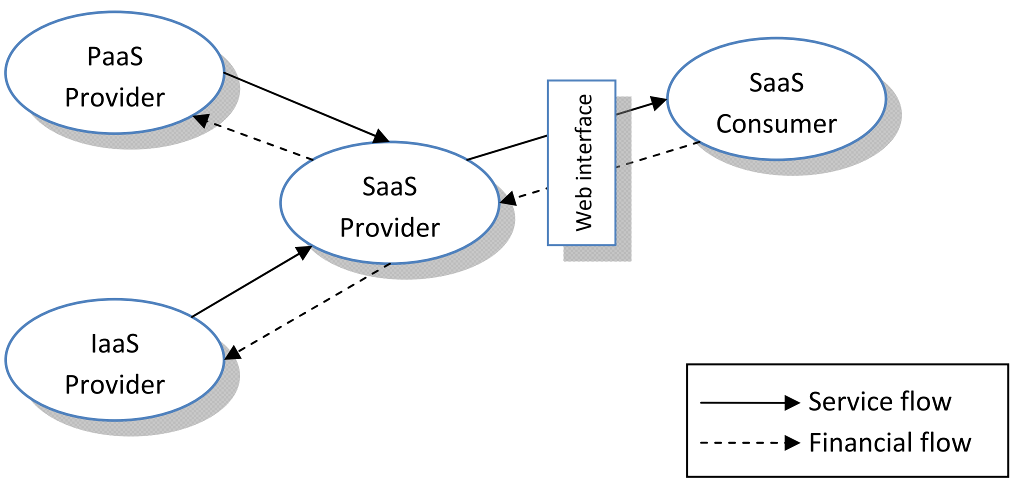

Figure 5 - Offloading of computing tasks with SaaS

2. *Platform as a Service (PaaS)*. NIST (2011, p. 2) provides the following definition of PaaS: *"With PaaS the capability is provided to deploy consumer-created or acquired applications using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations."*

PaaS according to NIST thus consists of four components, being 1) creating applications, 2) deploying applications, both self-created and otherwise acquired 3) control over an application hosting environment and 4) an underlying cloud infrastructure of hardware or operating systems out of reach of the PaaS consumer. With these features PaaS aims to relief developers, offering a one stop shop for the entire software lifecycle (Mitchell, 2008) bypassing investments and maintenance in infrastructure and leaving developers more resources for development and monetizing their services (Gonçalves & Ballon, 2011). The technical facilities in PaaS provide compatibility, gaining a larger audience for developers using the PaaS environment as more end-users can make use of their products (Breshanan & Greenstein, 1999). Applications built on PaaS can be targeted at the general public but also be meant for the internal use of a business customer. For business customers PaaS may possibly provide the advantage of simplifying otherwise fragmented IT landscapes, as applications built by in-house developers using a PaaS environment are compatible, in contrast to many proprietary applications. At the same time the business consumer can benefit from a large number of externally created compatible applications. We will illustrate the concept of PaaS with two examples:

- An application developer creates online word processing software using the application programming interfaces of Google's PaaS service, App Engine. When released, the word processor software is deployed online on Google's PaaS service. End-users can access the word processor from any device or location. The application developer does not need to consider the amount of end-users as the PaaS service will automatically scale to meet their numbers. When the developer releases updates the word processing software, all users automatically use the latest version. Meanwhile, end-users can acquire plug-ins for the word processor such as native spelling and grammar checkers from Google's App Engine marketplace.
- A web store is custom developed using Amazon's PaaS tools. The web store is deployed on Amazon's PaaS environment as well. The web store developer then re-uses two existing ecommerce functionalities in Amazon's PaaS services, the shopping cart and billing functionality. Amazon's billing functionality is compatible with the billing process of various suppliers, delivery companies and banks which also run on Amazon's PaaS, allowing the web store easy integration of their processes. At the same time customers of the web store are offered a familiar checkout process.

From these PaaS examples we conclude that NIST takes a mostly technical perspective on PaaS, defining the concept as combinations of hardware and software compatibility including environments to run applications on, application programming interfaces (API's) to access data and services running on the platform and plug in API's to add functionality to the platform (Andreessen, 2007). This technical perspective however omits the fundamental mediating function of platforms in matching supply and demand between different types of customers (Gonçalves & Ballon, 2011). The platform owner can gain from this mediating position (Figure 6) as seen in app stores for mobile applications, which provide value and gain revenues from both developers and end-users. The difference between the technical perspective on PaaS and the matchmaking perspective on PaaS is in the type of service delivered. PaaS can offer compatible components to run services on and allow these services to communicate with each other, which can be seen as machine-to-machine (M2M) services (H. Bouwman, De Reuver, Dreyer, Tuunainen, & Tuunanen, 2010). On the other hand PaaS can deliver end-user services through common elements in products as well as through matchmaking, marketing products and facilitating provisioning of products (Evans, et al., 2008). This matchmaking role is one of the main differentiators between PaaS and IaaS.

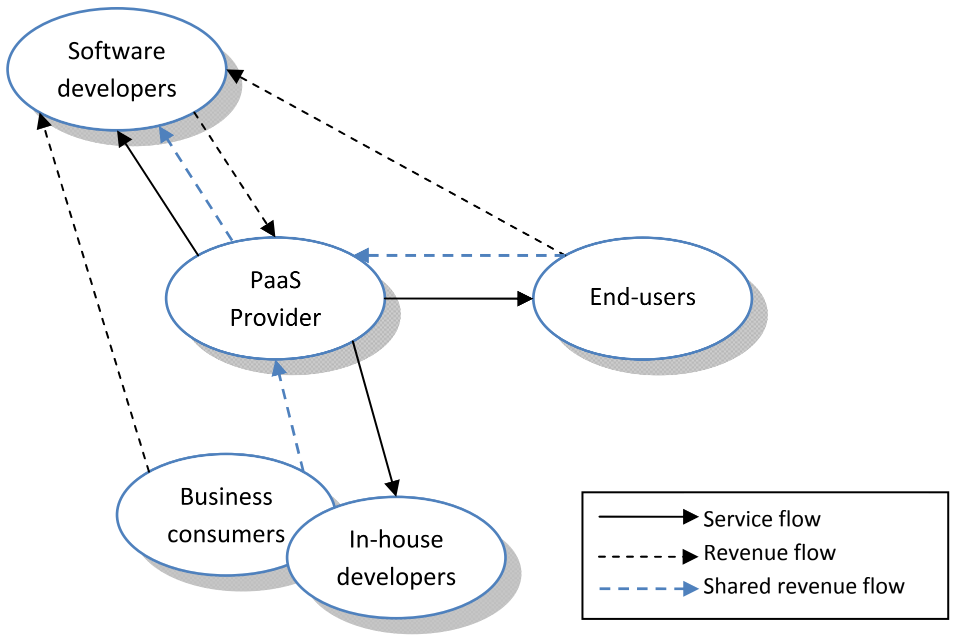

Figure 6 - PaaS providers as matchmaker for developers and end-users.

3. *Infrastructure as a Service (IaaS).* Infrastructure providers provide large scale computing resources such as storage, network and processing capacity. Infrastructure providers use virtualization to assign and split their resources dynamically according to customer demand (Vaquero, et al., 2008). Consumers can choose to deploy their own software on this infrastructure, including operating systems and applications (NIST, 2011). For consumers IaaS provides the advantage of having as much raw power or storage capabilities available as needed at any time, while only paying for the amount consumed. Scientist for example might temporarily turn to a cloud computing service for demanding simulations, rather than deploying expensive local (super)computers. Multinational firms can turn to IaaS services to make scalable data storage services available on a global scale, without deploying their own infrastructure and regardless of future storage demands. Consumers of IaaS might also be other cloud computing providers which deploy SaaS or PaaS (Figure 7).

The NIST (2011, p. 3) definition of IaaS provides limited guidance with regards to the 'network' part of computing resources, stating that "*the capability provided to the consumer is to provision processing, storage,* ***networks****, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications [..]and* ***possibly limited control of select networking components*** *(e.g., host firewalls).*" The first part of this definition states that the consumer is able to deploy and run arbitrary software on networks. The second part of the definition states that users obtain some degree of control allegedly software-like network components such as firewalls. The definition is not explicit about the type of networks provided and which networking components one can obtain control of. Other definitions provide little additional guidance, focusing on the scalable data storage, processing and virtualization properties of infrastructure services instead (Armbrust, et al., 2010; Buyya, 2009; Vaquero, et al., 2008; L. Wang & von Laszweski, 2008). We take three approaches to clarify the network component of IaaS. The first is IaaS as networks of connected servers. The second is network bandwidth or capacity to and from the IaaS provider. The third is extending IaaS to communication networks:

- The first possible approach to 'networks' in the IaaS definitions is that cloud computing data centers are in fact networks of connected servers, much like a local version of the Grid and Cluster Computing paradigms we discuss in section 2.1. A degree of intelligence has to be present in this network of servers to distribute computing loads across servers, to meet fluctuating customer demand and to attain resource efficiency for the IaaS provider. Large cloud computing providers often possess multiple networks of servers in geographically separated datacenter locations. Cloud computing providers such as Amazon provide consumers control over which of these networks to deploy their infrastructure services on. This control can be used to limit the consequences of outages in a single network of servers, for redundancy purposes in backup and storage and to limit service latency by deploying geographically nearby infrastructures.
- Second, the presence of 'network' resources in IaaS definitions might be due to a resemblance of IaaS with the older concept of online hosting services. With hosting services, end-users would obtain online software and storage as well as a set bandwidth (or traffic) limit to and from the hosting provider- in other words, network capacity. Nowadays with cloud computing and IaaS this network capacity part of hosting scales according to demand in a pay-per-use way.
- The third approach to networks in IaaS is to extend the notion to communication networks. In the telecommunication domain it is common practice for network owners to provide communication networks as a wholesale service to (mobile) virtual network operators (MVNO's). Multiple virtual network operators then share the infrastructure of the network owner. The virtual network operators benefit from circumventing the large sunk costs of deploying their own network. The actual network owners benefit from higher utilization of their network, providing better returns on investment. Similar developments are seen around wireless spectrum sharing between network operators themselves (Berkers, Hendrix, Chatzicharistou, & de Haas, 2010). Another aspect of IaaS in the telecom domain can be that of combining operator networks into a larger whole using virtualization techniques. Analogous to virtualized groups of connected servers, these large virtualized operator networks could for example provide large amounts of bandwidth on demand where needed (Carapinha et al., 2010; Nogueira, Melo, Carapinha, & Sargento, 2011). Combining operator networks can improve both utilization and geographical coverage. In some cases the expression of 'Network as a Service' (NaaS) is used around such shared or combined operator networks (Bailey, 2010), though this does not appear to be a formalized definition.

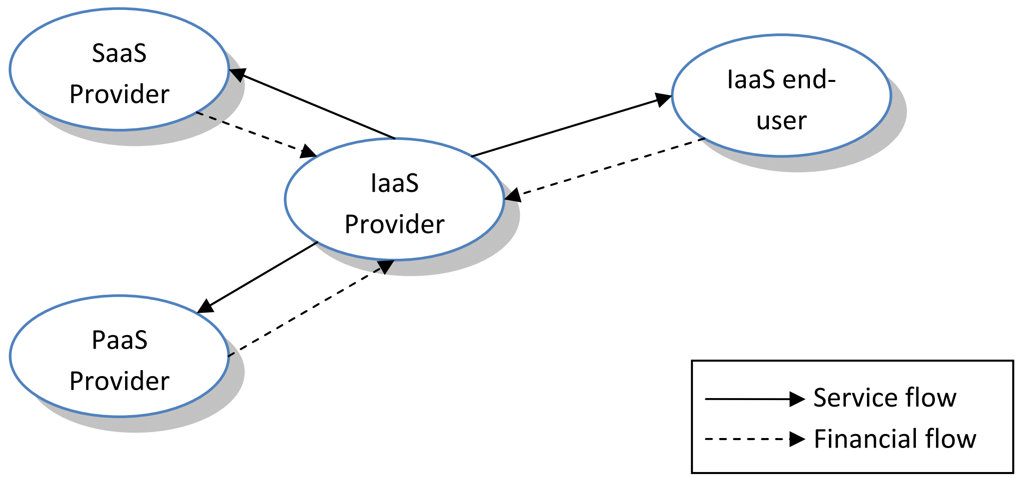

Figure 7 - IaaS providers serving both end-users and SaaS or PaaS providers

Reflection on the three service models, we notice that the NIST definition of cloud computing service models does not cover all the *as-a-Service models out in the field. A short exploration online already provides us with over 30 *aaS variants as seen in appendix C. Most of these variants however fit one of the three service models as defined by NIST, others might be considered part of marketing hype.

The service models are key in understanding what cloud computing entails. The concept of PaaS is of specific interest for our research towards multi-sided markets opportunities around mobile cloud. PaaS represents a shift from the single direction revenue streams in IaaS to a multisided revenue stream from both suppliers and consumers of services. A notable distinction here is that cloud computing services can entail both machine-to-machine (M2M) services and end-user services. PaaS offers M2M services in the shape of compatible components to run services on and allow these services to communicate with each other. PaaS can also offer the ability to market and provision these servers to end-users. In section 2.3.2 we will apply the three service models to the mobile domain.

2.3.3 Deployment Models

Whereas the service models of cloud computing tell us *what* resources are shared with cloud computing, the deployment models tell us *with whom* cloud resources are shared. The deployment models present a scale from user-specific 'private clouds' to 'public clouds' and hybrid variants overlapping these models (Figure 8).

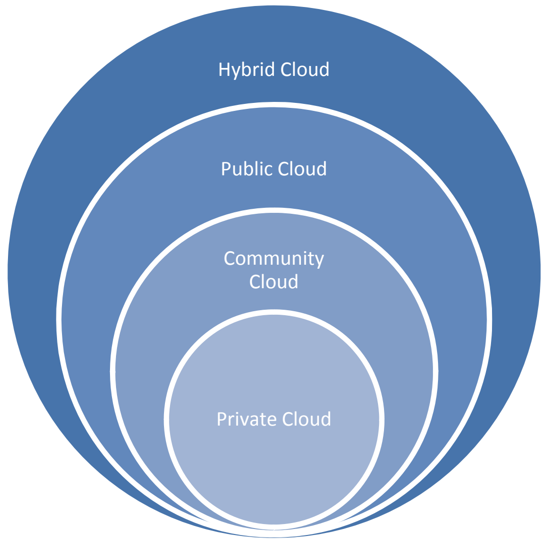

Figure 8 - Cloud computing deployment models and resource sharing audiences (NIST, 2011)

1. *Private cloud.* Private clouds are computing capabilities which are shared within a single organization or within the environment of single user. These computing capabilities can be located both on and off premise of the user and may be managed by a third party (NIST, 2011). One speaks of a private cloud instead of a corporate data centre when the IT functions offer the characteristics of cloud computing such as self-service tools and elasticity in resource allocation (Forrester, 2010). With off premise third party management one also speaks of hosted private clouds, which are comparable to traditional hosting or outsourcing – yet with the typical cloud characteristics such as flexible pay-per-use pricing (Forrester, 2010). Google might for example offer a multinational company a hosted private cloud which is shared by all country departments of that company.
2. *Community cloud.* Industry or community specific services characterize community clouds. Customers obtain aggregated services which may include specific business functions such as billing services or shared processes (Siemens, 2010). Community clouds are targeted towards organizations with shared concerns such as mission, security requirements, policy and compliance (NIST, 2011). Community clouds could for example be geared towards sectors such as healthcare or government, in which cloud computing provides shared services to all involved organizations.
3. *Public cloud.* Cloud services are made available via the Internet in a standardized, self-service and pay-per-use way (Forrester, 2010). Organizations selling public cloud services include parties such as Amazon, Terremark, Google and Microsoft. In the public cloud model computing resources could be shared with any number or type of users for numerous purposes.
4. *Hybrid cloud*. According to NIST (2011, p. 3) we speak of hybrid clouds when *"the cloud infrastructure is a composition of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds)"*. The typical use

case is that an organization keeps certain resources in-house for security reasons or because the capital expenditure has already been made. An example would be that a company keeps data storage in-house while it uses the computing power obtained from Amazon's Elastic Cloud service to process this data. According to the NIST definition hybrid clouds are composed of "two or more clouds", which would mean that the local resources need to have cloud characteristics as well.

The deployment models provide us with means to classify the audience mobile resources are shared with, which could range from people or devices in the private environment to people and devices the public environment. We apply the deployment models to the mobile domain in section 2.4.

2.4 Defining Mobile Cloud Computing

In the previous sections we reached a definition of cloud computing by first exploring computing paradigms related to cloud, comparing formal definitions and breaking down a selected definition into its component parts. In this section we will briefly retrace these steps, applying what we have learnt about cloud to mobile devices as the cloud computing resource. First we compare mobile cloud with the traditional cloud concept. We then apply the NIST definition of cloud computing to mobile cloud, followed by a breakdown of mobile cloud into characteristics, service models and deployment models.

Section 2.1 noted that cloud computing is associated with a large number of computing paradigms, including utility computing, grid computing and cluster computing. These paradigms can be distinguished by their respective computing resource owners and consumers. Cloud computing is characterized by sole owners of datacenters with *pooled* resources which are *shared* across multiple customers. The customers pay a single cloud computing provider for resources used. In a mobile cloud resource pool the ownership over the shared resources is in the hands of many different consumers rather than an individual organization. This provides possibilities to compensate device owners in return for sharing this device as well as for business roles to coordinate the tasks of pooling mobile resources and making these available for consumers[2]. This topic is further explored in section 2.5.

Aside from ownership over the resources, differences between cloud and mobile are also noted between on the level of the connection, devices and services. A first difference is that whereas the computers in cloud datacenters are connected via wired networks, mobile resources need to be pooled via wireless connections. Mobile devices can connect with each other in two ways, via the MNO or via ad-hoc direct local connections such as Wi-Fi or Bluetooth. A second difference is that mobile device resources are perishable due to battery limitations and their inherent mobility, moving in and out of network range. The resources themselves are also more heterogeneous due to differences in device capabilities and the presence of large amounts of sensors (e.g. audio, movement, light sensor). The third difference is that mobile devices come with operating systems which may predetermine which services may be possible on the device, whereas the computers in datacenters can be provided as a 'blank' resource.

Differences on the level of connection, devices and services are also relevant when mobile devices are used as a channel to consume (mobile) cloud computing services (Table 4). Fixed-line consumers enjoy low latency and high-bandwidth with flat fee data subscriptions, whereas mobile consumers are currently limited by the data caps, bandwidth and latency of wireless connections. Bandwidth and latency issues can be addressed with next generation mobile networks such those based on Long Term Evolution (LTE), closing the gap in bandwidth and latency with fixed-line connections. Mobile users can possibly circumvent MNO data caps by using direct methods to other (mobile) cloud computing resources. On the level of devices and services, large amounts of sensors in mobiles allow the consumption of new kinds of cloud services such as matching contextual information with cloud databases (Christensen, 2009). An example of this is seen in augmented reality application Layar, which matches camera images to location information 'in the cloud'. While this is an end-user prompted service, cloud computing could also be used for automatic configuration and deployment of services on mobile devices using context information which is unavailable on desktops or laptops (Christensen, 2009; Liang, Huang, Cai, Shen, & Peng, 2011).

[2] We refrain from comparing mobile cloud to mobile grids and mobile clusters as the interpretations of these concepts strongly vary. The mobile grid and cluster labels appear to be used interchangeably with few ties to their non-mobile counterparts, referring to both local ad-hoc resource sharing between mobile devices (e.g. McKnight, et al., 2004) as well as to large groups of mobile devices for distributed computing with a central coordination point and variants in-between.

Table 4 - Connectivity, device and service differences between fixed-line cloud and mobile cloud

Category	Factor	Traditional Cloud computing	Mobile Cloud Computing
Connectivity	Network access	Continuous fixed line (possibly through local Wi-Fi)	Interrupted wireless depending on MNO coverage, or available ad-hoc Wi-Fi or Bluetooth connections
	Network bandwidth	High and constant	Currently limited, variable dependent on network coverage and user movement speed
	Network latency	Typically ~8-35ms from user to DSL/Cable ISP in the Netherlands ~2-5ms for fiber optic connections	Currently typically 100ms due to mobile network latency. Will drop to ~10ms with next-generation networks
	Network data plans	Flat-rate	Trend towards data caps (De Vries, 2011), possibly differentiated fees per type of use depending on net neutrality
	Location	Fixed	Variable: on the move or fixed
Devices	Devices used	Desktop computer, laptop computer	Laptop, tablet, smart phone, feature phone etc. (Warner & Karman, 2010)
	Device properties	Standardized input methods, large displays, large resource pool in case of thick clients, scarce resources for thin clients	Currently limited battery life, processing power, storage capacity and memory (Kumar & Lu, 2010), varying form factors and input methods, fragmented OS and web interfaces
	Device sensors	Microphone, camera, light sensor (on laptops)	GPS, camera, microphone, proximity sensor, light sensor, barometer, NFC, gyroscope, accelerometer
Services	Service scope	Anything from applications to operating systems and enterprise resource planning packages	Limited due to device form factor, wireless connectivity, input and processing limitations
	Service focus	Full range of location bound applications e.g. home entertainment, office productivity	Focus on communication, information, entertainment and transaction services; location-aware, proximity aware applications (Chen & Cheng, 2010; Song & Yoon, 2010)

Having identified high-level differences between cloud and mobile cloud in terms of resource ownership, connectivity, devices and services we now move on to a definition of mobile cloud computing.

2.4.1 A Twofold Definition

Recalling the NIST definition from section 2.2, cloud computing was defined as (NIST, 2011, p. 2): *"a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models."* We apply the NIST definition to mobile cloud computing in two ways. First, mobile devices can be another channel to obtain cloud computing resources with via the network. Second, mobile devices can be part of the shared pool of configurable computing resources offering networking, storage, applications, services etc., which is the focal part of our research. This twofold interpretation of mobile cloud computing is supported by authors such as Elespuru and Shanklin:

- Elespuru (2009, p. 178):*"conceptually similar to existing cloud computing, but where computation and storage resources happen to be mobile devices, or they interoperate between traditional cloud and a new set of mobile cloud resources."*
- Shanklin (2009): *"cloud computing is the trend in which resources are provided to a local client on an on-demand basis, usually by means of the internet. Mobile cloud computing (MCC) is cloud computing in which at least some of the devices involved are mobile."*

Section 2.2 also provided a breakdown of eight common elements in cloud computing definitions. In Table 5 these common elements of cloud computing are applied to mobile devices as the cloud computing resource. Difficulties in translating these elements are noted around three elements:

- *Shared resource pool:* much of the research done towards mobile resource sharing is either on the level of direct device-to-device connections in the shape of peer-to-peer networks, ad hoc networks (Wijngaert & Bouwman, 2009) and mesh networks or towards groups of devices connecting as a cluster for use by a single managing organization (Elespuru, et al., 2009). Mobile cloud computing entails a combination of both aspects, sharing pooled resources with multiple customers.
- *SLA's:* SLA's or Quality of Service (QoS) guarantees are hard to fulfill with unpredictable availability of mobile resources. Offloading storage to mobile devices can have the consequence of data not being accessible when the device is turned off or out of network range. Devices could be occupied by their owners, leaving few available resources. Possibly one could enable SLA's for mobile cloud with *elastic applications* (Zhang, et al., 2009) which allow computation tasks to seamlessly merge to non-mobile cloud computing resources when the shared mobile resource pool is unavailable or does not suffice.
- *Pay-per-use:* it is currently unclear how or whether pay-per-use can be arranged for mobile cloud computing as a single resource owner is lacking.

Table 5 - Common elements of cloud computing applied to mobile cloud resources

Common elements of cloud computing (NIST, 2011)	Element in Mobile Cloud	Description
Virtualization of resources	Yes	• Virtual overlay networks on top of mobile devices (Niemegeers & Groot, 2002; Samimi, McKinley, & Sadjadi, 2006)
Variety of resources	Yes	• Processing power, storage, sensors, connectivity (Ananthanarayanan & Zats, 2009; Beng, 2009; Elespuru, et al., 2009; Marinelli, 2009)
Shared resource pool	Knowledge gap	• Often distinctions between mobile resource sharing (Dodson, Cannon, Hang, & Lam, 2011; Wijngaert & Bouwman, 2009) and mobile resource pooling (Elespuru, et al., 2009)
Scalability (automatic/dynamic)	Yes	• Scaling the number of devices required for processing, storage, sensing or connectivity according to service requirements (Marinelli, 2009)
Convenience in use and access	Yes	• Automated service configuration and delivery (Christensen, 2009) • End-user to end-user sharing requests without service provider interaction (Wijngaert & Bouwman, 2009)
Network enabled	Yes	• Wireless via mobile network operator • Ad-hoc or local connectivity methods (Wi-Fi, Bluetooth)
Service Level Agreements (SLA's)	Knowledge gap	• Perishable mobile resources: battery and connectivity • Multiple resource owners with unpredictable usage patterns; may not be able to guarantee QoS
Pay-per-use	Knowledge gap	• Compensating individual resource owners • Unknown what or how to compensate e.g. data subscription, device or energy expenses, goodwill

Concluding this section we define mobile cloud computing as: *mobile devices as a channel to obtain cloud computing resources with via the network and/or mobile devices combined as (part of) a shared pool of computing resources.* We will now apply the essential characteristics, service models and deployment models as explored in section 2.3 to mobile cloud in order to fill the knowledge gaps encountered.

2.4.2 Mobile Cloud Characteristics

The five 'essential' characteristics of cloud computing are applicable to the general concept of mobile devices themselves acting as the cloud computing resource as shown in Table 6.

Table 6 - Essential characteristics based on mobile cloud resources

Cloud Characteristic	Application to Mobile Cloud
On-demand self-service	• Manual on-device prompts to switch on or discover additional mobile resources (Christensen, 2009; Wijngaert & Bouwman, 2009) • Automatic detection of additional available mobile resources (Ananthanarayanan & Zats, 2009)
Network access	• Sharing & pooling mobile resources via (mobile) network operators • Sharing & pooling local mobile device resources via ad-hoc connections methods such as Wi-Fi or Bluetooth (Ananthanarayanan & Zats, 2009)
Resource pooling	• Aggregating mobile devices for collaborative tasks such as computation, sensing and connectivity (Ananthanarayanan & Zats, 2009; Beng, 2009; Elespuru, et al., 2009; Marinelli, 2009; Satyanarayanan et al., 2009; Want, Pering, Sud, & Rosario, 2008)
Rapid elasticity	• Scaling the number and range of mobile devices used for tasks as needed, from personal or local devices (Niemegeers & Groot, 2002) to remote devices accessed via internet (Marinelli, 2009)
Measured service	• Compensating individual device owners for resource usage • Compensating a third party for coordination of multiple mobile device resources • No compensation, incentives such as trust or reciprocity in resource sharing (Wijngaert & Bouwman, 2009)

Differences are noted when applying the characteristics of *on-demand self-service* and *measured services* to mobile cloud resources.

- *On-demand self-service* would not entail purchasing computing capacity via a website, but rather discovering additional mobile resources by on-device prompts. These prompts could be user-initiated, e.g. 'find compatible users for additional bandwidth now' or 'incoming music sharing request' (Wijngaert & Bouwman, 2009) or automated as a M2M service discovering additional resources while on the move, e.g. always using nearby shared connections if available (Ananthanarayanan & Zats, 2009).
- *Measured services or pay-per-use* as previously noted does not directly translate to mobile devices as the cloud resource. Compensating multiple end-users for using their device is a more complex effort compared to paying a single cloud computing provider for using server time.

We take three approaches to apply measured services to the mobile domain. The first approach is to compensate individual owners of mobile devices for using their resources. The second approach is to compensate a third party for the coordination effort of pooling mobile resources of multiple end-users. The third approach is reciprocity in resource sharing. In the first approach, device owners are compensated themselves. Device owners could be compensated for providing resources on multiple levels. This could include amongst others the bandwidth costs incurred by connecting with their device via the network and the costs of (re)charging the device due to increased energy consumption. One could also think of providing additional compensation for those with more powerful mobile resources and additional hardware or subscription expenses. In the second approach a mediating party coordinates which mobile devices are available to provide additional resources. This role could be similar to that of cloud computing providers -load balancing in the mobile resource pool- or the role of network operators, connecting different devices and providing for billing when resources are shared. In the third approach, no pay-per-use type compensation is provided. Mobile resources are then provided on terms of reciprocity e.g. only those can tap into the mobile resource pool that provide resources themselves much like peer-to-peer file sharing protocols such as Bittorent. Another possibility is that mobile resources are shared based on altruism or trust such as within communities. We will explore the viability of different options for resource sharing compensations during the interview phase.

2.4.3 Mobile Cloud Service Models

The service models express the type of resources shared with mobile cloud: computing, software, platforms and infrastructure (Table 7). This section elaborates on mobile cloud based service models.

Table 7 - Service models based on mobile cloud resources

Service Model	Application to Mobile Cloud
SaaS	• Mobile SaaS for end-user services: user-prompted mobile applications delivered from other devices (Dodson, et al., 2011; Wijngaert & Bouwman, 2009) • Mobile SaaS for M2M services: devices automatically sharing services, configuration settings and applications (Christensen, 2009; Liang, et al., 2011; McKnight, et al., 2004)
PaaS	• Mobile devices as the PaaS infrastructure (Elespuru, et al., 2009) • Mobile devices as extension of existing PaaS (e.g. Zhang, et al., 2009)
IaaS	• Mobile connectivity IaaS (Ananthanarayanan & Zats, 2009), processing IaaS (Elespuru, et al., 2009), sensor IaaS (Beng, 2009; Zhang, et al., 2009), storage IaaS (Marinelli, 2009) • Mobile devices as part of hybrid fixed-plus-mobile IaaS (Zhang, et al., 2009)

Mobile Software as a Service. Traditional SaaS entails applications which run on the cloud computing resources of service providers rather than locally (NIST, 2011), with the underlying infrastructure invisible to the application consumer. Converting this to mobile cloud computing resources, Mobile SaaS would then entail mobile applications or services which run on mobile devices rather than locally.

- Mobile SaaS for end-users could entail that a group of people want to play a card game using mobile devices. Only one device has the card game installed. The host device pushes a private card deck to each player's device, displaying it via the web browser (Dodson, et al., 2011). Many similar examples can be given e.g. music sharing, video sharing etc.
- Mobile SaaS for M2M services could entail that mobile devices collaboratively provide services, configuration settings and applications (H. Bouwman, et al., 2010). Using adapting to security settings as an example, mobile devices can belong to a shared security service category (Liang, et al., 2011) and take on the security configuration of surrounding devices, such as when walking into an office environment. Friend finder services could also apply as mobile devices automatically detect users with similar interests and automatically launch social network services when in the vicinity of likeminded individuals.

Many similar use cases are available in research towards wireless grids, ad-hoc networks, mesh networks and others. However, these examples do not fully embrace the notion of SaaS, as the underlying infrastructure is not a shared resource pool. A single mobile device can share resources with one or more other devices, which entails sharing but not pooling. One can speak of a shared resource pool when multiple devices are combined to share resources across multiple consumers. We will leave the remainder of this SaaS definition discussion for future research and will for now consider one-to-many mobile resource sharing to be SaaS as well.

*Mobile Platform as a Service***.** As discussed in section 2.3.2 PaaS providers provide online hosted platforms for application development, deployment and provisioning such as Microsoft Azure, Google App Engine and Amazon EC2. Underneath this platform is a cloud infrastructure hidden from the PaaS consumer. Translating PaaS to mobile resources this would entail that mobile devices become the hidden infrastructure to deploying PaaS services on. Mobile PaaS could potentially be provisioned as an extension of normal PaaS, where a traditional PaaS provider extends their offerings to mobile resources, adding resources such as sensors. Large industry players such as Google and Microsoft provide both cloud computing services as well as mobile operating systems. These players may possibly be in the position to implement flexible architectures which combine both mobile and stationary resources into PaaS, by adding devices with their OS to the shared resource pool, e.g. Google Android plus App Engine, Microsoft Azure plus Windows Phone. Figure 9 shows a conceptual outline of Android OS users as a shared resource pool for sensors and the business opportunities this creates for the platform owner.

Making mobile devices available as PaaS requires some form of coordination to attain a shared pool of mobile resources and perform load balancing in this pool. Architectures such as the MapReduce Algorithm contain a coordinating server to this end. The literature discussing these architectures however does not address the question of who could perform the coordination effort and due to which incentives. Typically with PaaS as a matchmaking platform between application or service developers and consumers, the PaaS owner is in a position to acquire revenues from both sides of the platform. With mobile PaaS this is different as end-users are the resource owners. However, there could still be incentives for a mobile PaaS coordinator to acquire revenues from developers and sharing revenues with end-users by facilitation matchmaking between multiple end-users and developers. Identifying which parties can take in the matchmaking role for mobile PaaS will be one of our main interview topics.

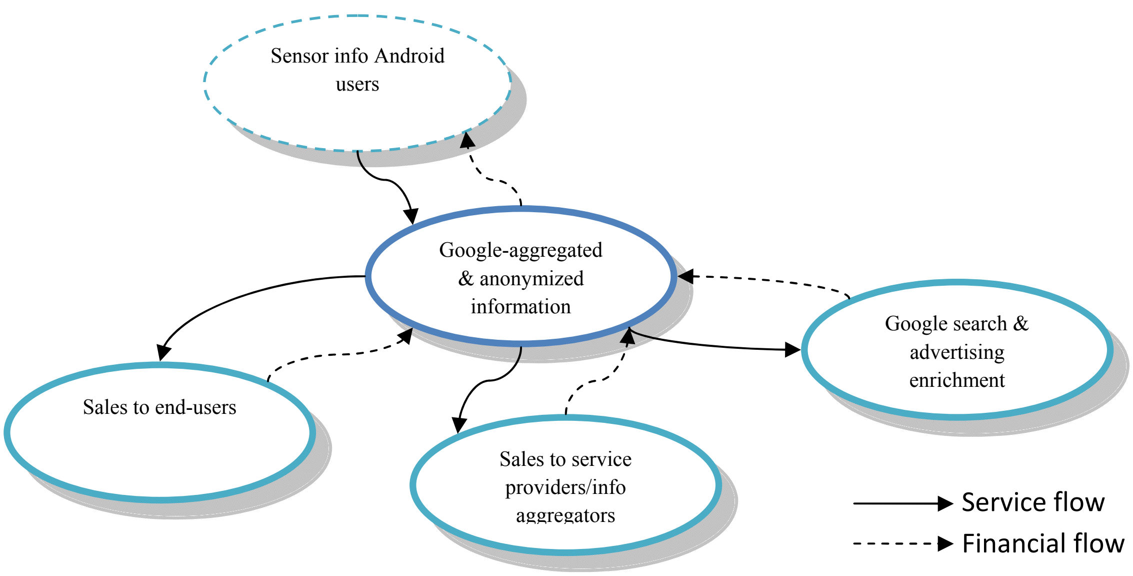

Figure 9 - Conceptual mobile sensor resource pooling based on Google Android

Mobile Infrastructure as a Service. IaaS according to NIST (2011) provides large scale computing resources such as processing, storage and network where the ability is provided to consumers to deploy and run arbitrary software, including operating systems and applications. IaaS in the mobile domain is different in three ways. First, traditional IaaS provides the illusion of near infinite computing resources available on demand (Armbrust, et al., 2010). As mobile resources are perishable, the near infinite label does not apply. Second, the mix of resources provided by mobile devices is more heterogeneous, with divergent device capabilities. Mobile devices also provide a larger scope of resources than a cloud computing datacenter, especially due to their large variety of sensors. The third difference is that mobile devices are not a blank resource as they come with a pre-installed OS which presets what is possible on the device. We illustrate IaaS with two examples.

- MapReduce (Elespuru, et al., 2009) is an algorithm created by Google to dissolve problems in smaller pieces to solve them with multiple computing sources. End-users can opt in to a pool of mobile devices by means of applications. Computation requests from applications at the end-users are then split by a remote server, which segments computation tasks amongst mobile devices. Once processed the segments are aggregated by the mobile server and sent back to the requesting mobile device in a browser or application-based way.
- AggreGATE (Ananthanarayanan & Zats, 2009) is a possible example of mobile-based connectivity IaaS. AggreGATE consists of an application programming layer at the device and a central coordinating server. The central coordinating server keeps tabs on which mobile devices can be shared and pooled to boost the connectivity of different end-users. A possible use case for these shared connectivity pools: (Ananthanarayanan & Zats, 2009, p. 3): Alice is travelling on a bus and has to email a presentation file (few megabytes) urgently. But she realizes that her 3G connection would take a prohibitively large amount of time for the task. There are two other people in the bus, Bob and Carol, who also have 3G connectivity but currently not using their smartphones. The AggreGATE layer on Alice's PDA enlists Bob and Carol as collaborators and parallelizes the upload, speeding up the process.

As with Mobile PaaS, Mobile IaaS could also be provisioned as an extension of IaaS, where a traditional IaaS provider extends their offering to mobile resources. This can provide benefits such as increased availability in cases such as datacenter downtime or lack of network access to the datacenter. In those cases the IaaS consumer would turn to mobile devices which are in the shared resource pool of the IaaS provider. This is made possible by technology such as the elastic weblets developed by Pennsylvania State University. These weblets can be freely moved between mobile and stationary devices to shift computing tasks (Zhang, et al., 2009). Similarly one could also consider device-to-device connectivity as an extension of the Network as a Service of mobile network operators.

As a final conclusion regarding mobile IaaS we note that most of the mobile cloud IaaS architectures highlighted in Table 7 could also be provisioned as PaaS, should they be extended to an integrated deployment and matchmaking environment.

2.4.4 Mobile Cloud Deployment Models

The deployment models define mobile cloud computing in terms of the audience mobile resources are shared and pooled with as shown in Table 8.

Table 8 - Deployment models based on mobile cloud resources

Cloud Deployment model	Application to Mobile Cloud
Private cloud	• Mobile resources shared between the personal mobile devices of an end-user (IEEE, 2001; Zimmerman, 1996) • Mobile resources shared in private locations such as a vehicle or home environment (Niemegeers & Groot, 2002)
Community cloud	• Mobile resources shared in environments such as offices, schools, events or associations as well as on the level of social networks or families
Public cloud	• Mobile resources shared with large user bases such as the customers of a mobile network operator, the users of a specific service provider, mobile OS or the general public
Hybrid cloud	• Basic interpretation: mixtures between private, community and public mobile resource clouds • Broad interpretation: mixtures between mobile and non-mobile resource sharing audiences e.g. combined private mobile resources supplemented with traditional datacenter public cloud

The audience with which mobile resources are shared with can change on the fly due to relocating mobile devices, assuming that direct device-to-device connections are possible. An end-user might therefore make use of a private mobile cloud at home, use public mobile clouds while travelling to work and switch to an office community mobile cloud while at work. In contrast, non-mobile deployment models consist of datacenters set up for more stable user groups independent of their location.

Conceptually these on the fly changes in mobile sharing audiences show similarities to mobile resource sharing concepts such as Personal Networks (Niemegeers & Groot, 2002) and Personal Area Networks (PAN) (IEEE, 2001; Zimmerman, 1996). In these concepts mobile resource sharing can extend on demand from personal resources to resources belonging to others in an ad hoc fashion with remote mobile devices or devices in the vicinity of the user (Niemegeers & Groot, 2002). This description of mobile resources sharing corresponds with scaling from private mobile cloud -personal resource sharing- to community or public mobile clouds -third party resource sharing- with the cloud characteristics of on-demand and rapid resource elasticity.

On the fly changes in resource sharing audiences complicate the process of establishing mobile resource sharing as multiple end-users need to reach an agreement to share and pool resources and on which terms. Wijngaert & Bouwman (2009) indicate that the success of mobile resource sharing agreements is strongly influences by the context in which mobile resources can be shared. A trusted context positively influences the willingness to share. This trusted context is more difficult to establish when sharing audiences changing on the fly, lacking the comparatively predictable datacenter deployment environments from the likes of Microsoft or Google. A possible solution is that a mediating party establishes which devices and users are trusted, pooled and shared and to which circle –private, community, public- these trusted resources belong. The type of cloud services allowed could then differ per circle. During the expert interviews we will try and determine which kind of organizations could take in this mediating role.

2.5 Chapter Conclusion

This chapter focused on the research question: *what is mobile cloud computing and how is it related to cloud computing?* Using existing definitions of cloud computing, mobile cloud computing was noted to be: *mobile devices as a channel to obtain cloud computing resources with via the network and/or mobile devices combined as (part of) a shared pool of computing resources.*

Differences between cloud and mobile cloud were noted in the properties of smartphones as a cloud computing resource due to multiple owners, heterogeneous hardware, connectivity properties and in mobile operating systems. How to compensate multiple individual smartphone owners is a knowledge gap. With traditional cloud computing the characteristic of pay-per-use applies and a datacenter owner is paid. It is unclear whether a smartphone resource coordinator or individuals may also be compensated.

Concerning the type of resources shared with cloud computing the concept of Platform as a Service (PaaS) was noted to be relevant for this research. PaaS can serve as a matchmaker between mobile resource providers, mobile resource consumers and mobile resource developers. The business relations around such multi-sided platforms may foster innovation by complementing functionality in the platform with external complements (Evans, et al., 2008; Gawer & Cusumano, 2002). PaaS may be a driver and enabler of production, provisioning and consumption of mobile services. When translated to mobile devices as a PaaS resource, unique mobile resources such as sensors can be made available to multiple types of customers. Knowledge gaps are noted around who can provide the role of matchmaker for mobile PaaS.

We recall that the interactions around multi-sided platforms can be labeled as ecosystems, or networks of enablers and complementary service or product providers (Basole, 2008). Ecosystems are built on core capabilities which deliver the customer a central product (multi-sided service platform) as well as a wide variety of complementary offers (Moore, 1996). In the next chapter we will further explore how ecosystems theory can provide guidance in identifying feasible and viable networks of mobile cloud enablers and complementary service or product providers.

3 Theoretical Background: Business Ecosystems

In the previous chapter we have discussed the multi-sided properties around mobile cloud platforms. The properties of these platforms and the dynamics around them can be labeled as an ecosystem. Ecosystems are a frequently used perspective to study business environments in the mobile telecom domain. However, the approaches to this perspective vary both in literature and practice. In order to find analytical tools to evaluate mobile platforms with, this chapter focuses on the second research question: *What are the ecosystems around platforms and how can these be analyzed?* We will answer this question by first looking at definitions of business ecosystems, categorizing ecosystems theory and deriving criteria for the evaluation of ecosystems from this theory.

Business ecosystems are an analogy for biological ecosystems. Rothschild (1990, p. xi) introduced the ecosystems analogy with the description: *"a capitalist economy can best be comprehended as a living ecosystem. Key phenomena observed in nature –competition, specialization, cooperation, exploitation, learning, growth, and several others- are also central to business life"*. The ecosystem concept gained ground in 1993 with a Harvard Business Review article by Moore (1993, p. 76), in which members of an ecosystems are stated to *"work co-operatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations"*. Moore (1996) later provided a further definition of ecosystems as *"an economic community supported by a foundation of interacting organizations and individuals. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders"*.

The use of the biological ecosystem metaphor to study business phenomena is an evolution of earlier approaches to study inter-organizational networks such as value chains (Porter, 1985), value networks (Haglind & Helander, 1998) and business networks (Kambil & Short, 1994). Value networks are often used in the mobile domain to describe those organizations which cooperate to provide a specific service concept (De Reuver, et al., 2010). Value networks differ from ecosystems because of this focus on co-operative structures and a single service. Members of a value network have predefined tasks and usually only compete at the time when the members of the value network are chosen (Peltoniemi & Eng, 2004). Business ecosystems on the other hand include both competition and cooperation at the same time and are centered around platforms, which both enable and drive the creation of a wide range of unpredictable new products and services (Basole, 2008).

Many variations on this ecosystems analogy exist. Frosch and Gallopoulolos (1989) discuss 'industrial ecosystems' in which industry materials are recycled from end-to-end (Frosch & Gallopoulos, 1989). Mitleton-Kelly (2001) argues that organizations participate in 'social ecosystems' which consist of firms and institutions which co-evolve. Adner & Kapoor (2010) discuss 'innovation ecosystems', while Rothschild (1990) introduced 'economy as an ecosystem'. The many different definitions of ecosystems show a lack of consensus regarding what an ecosystem is. Anggraeni et al. (2007) present an overview of ecosystem definitions in literature. The core of these definitions appears to be that ecosystems consist of a network of interrelated firms around a core technology which are mutually dependent on each other for their performance and survival (Den Hartigh & Van Asseldonk, 2004; Peltoniemi, 2005). Each member of an ecosystem will share the fate of the network as a whole, regardless of their strength (Iansiti & Levien, 2004b). With mobile application platforms we see this when product suppliers (content, applications and services) concentrate around an app store. When end-users leave the app store network, the value of the platform declines for the platform owner, product suppliers and eventually end-users, as product suppliers will leave as well. Similarly when more suppliers adopt the app store, the value of the app store platform rises for all parties (Den Hartigh & Tol, 2008).

Moving on to analyzing ecosystems, we observe that ecosystems at least consist of interrelated firms with some kind of collective performance. Seeking theoretical guidance in the analysis of ecosystems we note that much of the research performed is at a conceptual level rather consisting of empirical work (Anggraeni, et al., 2007). This is an indication that ecosystems as an analytical approach is still maturing (Adomavicius, et al., 2006). Anngreani et al (2007) categorize ecosystems theory in four key domains: 1) the members of an ecosystem 2) the networks between these members 3) the performance of the ecosystem and 4) the governance of the ecosystem. This is in line with our earlier observation that ecosystems consist of interrelated firms with some kind of collective performance, the ecosystems theory developed by Iansiti and Levien (2004a) which provides measures to express the health and performance of ecosystems as well as the work of De Reuver et al. (2010) which describe roles and governance strategies for firms in ecosystems.

The chapter is built up according to these four domains. First, we look at which member roles can be identified in ecosystems in section 3.1. Second, we look at how ecosystems are structured and which dynamics exists around these structures in section 3.2. Third, we seek measures to express the performance of an ecosystem in section 3.3. Finally, we look at how governance can influence the members, network and performance of an ecosystem in section 3.4. In each section we will explore ways to analyze conceptual mobile cloud ecosystems, selecting criteria which can be used for an upfront qualitative evaluation of the viability of an ecosystem without taking an actor perspective. Section 3.6 concludes with an overview of the elicited criteria.

3.1 Ecosystem Members

Ecosystems contain a number of different species, or members. These members are organizations or individuals which may have different objectives and resources to accomplish their goals in. Iansiti and Levien (2004b) define three types of ecosystem members: keystones, niche players and dominators.

- Keystones: keystones provide the platform foundation with which parties in an ecosystem can create and share value and maintain the overall health of ecosystems. Keystones connect members in an ecosystem, comparable to the central hub in a network (Basole, 2008). Keystones maintain ecosystem health by limiting or removing other parties from the ecosystem to maintain stability, while leveraging their platforms to facilitate development and transactions of complementary goods and promote diversity in members and products.
- Dominators: the central position of keystones provides temptations to extract maximal value from the ecosystem, leading to dominator behavior. Dominators try and control the ecosystem through vertical and horizontal integration. Therefore dominators are larger in size than keystones, discouraging diversity in the ecosystem by taking over the functions of other firms, or species (Iansiti & Levien, 2004b). The gains of such a strategy often are short-term as little value is left for other companies in the ecosystem, potentially leading to collapse (Iansiti & Levien, 2004a). In emerging ecosystems dominator behavior would limit innovation. According to Basole (2008) the dominator strategy may be more viable in a mature industry with slow change and less reliance on innovation.

- Niche players (or complementors): the biggest portion of an ecosystem consists of niche players, both in quantity and diversity, e.g. the developers and end-users in mobile app store ecosystems. Niche players have specialized capabilities which make use of the platform facilities provided by the keystone. They develop complementary or compatible products to benefit from the economies of scale offered by the platform (Anggraeni, et al., 2007). Game developers for example provide software for a videogame platform. The success of niche players depends on the effectiveness of the keystone's strategies. Though mutually dependent, niche players can conflict with keystones, dominators and other niche players when their specialization and differentiation is at stake, expressing the presence of both competition and cooperation in ecosystems. This can for example happen when the keystone attempts to integrate the core capability of a niche player into the platform. Niche players can use the threat of leaving to alternative or competing platforms to keep dominators at bay and to influence the strategies of keystones (Iansiti & Levien, 2004b).

The position of keystone is a desired position due to the possibility of high rewards when the platform becomes dominant (Shapiro & Varian, 1999). Platforms can provide competitive advantages such as economies of scale, barriers to entry and persistence over time, leading to long-lasting buyer-seller relationships (Bresnahan, 1999). This desired keystone position leads to standard wars between competing technological platforms (Church & Gandal, 1992). However, only few firms can become platform leaders as the strategy is high in cost and risk (Anggraeni, et al., 2007) and the market can only support so many platforms. The resource based view states that lasting platform advantages can be gained with valuable, rare, inimitable and non-substitutable resources (Barney, 1991). This is an incentive for complementors to collaborate with the platform as they are mutually dependent on its resources (Pfeffer & Salancik, 1978). Important resources for platforms include control over the customer relationship, data or transaction (Weil & Vitale, 2001) and control over tangible, intangible and organizational assets (De Reuver, et al., 2010). Knowing that the keystone position is both attractive and hard to get raises the question of what likely platform positions for mobile cloud can be.

When looking at where to position platforms in the mobile industry multiple classifications are possible. Platforms can be categorized by their presence in a technological layer, by the functionality they provide or which industry player they are positioned at. Mobile cloud platforms could be technically positioned on many places e.g. in generic client application for mobile devices, in specific-purpose applications, in the mobile OS or firmware. The functionality platforms can provide can be classified as enabler, broker, neutral or system integrator which differ in terms of control over the customer relation and assets (Ballon, 2009). De Reuver et al (2011) argue that multi-sided platforms are centered around devices, operators or service providers. Examples of this categorization are seen in Figure 10. Device centric platforms focus around smartphones with their app communities. Operator centric platforms are seen in portals such as Vodafone Live!/360 (Gonçalves & Ballon, 2011). Service provider centric platforms are often web-based, such as Facebook's social network and developer community, allowing for device and operator independency. Device, operator and service provider centric platforms provide a workable classification for mobile cloud platforms. End-users sharing mobile resources could be the clients of a mobile network operator, the clients of a handset brand or OS e.g. iOS or the clients of a specific service provider e.g. social media platforms. Depending on how the platform is arranged in terms of customer relation and asset ownership variants in-between are possible, e.g. clients of multiple operators or the Android users within one operator client base. Due to its ability to elicit platform positioning we will continue to use the device, operator and service provider centric classification during the interviews.

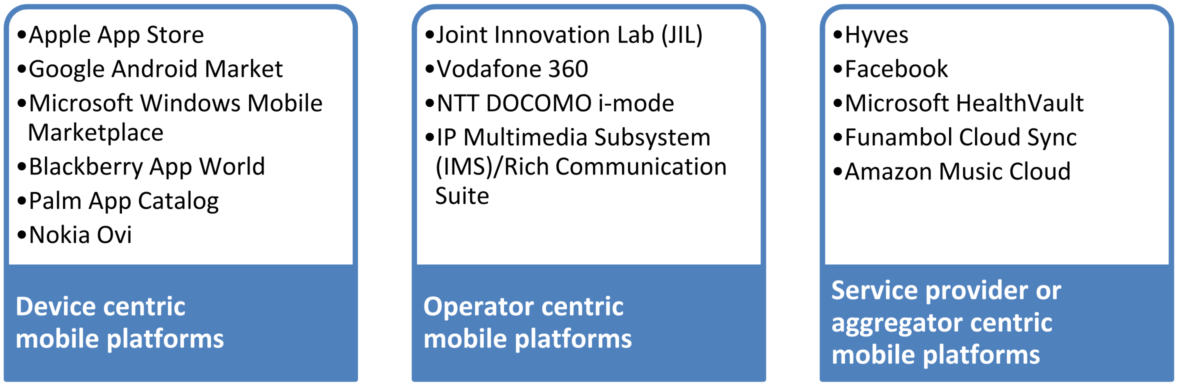

Figure 10 - Examples of device centric, operator centric and service provider centric platforms (De Reuver, et al., 2011)

3.1.1 Selection of Member Criteria

Three ecosystem criteria are derived from theory regarding ecosystem members:

- The presence of a keystone as a platform leader to connect ecosystem members and promote the health of the ecosystem with rules or platform improvements. Keystones in the mobile domain could be device and/or device OS manufacturers, operators or service providers. Aside from the actor or role positioning question of who becomes keystone, the technical positioning and functionality offered by the platform determines the way the keystone role is fulfilled.
- Complementors are required to complement the platform in strength, diversity and quantity. Niche players in the mobile domain are amongst others application developers, content providers and service providers. With mobile cloud platforms the device owners providing mobile resources are considered complementors as well.
- Strong or unique resources should be present in the ecosystem as a barrier to entry preventing others from copying the service proposition. These resources could be present at both the keystone and niche players e.g. Dell complementing the Windows OS platform with large hardware sales.

The dominator role is omitted as it is more suitable to mature ecosystems or platforms while mobile cloud entails emerging ecosystems or platforms. When analyzing mobile cloud platforms we should thus identify whether these are viable when positioned as handset centric, operator centric or service provider centric, how positioning the ecosystem at one of these actors affects the ability to compete, attract and retain complementors and whether the ecosystem members have sufficiently strong resources.

Figure 11 presents an overview of the selected ecosystem member viability criteria. We will provide such an overview after each section in this chapter.

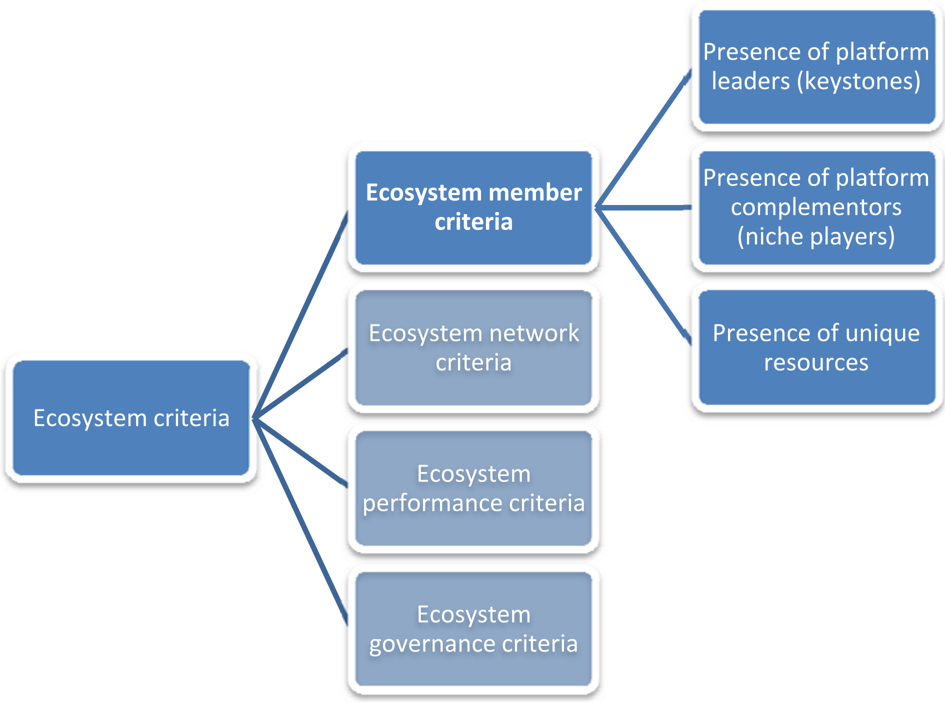

Figure 11 - Selected member criteria

In the next section we will look at the relationships between the members in an ecosystem, how their relationships can be structured and what the dynamics of their interactions entail.

3.2 Ecosystems as Networks

The ecosystem analogy is built on a large theoretical foundation regarding inter-firm relationships and collaboration, inter-organizational network analysis, and complexity theory (Basole, 2008). Moore explains business ecosystems as complex networked systems in which firms coexist, are interdependent and form symbiotic relationships (Moore, 1996). In these networks firms both compete and co-operate simultaneously, engaging in co-opetition (Brandenburger & Nalebuff, 1997) to protect and develop the ecosystem (Moore, 1996). Development is a main trait of ecosystem networks, which are capable of adapting to changes both within the ecosystem and in the environment. This trait is extensively discussed in theory using complexity concepts such as self-organization, emergence, co-evolution and adaptation (Peltoniemi & Vuori, 2004). To categorize this abundance of related literature we divide the theory regarding ecosystems as networks in two parts: structure and dynamics. At the end of this section we elicit ecosystems viability criteria from both parts.

3.2.1 Ecosystem Structures

Analyzing ecosystem structures is possible by capturing the organizations, organization types, organizational attributes and their relationships (Basole, 2009) . This information can be used to visualize the structure of an ecosystem as seen in Figure 12. This type of structure visualization is highly data-intensive and requires access to or creation of databases containing extensive financial and transaction information in order to draw node sizes, proximities and network maps (Basole, 2009). A benefit of the visualization method is that not only the ecosystem around a single platform is shown, but the interaction with competing ecosystems is shown as well.

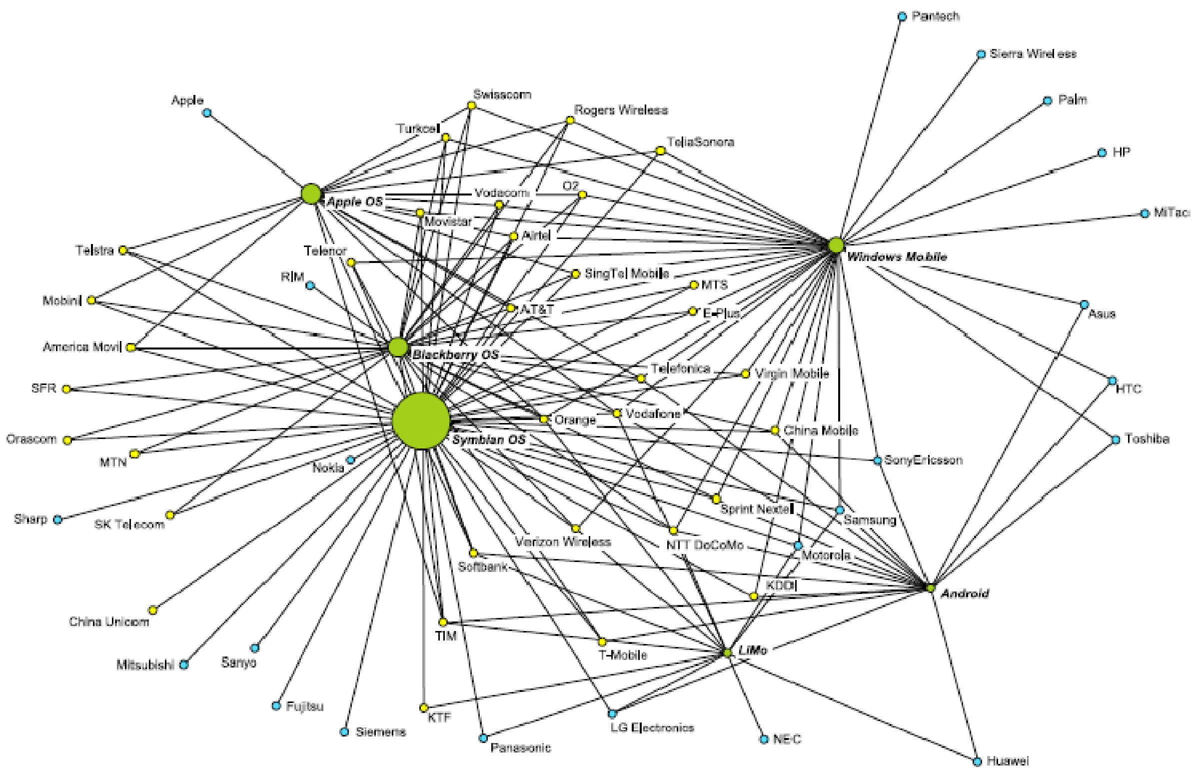

Figure 12 - Structure visualization of the 2008 Mobile OS ecosystem (Basole, 2009)

This social network style approach to modeling ecosystem structures is less appropriate for this study towards conceptual mobile cloud platforms as we lack the means to create a database of interactions. As an alternative approach to defining network viability one can look at 1) acceptable role divisions and 2) acceptable revenue sharing arrangements as a criteria (H. Bouwman, et al., 2005). Role divisions are relevant due to competition for the position of keystone or over the customer relation and assets. Revenue sharing is important for the share of revenue taken by the platform owner versus the share of revenue going to suppliers. During the interview phase we will explore what role and revenue division arrangements between mobile cloud platform enablers, developers and end-users providing mobile devices are viable. We now move on to the dynamics which are enabled by the structure of an ecosystem.

3.2.2 Ecosystem Dynamics

Ecosystem dynamics can have both internal and external origins, triggering interaction between ecosystem members (Anggraeni, et al., 2007). These interactions are the results of the multi-sided platforms at the core of ecosystems, connecting different members and increasing the value of the platform as more members join. Metcalfe's Law (1995) states that the value of a telecommunications network is proportional to the square of the number of users (n^2) connected to the system. This phenomenon can be categorized under the label of network externalities or effects[3]. Both direct and indirect network externalities play a role in the economics of infrastructures Direct network externalities entail the physical effect of having more physical nodes to connect with, the classic examples being telephones or fax machines (Shapiro & Varian, 1999). Indirect network externalities occur when value is obtained from complementary goods, such as when the supply of software for personal computers

[3] The term network externalities appears to be used interchangeably with network effects. Though some researchers such as Liebowitz and Margolis (1998) make further distinctions between network externalities and network effects we will continue with the term externalities.

increases depending on the number of computers sold (Katz & Shapiro, 1985). The value captured from network externalities can however differ between participants in a network. Individual users might for example not always be able to internalize the externalities offered by new joiners while the network owner can (S.J. Liebowitz & Margolis, 1994) as could be the case when individuals share smartphone resources for mobile cloud services without some form of compensation from the platform coordinator.

Network externalities cause platform switching costs for consumers. Switching costs can prevent multi-homing: customers will refrain from using multiple platforms at once because of high costs (Doğanoğlu & Wright, 2006). When network externalities exist, collective switching costs apply as the combined switching costs of all members. The classic example would be that people stick with the classic QWERTY keyboard, even though more efficient keyboard layouts exist. This leads to lock-in, which can be actively managed by a platform owner (Rogers, 2003). App stores present an example of platform owners creating lock-in. Applications will only work with handset of the app store provider, causing loss of apps in case the customer switches.

3.2.3 Selection of Network Criteria

The category networks provides us with three ecosystems criteria (Figure 13):

- Acceptable division of roles: this criterion relates to platform ownership, customer relationships and the type of assets shared per role.
- Acceptable division of revenues: this criterion may entail the revenue split between a mobile cloud platform owner, service providers and individuals providing smartphone resources.
- Network effects: mobile cloud platforms should result in both direct network effects and indirect network effects, providing many smartphones to connect with, as well as new mobile cloud services built for collaborating mobile devices.

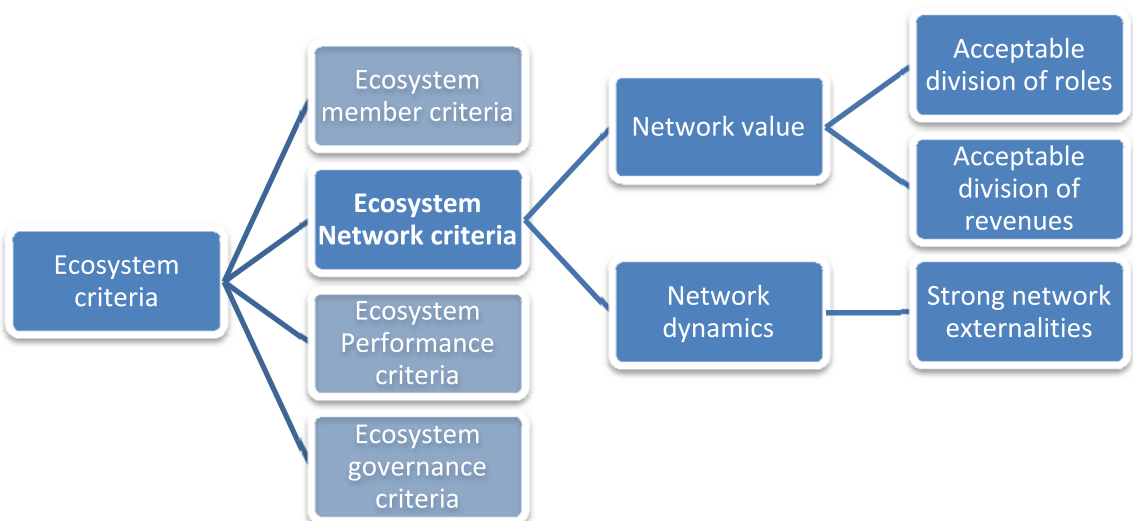

Figure 13 - Selected network criteria

Depending on the strength of its members, structure and dynamics, the performance of an ecosystem may vary. In the next section we seek ways to express the performance of an ecosystem.

3.3 Ecosystem Performance

The performance of an ecosystem determines whether it creates sufficient value for its members and whether this value is sustainable over long periods of time. Seeking criteria to judge the performance of an ecosystem we turn to Iansiti and Levien's (2004b) three measures of ecosystem health: niche creation, productivity and robustness. Some work remains to be done in making these measures more operational and relevant for ecosystems based on (multi-sided) software platforms. The ecosystem health indicators appear to change and contain overlap throughout various publications (Iansiti & Levien, 2002, 2004b; Iansiti & Richards, 2005). In the following section we will go through the three measures of ecosystem health, discussing a number of sub measures which may be appropriate as criteria for a qualitative analysis of ecosystem performance.

3.3.1 Niche Creation

Niche creation stands for the capacity to create meaningful firm, product, function and technical variety in the ecosystem (Iansiti & Richards, 2005). Niche creation mirrors biodiversity through the variety of members and the results of their activities in the ecosystem. A wide range of content, services and applications will be able to cater to a long tail of customer demand niches (Anderson, 2006) including different price segments, geographical markets, distribution channels and complementary goods. For multi-sided platform this means that attaining large numbers of customers on both sides of the platform does not suffice: a wide range of customers and output should be present as well. Ecosystem diversity is therefore our first ecosystem niche criterion.

Niche creation also refers to the adoption of innovation in an ecosystem. In healthy ecosystems new technologies are continuously transformed into new businesses and products (Iansiti & Richards, 2005). In the mobile domain we witness innovation in a variety of ways, including user interfaces, payment methods, handset OS functionality, mobile device sensor upgrades, location based services etc.. Adoption of innovation is therefore our second ecosystem performance criterion.

Iansiti and Richards (2005) propose financial measures to express the effectiveness of niche creation: *return on venture capital invested in innovation* and *firm valuations by investors as an indicator of the future prospects of innovation*. As we do not perform empirical financial measurements these measures are not further used. Niche creation thus provides us with two ecosystems performance criteria (Figure 14):

- Ecosystem diversity
- Adoption of innovation

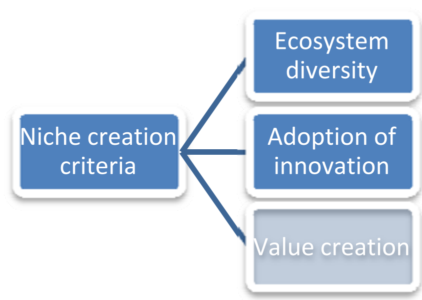

Figure 14 - Selected niche creation criteria

We now move on to the productivity measures of ecosystem performance.

3.3.2 Productivity

Productivity entails that an ecosystem can deliver products with continuous performance improvements: more results delivered with the same or less means (Iansiti & Richards, 2005). Three measures of ecosystem productivity include (Iansiti & Levien, 2002):

- *Total factor productivity*: traditional economic productivity analysis such as labor productivity (output/hour/person) is given as an example measure for ecosystem productivity.
- *Productivity improvement over time*: this refers to growth of the rate at which new products are delivered, such as applications, content or services. Improvement also stands for completing the same tasks at progressively lower costs.
- *Delivery of innovations*: Iansiti and Richards argue that both increased product delivery rate and cost savings are the result of continuous innovation in processes, technologies and ideas in the ecosystem.

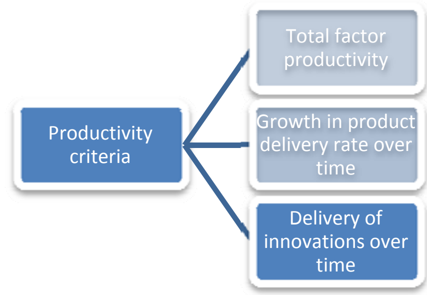

Figure 15 - Selected productivity criteria

Total factor productivity is not applicable for the qualitative analysis performed in this research. The growth *rate* of new products with mobile cloud is unpredictable with hypothetical ecosystems as well. We omit these measures as they are not practically applicable with the lack of quantitative data in this research, selecting one productivity measure as a performance criterion (Figure 15):

- Ddelivery of innovations over time: a mobile cloud platform should enable a continuous stream of innovative services based on mobile resources

3.3.3 Robustness

Business ecosystem robustness is related to Darwin's survival of the fittest paradigm. Business ecosystems which are able to resist and adapt to both internal and environmental changes are able provide their members and customers sustainable benefits. There are a number of ways to measure ecosystem robustness (Iansiti & Levien, 2002; Iansiti & Richards, 2005):

- *Survival rates:* ecosystem members should have high survival rates viewed either over time or in comparison to other ecosystems.
- *Persistence of ecosystem structure:* external impacts have limited influence on the relationships between members and technology in the ecosystem.
- *Limited obsolescence:* the majority of ecosystem members and technology retains continued use after strong changes in the ecosystem environment, as little of the capacity is 'obsolete'.
- *Predictability:* changes as a consequence of disruptions are predictably located so the core of the ecosystem remains the same. This is possible with a platform which is built with adoption of new technologies and modules in mind.
- *Continuity of user experience and use cases:* end-user experiences undergo evolution rather than disruptive evolution when new technology is introduced. This evolution is seen in incremental iOS updates and with new Windows operating systems.
- *Financial indicators* such as the Goldman Sachs Technology Composite Index for stock research.

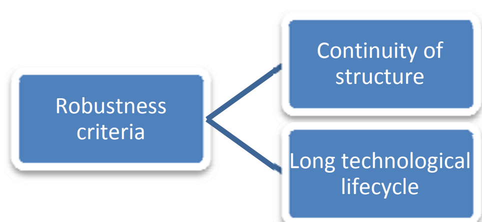

Figure 16 - Selected robustness criteria

Several of these robustness measures contain overlap and are ill-suited for analysis of conceptual ecosystems. We therefore group the indicators regarding persistence, continuity, predictability and obsolescence into two parts which we use as ecosystem robustness criteria (Figure 16):

- the continuity of the ecosystem structure
- Long technological lifecycle

These criteria express that the inter-firm structure around a platform should not be easily disrupted e.g. by new entrants and that the technology in and around the platform should be able to evolve to adapt to changes in the environment.

3.3.4 Selection of Performance Criteria

In this sub section we converted ecosystem health measures to ecosystem performance criteria. Figure 17 shows the selection of ecosystem health criteria which are deemed suitable for a qualitative evaluation of ecosystem performance.

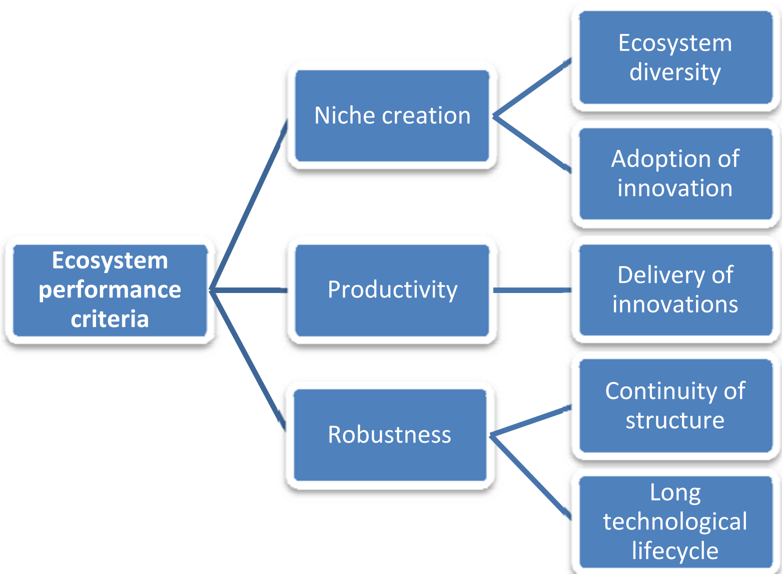

Figure 17 - Selected ecosystem performance criteria

3.4 Ecosystem Governance

Governance is what ecosystem members can do to influence the network of organizations around them. Proper governance of the relation between the platform provider, application developers, service providers and end-users strongly influences platform success. The label governance is used rather than management to express the difference between the hierarchical relation associated with management, and the merely influential relation a firm has within an ecosystem or network (Den Hartigh & Van Asseldonk, 2004). In a software platform based ecosystem, governance determines amongst others the structure, process and power of decision making (Von Tunzelmann, 2003) regarding API's, source code, interfaces, standards, revenue sharing and barriers to entry. Barriers to entry are a recurring discussion regarding governance of platforms. De Reuver et al. (2011) note a tension between making service development via the platform as flexible as possible for service providers and end-users while keeping control over the platform assets to maintain a strategic advantage. Technological choices of the party which governs a platform determine this control. More flexible technology can attract a larger number of platform complementors, while closer control leaves more options for differentiation.

3.4.1 Selection of Governance Criteria

Governance issues vary depending on how a platform is positioned (operator centric, device centric or service provider centric) as each of these possible platform positions comes with specific technological and organizational assets and a different customer relation. Operators may have a billing relation, devices bind users via apps while service providers may have global device independent relationships. We select two governance criteria for ecosystems (Figure 18):

- influence over the technical assets of the platform
- influence over the customer relation

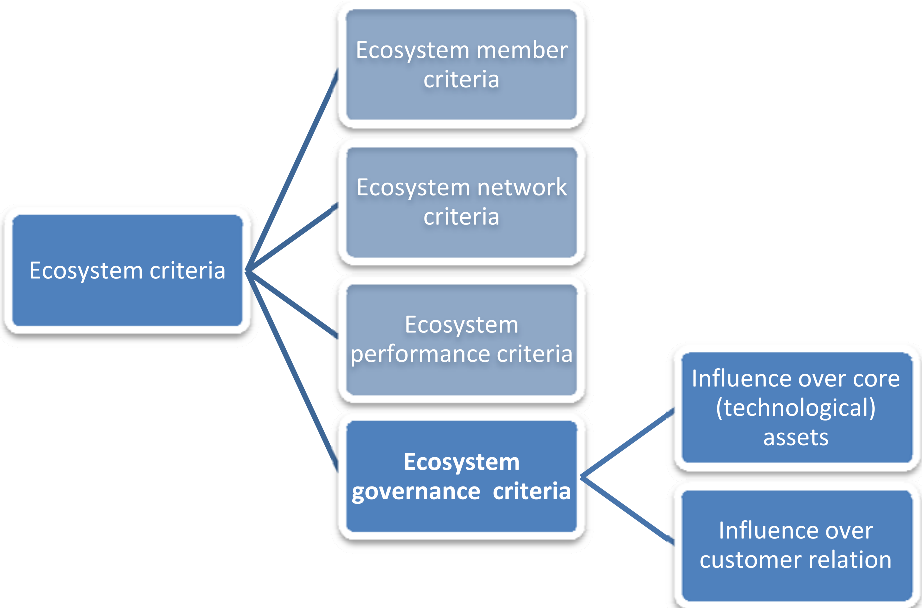

Figure 18 - Selected ecosystem structure criteria

3.5 Criteria Obtained from Business Model Theory

In section 3.2 we used two critical success factors (CSF's) obtained from business model literature to express criteria regarding the network viability of ecosystems. The consulted CSF's provide a wide range of CSF's regarding network value and customer value (De Reuver, et al., 2011) to explore the feasibility and viability of business models during the lifecycle of mobile services. To complete our selection of ecosystem viability criteria we explore the full list of CSF's. Table 9 presents the customer and network value CSF's and their ability to serve as additional ecosystems viability criteria. From this table we acquire one additional criterion: customer value, which can be used to express the attractiveness of the core service proposition of a platform for suppliers and end-users. This supplements the ecosystems performance indicators which are focused on the performance of ecosystem rather than the platform proposition (section 3.2.1). The customer value CSF will be used during interviews

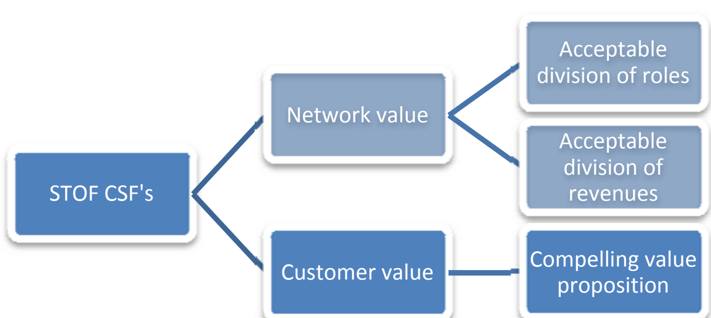

Figure 19 - Selected CSF's from business model theory (De Reuver, Haaker, & Bouwman, 2006)

to determine how industry actors perceive the value of a mobile cloud platform (Figure 19).

Table 9 - Applicability of business model CSF's as ecosystems criteria (De Reuver, et al., 2006)

CSF category	CSF's	Applicable?	Rationale
Network value	Acceptable risks	No	Not deemed relevant for the level of analysis and the exploratory nature of this research
	Acceptable profitability	Yes network value	Renamed to *acceptable division of revenues* as costs estimations are unavailable at this point
	Sustainable network strategy	No	Overlaps with health indicator 'robustness'
	Acceptable division of roles	Yes network value	Related to platform positioning in functionality layer, roles and interactions
	Network value	No	Overlaps with ecosystem health indicators productivity and niche creation, which provide a further breakdown of network value
Customer value	Clear target group	No	Multi-sided platforms could aim to draw diverse niches of customers rather than set target groups
	Compelling value proposition	Yes -customer value	The core mobile cloud platform concept should be appealing for supplies and end-users
	Customer reach	No	Overlaps with the member criterion "presence of platform complementors/niche players" which entails customers.
	Acceptable quality of service delivery	No	Not deemed relevant for the level of analysis and the exploratory nature of this research
	Non-obtrusive customer retention	No	Overlaps with degree of customer lock-in/ preventing multi-homing
	Customer value	No	Considered to overlaps with STOF CSF compelling value proposition

3.6 Chapter Conclusion

This chapter focused on the question: *what are the ecosystems around platforms and how can they be analyzed?*

Ecosystems were found to consist of a network of interrelated firms around a core technology which are mutually dependent on each other for their performance and survival. Ecosystems can be analyzed in four categories: their members, the network of relations between these members, the performance of the ecosystem and the governance of the ecosystem.

From each category a number of ecosystems feasibility and viability criteria were derived using ecosystems theory, multi-sided platform theory, theory providing guidance in expressing the health of ecosystems and business model theory. A large number of financially-related criteria encountered in were omitted as they require quantitative data not available during this research.

Our final selection of ecosystem feasibility and viability criteria is shown in

Table 10. These criteria were selected on their applicability to a qualitative evaluation of ecosystems feasibility and viability without taking a specific actor perspective. We note overlap between feasibility and viability in the criteria: whereas a certain platform leadership position may be technologically and organizationally feasible, it may have consequences for mobile cloud service viability due to the existing user base of that platform.

Table 10 - Overview of selected ecosystem feasibility and viability criteria

Category	Relevance	Criteria
Members	Availability of resource-rich members	• Presence of platform leaders (keystones) • Presence of complementors • Presence of unique resources
Network	Network value & network dynamics	• Acceptable division of roles • Acceptable division of revenues • Strong network externalities
Performance	Niche creation *Firm, product, technical variety*	• Ecosystem variety • Adoption of innovation
	Productivity *Rate of delivery of innovations*	• Delivery of innovations over time
	Robustness *Resistance to environmental changes*	• Continuity of structure • Lengthy technological lifecycle
	Customer value	• Compelling value proposition
Governance	Management of inter-firm dependencies	• Influence over core technological assets • Influence over customer relation

In the next chapter we will apply these criteria to set up a protocol for interviews towards mobile cloud platform feasibility and viability.

4 Interview Methodology

In the previous chapter we identified a number of criteria suitable to judge the feasibility and viability of business ecosystems. In this chapter we lay out the interview setup where we translate these criteria to an interview protocol. As mobile cloud platforms currently exist in conceptual or prototype forms focusing on technical architectures, these interviews provide insight in the real-world business feasibility and viability of mobile cloud computing. We conduct interviews around use cases discussing three specific mobile resources which can be shared and pooled: connectivity, processing and sensors. Though the cloud computing paradigm describes heterogeneous resource pools, several of the mobile cloud architectures in literature currently focus on just one type of mobile resource sharing, e.g. AggreGATE for connectivity or MapReduce and Weblets for processing (Ananthanarayanan & Zats, 2009; Zhang, et al., 2009). The three use cases are discussed one by one with the same questions to elicit a broad range of relevant factors depending on the type of smartphone resource shared. This allows us to generalize the results of each case to conclusions regarding the feasibility and viability of mobile cloud platforms.

4.1 Three Use Cases

Interviews were conducted according to the format seen in appendix D. The use cases and underlying architectures are based on comparable architectures and cases found in technical papers. We omitted shared smartphone storage in our interviews as few architectures for this application are available, most likely because smartphone connectivity and battery limitations are a showstopper for access to storage. During our literature review, only the Hyrax (Marinelli, 2009) architecture was noted to focus on storage. To structure the discussion we split the mobile cloud concept into three use cases based on architectures discussed in section 2.4:

- Shared connectivity pools as seen in AggreGATE (Ananthanarayanan & Zats, 2009)
- Shared processing pools such as seen in MapReduce (Elespuru, et al., 2009; Zhang, et al., 2009)
- Shared sensor pools as discussed by Beng (2009)

The three selected use cases all have the same architecture of a coordinating server which matches a shared pool of smartphone resources with end-users or service providers requesting resources from this pool. The sensor use case is not based on a specific architecture but extended from the coordinating server based architecture of AggreGATE and MapReduce. With all cases the initial assumption was communicated that only smartphones are part of the shared resource pool.

The processing and sensor use cases have the properties of PaaS. End-users and service providers can access the shared mobile resource pool to acquire resources from or deploy services on. To prevent discussions regarding the definitions of PaaS during the interviews, the cases were renamed to connectivity cloud, processing cloud and sensor cloud.

AggreGATE represents a connectivity IaaS service and may therefore not fully embrace the notion of a multi-sided platform as seen in PaaS. We added AggreGATE to the list of use cases as connectivity is one of the unique resources mobile devices add to cloud computing and because most of the issues surrounding shared connectivity pools also apply to the processing and sensing case, such as how to compensate end-users for sharing resources, where to locate the coordinating server.

4.2 Selection of Respondents

Maximum diversity in respondents was sought to obtain a wide range of perspectives on mobile cloud. Rather than interviewing the same type of respondent more than once, breadth in feedback was sought. The drawback of this approach is that the results cannot be generalized to specific perspectives, as not enough respondents in each category were interviewed. Aside from seeking diversity we made sure to include respondents in the 'operator centric', 'device centric' or 'service provider centric' classification (De Reuver, et al., 2011) to acquire feedback from possible platform owners and stakeholders. Illustrating the scope of our respondents, 10 of the 14 segments in the generic mobile ecosystem as formulated by Basole (2008) (Figure 20) were interviewed. The segments not interviewed are photography, gaming, cable providers and silicon vendors which are not considered key for an understanding of smartphone based mobile cloud.

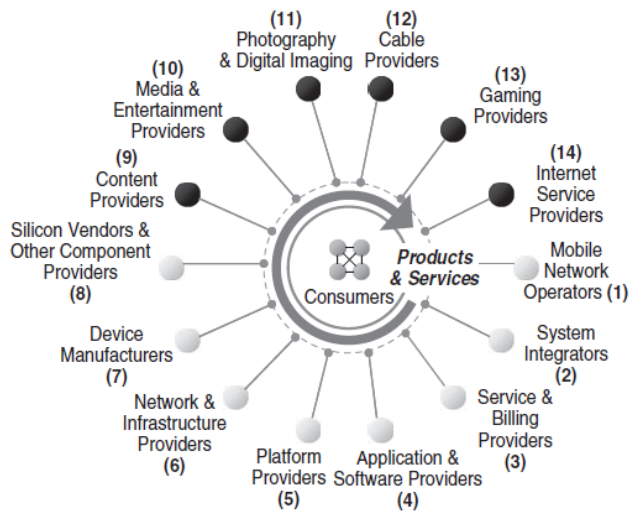

Figure 20 - Segments in a mobile ecosystem according to Basole (2008)

Interview candidates were acquired in a number of ways. First, the network of industry guest lecturers at Delft University of Technology was consulted. Second, LinkedIn searches were conducted to find practitioners with specific expertise and subsequently cold-call these. Third, contacts were made at the Capgemini cloud computing conference of September 2010 (Utrecht) and the Exact IIP-SaaS knowledge session in September 2010 (Delft). Fourth, the client network of the Dutch branch of KPMG was consulted. Finally, interviews were acquired via referrals from interview candidates themselves.

We were unable to interview handset OS developers and cloud computing service providers. Handset OS developers are traditionally located outside of the Netherlands, retail channels notwithstanding. Though their Dutch offices were approached for referrals to foreign offices this did not lead to interviews. Some of our respondents noted that mobile OS developers may have reservations in sharing information on their roadmaps. Cloud computing vendors were approached but replied negatively in two ways. First, they did not consider mobile cloud innovations as their domain but rather that of service providers and handset or OS developers. Second, the Dutch offices of cloud computing providers stated to be dedicated sales teams with less in the way of research towards future technologies. An interesting comment from one cloud computing service provider was that they considered mobile resource based cloud as part of the hype to label everything as cloud. Our final list of respondents can be consulted in Table 11.

Table 11 - Overview of respondents, functions and expertise

Interview candidate	Organization	Function	Expertise
Hugo Huis in't Veld	KPN Mobile and Wireline Network Operator and Internet Service Provider	Senior Innovation Manager	Mobile innovations
Patrick Steemers	Capgemini Consultancy/System Integrator	Principal Consultant Telecom, Media, Entertainment	SaaS/PaaS for mobile, infrastructure implementations, mobile strategy
Bart Bastiaans	KPMG Consultancy	Manager IT Infrastructure & Architecture	Wireless technology, architectures, mobile security
Mick Coulson	Acision Messaging platform provider	Product manager mobile data services	Mobile messaging platforms
Frank Berkers	TNO Research Institute	Researcher business innovation & modeling	Technology trends & stakeholder analysis
I. Niemegeers	Delft University of Technology	Researcher Wireless & Mobile Communications	Collaborative device applications, personal networks
Joost van der Plas	Hyves Mobile Virtual Network Operator & Social media platform	Manager Mobile	Mobile plus social media platform convergence
Patrick Blankers	Ericsson Infrastructure provider	Manager Strategy & Regulation	Mobile telecom infrastructures
Jose Santiago Nunez	TomTom Navigation solutions	Product labs manager	Multi-platform application development, device-to-device applications, location services
Arjen de Vet and Lassi Kurkijärvi	Sanoma media Content & Media provider	Manager ICT	Mobile marketing and content, mobile video
Fred Herrebout	T-Mobile Mobile Network Operator	Strategy manager	Operator centric strategy
Rene Witjes	Service2media Application & software provider, development platform provider	International Business Developer	Cross-platform application development and sales
Marcel Wendt	Golden Bytes Billing & infrastructure provider	CTO, founder	Mobile technology innovations, operator interconnect infrastructure
Dennis Kokkelink	Samsung Handset manufacturer	Mobile Telecom content manager	Handset and OS differentiation, handset marketing and sales

4.3 Interview Protocol

The interviews were designed to apply the ecosystems viability criteria to three mobile cloud use cases with similar architectures. Interviews lasted one hour, in two select cases reduced to 45 and 30 minutes to fit the agenda of the respondent. Prior to the appointment the respondents were sent an introductory document containing the research objective and use cases for mobile cloud as seen in appendix D. With the consent of the respondent the interview was recorded for processing into a transcript afterwards. The interview questions were derived from the ecosystems viability criteria as discussed in chapter 3. Table 12 shows the questions alongside the criteria. Due to time constraints during the interview we omitted converting the governance criteria to specific questions and merged some criteria into one question.

Table 12 - Conversion of criteria to interview questions

Category	Criteria	Questions
Members	• Presence of platform leaders (keystones) • Presence of complementors • Presence of unique resources	1. Which organizations would be 1) capable of and 2) willing to attain ownership of this platform? 1.1. Operators, Device/OS, Service providers? 1.2. What would be the critical assets to determine platform ownership? 1.3. Which complementors would the platform require?
Network	• Acceptable division of roles • Acceptable division of revenues • Strong network externalities	2. Which role divisions would be acceptable for the parties enabling the platform service? 2.1. Which revenue sharing models are likely to be supported between these parties? 2.2. Is the user base in this division model sufficient to provide enough smartphones to connect with?
Performance	• Ecosystem variety • Adoption of innovation • Delivery of innovations over time • Continuity of structure • Lengthy technological lifecycle • Compelling value proposition	3. Is the core service platform proposition attractive enough to attract a wide range of customers to the platform: smartphone providers, end-users, service providers? 3.1. Which type of services or applications would you expect drive demand for this mobile cloud platform? 3.2. In what ways would end-users be a) attracted and b) retained? 3.3. Which telecom market developments could have an impact on the lifecycle of a mobile cloud platform? (e.g. LTE-A, HTML5)?

4.4 Qualitative Data Analysis with ATLAS.ti

Interview transcripts are processed using the ATLAS.ti software tool for qualitative analysis of textual data. ATLAS.ti aids in systematically categorizing interview feedback and visualizing the relations between findings. For this purpose, our list of ecosystems criteria was first converted to a reference causal framework of ecosystems feasibility and viability criteria. The visualization of the framework can be seen in Figure 21. Quotations of interest or recurring quotations in the interview transcript are coded as variables in ATLAS.ti and grouped according to this framework. Such coding allows us more convenience in the analysis of interview results by providing overviews of related quotations. Furthermore, ATLAS.ti indicates the amount quotations underlying a code, giving a possible hint towards the importance of a code. The left number next to the code visualization expresses the amount of underlying quotations, while the number on the right expresses the amount of related codes (Figure 21).

As we obtain qualitative results we have chosen to divide codes into success factors (causes of feasibility and viability) and inhibitors (limit feasibility and viability). The framework in Figure 21 is applied to each use case discussed during the interviews, leading to an overview of success factors and inhibitors for connectivity, processing and sensor cloud separately as well as an overview of success factors and inhibitors which are common across the use cases and thus apply to mobile cloud in general.

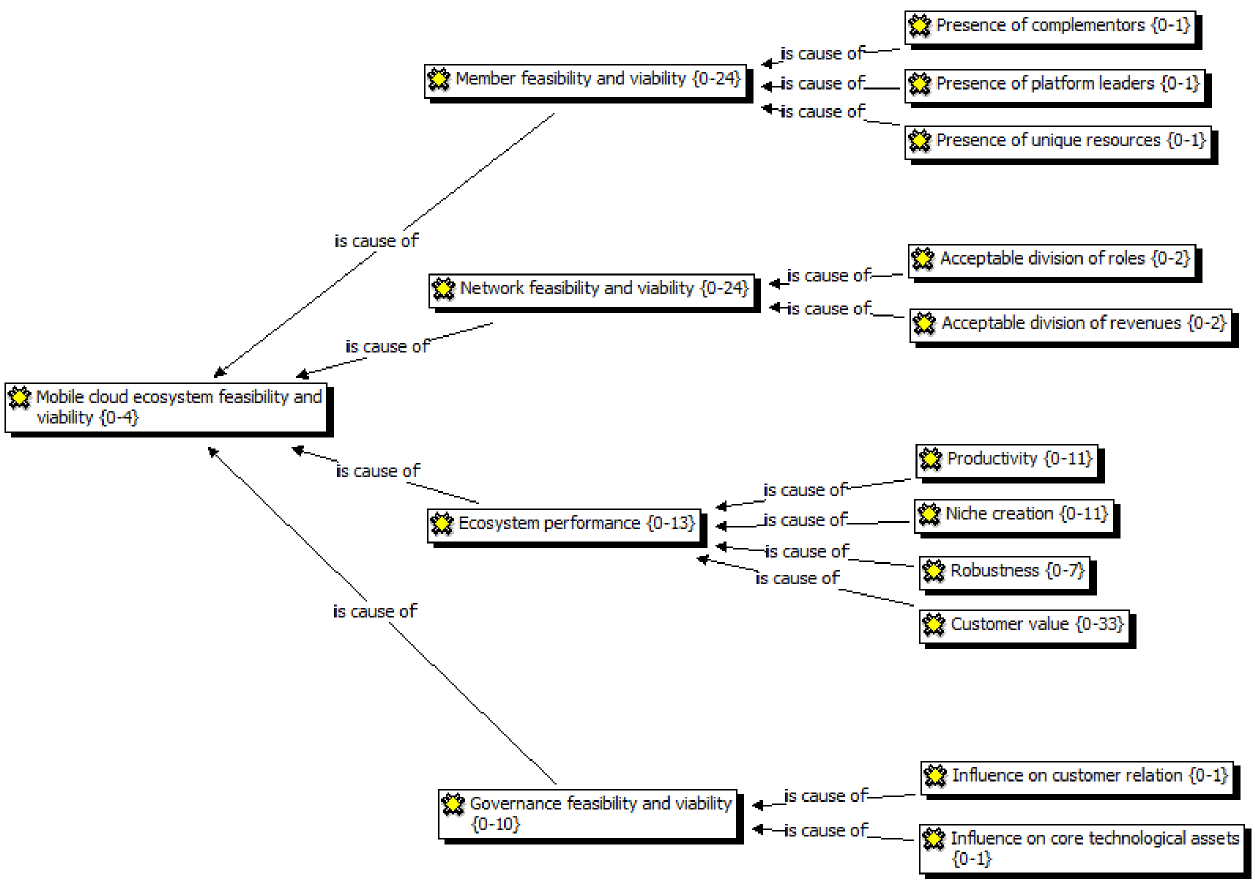

Figure 21 - Translation of criteria to causal model in ATLAS.ti

In the next chapter we will elaborate on the interview results based on this setup.

5 Interview Results

In this chapter we discuss the interview results, focusing on the question: *what are success factors and inhibitors which determine the real-world feasibility and viability of mobile cloud platforms?*

The answer(s) to this question were obtained during a series of 14 interviews using the theoretical framework from chapter 3 and the questionnaire formulated in chapter 4. The interviews yield results regarding the general success factors and inhibitors of mobile cloud ecosystems in the theoretical categories of members, network and performance. The results in each category will be discussed in each subsection. Section 5.1 discussed the results in the category members. Section 5.2 discusses the results in the network category. Section 5.3 discusses the results in the performance category. Section 5.4 presents use case specific results for the connectivity, processing and sensor case.

Each section firsts presents a table with the main success factors and inhibitors found per category. Individual success factors and inhibitors are discussed afterwards.

5.1 Ecosystem Member Results

In chapter 3 three criteria expressing requirements to the members of an ecosystem were formulated: *presence of platform leaders (keystones), presence of complementors, presence of unique resources*. The corresponding main success factors and inhibitors for these criteria are shown in Table 13.

Table 13 - Main success factors and inhibitors in the category members

Category	Success factors	Inhibitors
Members	• Platforms with already large ecosystems of service providers and mobile end-users are considered most likely to become mobile cloud platform owners due to existing network effects. • Handset OS vendors may extend their app store service offerings with mobile cloud services, making devices more attractive. At the same time they can sell access to the shared mobile resource pool to third party service providers. • Internet based service providers may gather large audiences of end-users and service developers which are not bound to a single operator or OS.	• Parties which lack the capability to innovate or mobilize innovation are unlikely to become mobile cloud platform owners. Operators are therefore considered less likely to be the platform owner in mobile cloud ecosystems. • Operators are considered to be less likely to support mobile cloud platforms as mobile cloud services increase the load on their (currently) strained networks. Operators may actively discourage mobile cloud services, possibly exploiting the mutual dependencies between operators and handset vendors in handset subsidies.

During the interviews our respondents generally addressed these three criteria in one go: possible platform leaders were identified by their specific resources and existing ecosystem of end-users and mobile service providers. We led the interview using the classification of operator-centric, handset-centric and service provider-centric platforms (De Reuver, et al., 2011), resulting in three conclusions with regards to platform leadership for mobile cloud computing:

1. The operator is considered an unlikely position for mobile cloud platforms
2. The handset OS is considered a likely position for mobile cloud platforms
3. Service providers are considered a likely position for sensor-sharing based mobile cloud (Figure 24)

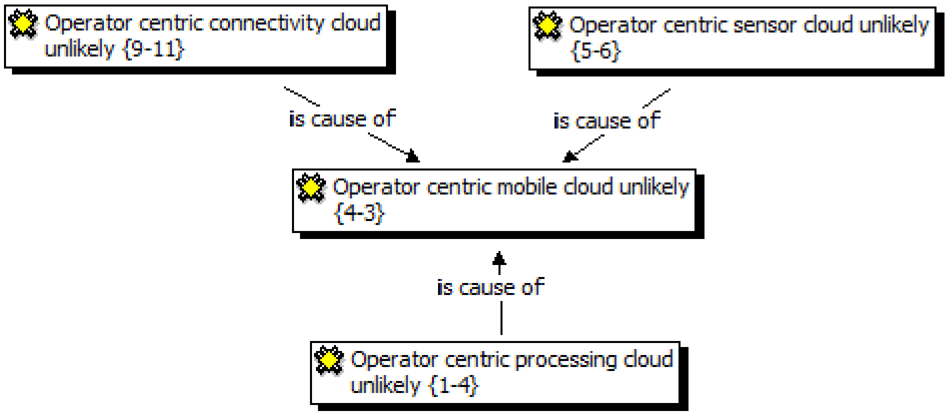

Figure 22 - Operator centric mobile cloud is considered unlikely

Operators are considered an unlikely position (Figure 22) for mobile cloud platforms for five reasons:

- *Operators as bit pipes*: operators have previously tried and failed to succeed with value-added services such as location based services or app stores. Their role is now considered to be providing the network which other service providers exploit.
- *Operator user base limitations*: many operators lack a large international user base, while many users are required to provide a large shared resource pool and to attract a large number of developers.
- *Lack of innovation power:* operators the lack the applications, creativity and innovation power to benefit from mobile cloud as well the ability to mobilize innovation from a developer community.
- *Bandwidth scarcity:* sharing resources between devices increases load on the operator. The respondents consider this as a drawback as operator networks are strained. This perception may change should operators eventually find profitable business models for bandwidth consumption.
- *Lack of service availability guarantees:* as mobile resources are perishable an operator cannot guarantee the size or scope of a shared mobile resource pool. This dependency on individual device owners is a risk for operators, which may face increased helpdesk pressure when a mobile cloud service does not perform as expected.
- *Complexity in connecting devices:* operator billing is considered to be a complex process which would be further complicated if end-users would be additionally billed due to connectivity or other kinds of resource usage from other end-users.

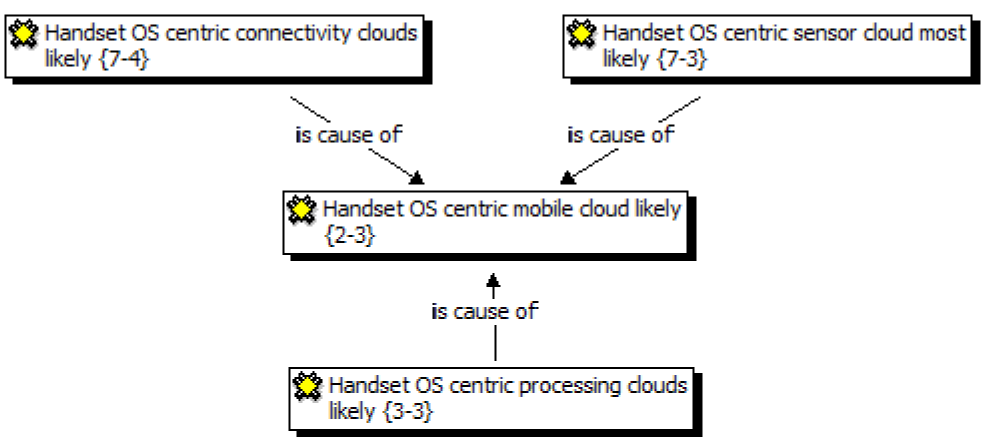

Figure 23 - Handset OS centric mobile cloud platforms is considered likely

The handset OS is considered a likely place to locate mobile cloud platforms (Figure 23), regardless of the type of resource sharing conducted. Reasons cited for this are:

- *Handset differentiation incentives:* differentiating handsets from the competition is the reason the handset OS vendors started with app stores. Mobile cloud can provide a new lever for differentiation, making devices more attractive to have as they can do 'more' than traditional standalone devices.
- *Strong existing communities:* mobile cloud could extend the amount and scope of services offered via app stores, profiting from the existing service provisioning infrastructure and end-user plus developer relation. This could drive service sales and provides convenient standardization, as existing development tools can be re-used.
- *The OS as an enabler for mobile cloud:* via the OS an operator or service provider can choose to activate mobile cloud functionality for its user base, much like MNO T-Mobile offers the Visual Voicemail function in iOS.

Service providers are considered as likely platform owners for mobile cloud based on sensor sharing (Figure 24). Social media platforms were associated with customers used to giving up an above average share of privacy, including mobile sensor information.

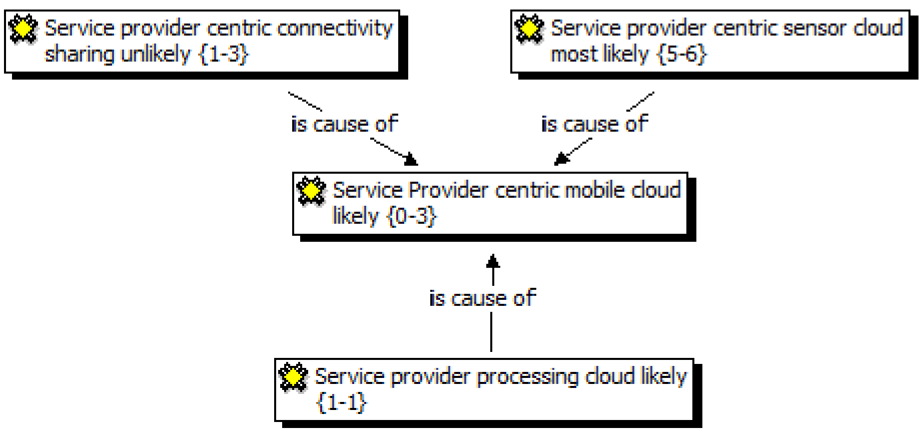

Figure 24 - Service provider centric mobile cloud platforms considered likely for sensor sharing

- *Large user bases:* internet-based service provides (e.g. Facebook) have user bases running in the hundreds of millions, providing a large number of peers to obtain mobile resources from and develop mobile cloud services for. These user bases are larger than that of an operator or a handset OS.
- *Flexibility:* when compared to network operators and handset/OS vendors, internet-based service providers are the least institutionalized mobile cloud platform owner. The impact of experimenting with new mobile cloud services is limited, unlike that of an OS vendor which has to roll out new firmware globally or that of an operator which has to integrate the functionality with a myriad of existing infrastructure and processes.
- *Innovation power:* killer applications for mobile cloud are expected to emerge in the corner of internet service providers which have both the capability to innovate and mobilize innovation from large developer communities.
- *Social applications:* sharing mobile resources can be considered as 'a social thing'. The communities around service providers such as social media platforms are already used to sharing information from their mobile devices in some way, such as with Foursquare.

Connectivity is not expected to be service provider centric as it is not their traditional domain, but that of the MNO's. Operators may also not appreciate service provider bases connectivity sharing architectures in which mobile devices directly connect with each other, e.g. Skype, as it would be disruptive to their business.

This summarizes the interview results regarding the platform positioning for mobile cloud computing. In section 5.4 we will discuss more detailed results regarding platform positioning in relation to the type of resources shared. We now move to the feedback obtained regarding network feasibility and viability.

5.2 Ecosystem Network Results

In chapter 3 we selected three criteria regarding network feasibility and viability: *acceptable division of roles, acceptable division of revenues,* and *strong network externalities*. The main success factors and inhibitors in the category network are shown in Table 14.

Table 14 - Main success factors and inhibitors in the category network

Category	Success factors	Inhibitors
Network	• Selling access to a shared smartphone pool is considered valuable. The platform owner may acquire revenues for allowing access to the sensors or sensor data acquired in the shared mobile resource pool. • To allocate the costs caused by smartphone resource sharing, intermediary service providers may take in the role of facilitating billing between operators, e.g. when end-users of multiple operators share connectivity resources.	• Sharing resources between smartphone is considered to cause billing complexity as end-users consume each other's data subscriptions and tilt network loads towards multiple operators. • HTML5 and application specific alternatives challenge mobile cloud platform ownership silo's at the handset OS or operators. Internet service providers can potentially engage all smartphone owners. • The focal use case architecture of a coordinating server which distributes tasks across a shared mobile resource pool is considered limiting, due to the need to engage the operator network. Peer-to-peer alternatives which allow smartphones to connect directly to resources in their environment are considered attractive.

The criterion of strong network externalities was already dealt with in the last section, where likely platform owners were shown to be those with already large user bases and thus network effects. Acceptable division of roles and revenues were dealt with on a high level during the interviews. Rather than specifying different platform value network configurations, the general concept of a platform owner pooling mobile resources, sharing these across end-users and making these available to service providers was discussed to elicit potential roles and dependencies.

Success factors for mobile cloud networks are:

- *Handset OS social media integration:* many OS vendors collaborate with social media platforms, integrating social media functionality such as contact integration in their handsets. Further collaboration with regards to mobile cloud user bases and services may ensue.
- *Selling aggregated sensor information:* acquirers of sensor information are likely willing to pay to the party coordinating the shared mobile sensor pool. A comparable situation pointed to is Vodafone in the Netherlands selling mobile location data to TomTom for navigation purposes. Alternatively the coordinator may use the sensor data for own purposes, e.g. Google with advertising and maps.
- *Intermediary service provider connectivity facilitation:* this relates to connectivity sharing between mobile devices. For a sufficiently large user base, the customers of all operators should be able to

connect with each other. The customers of operator A can however cause traffic for customers of operator B. This could lead to skewed loads on certain operator networks. An intermediary service provider could mediate in billing loads handled on other networks, much like service providers currently handle SMS interconnect and billing between operators.

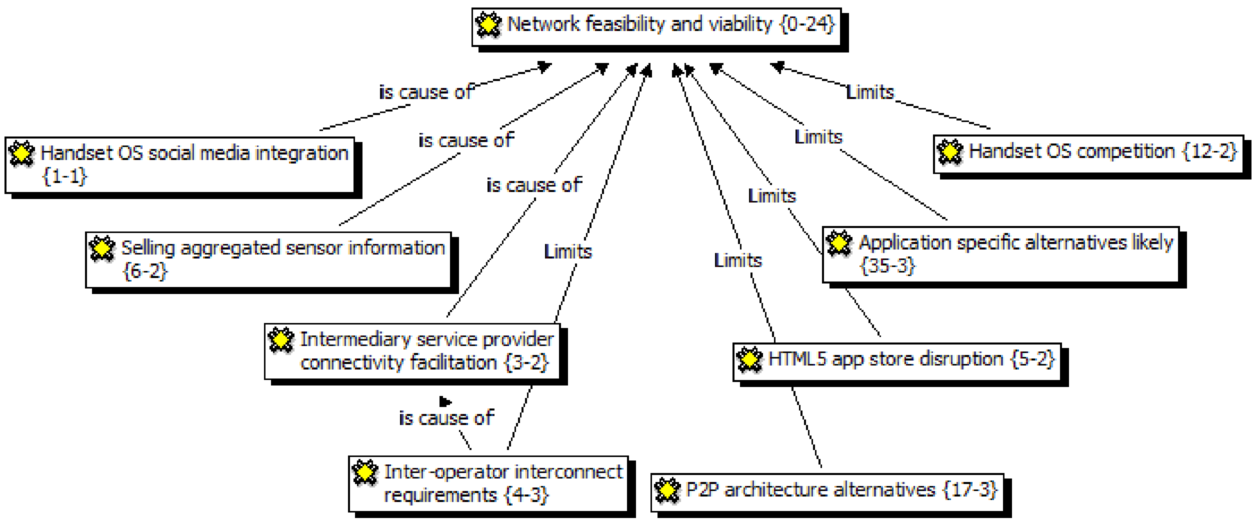

Figure 25 - Success factors and inhibitors of mobile cloud networks

Inhibitors of mobile cloud networks are:

- *Inter-operator interconnect requirements:* Inter-operator billing could be a solution for connectivity shared between operators but is considered a complex endeavor.
- *Handset OS competition:* OS vendors likely to keep mobile cloud as a feature specific to their OS rather than making it a universal standard. This would differentiate the mobile service offerings in their app store. To enforce this they could block access to OS-specific features such as contacts or sensor hardware access in both API's and their terms and conditions.
- *Application specific alternatives:* OS vendors already provide in the API's and software development kits (SDK's) which can access mobile device connectivity, processing and sensor features. Service providers can thus access these features by means of an application on the mobile device. Any device running the application thus becomes part of a 'mobile cloud', possibly for a specific purpose rather than a flexible shared resource pool. Examples mentioned include a YouTube app allowing for collaborative video downloads, or TomTom users uploading speed and location statistics.
- *HTML5:* cross-platform development tools such as HTML5 allow mobile service developers to largely become their own mobile cloud platform owners, aggregating mobile resources without the obligation to share revenue with app stores from the likes of Google and Apple.
- *P2P alternatives:* recurring feedback indicates that our respondents in several ways consider ways for mobile devices to directly connect with nearby devices more interesting than first contacting a coordinating server. This allows users to omit the operator network, which copes with limited spectrum and bandwidth and could possibly disrupt the existing power position of the operators. An example mentioned was that all Android OS smartphones could be part of an Android community, automatically connecting with nearby Android phones via Wi-Fi or Bluetooth.

The network feasibility and viability results indicate that there is potential in offering mobile resources as a shared pool and obtaining compensation for access to this pool. It is however also indicated that application-specific and cross-platform alternatives exists to a general-purpose shared mobile resource pool. This may undermine the ability of a mobile cloud platform owner to obtain a large mass of customers. Many respondents also question the need for a central coordinating role in combining mobile resources, instead pointing to alternatives in local ad-hoc resource pooling and sharing. Having discussed the network feasibility and viability results we now move to the interview results regarding mobile cloud ecosystem performance.

5.3 Ecosystem Performance Results

In chapter 3 a number of criteria expressing the performance of an ecosystem were formulated in four categories: *niche creation, productivity, robustness and customer value*. The main findings in this category have been summarized in Table 15.

Table 15 - Main performance success factors and inhibitors

Performance Category	Success factors	Inhibitors
***Niche creation* (Appendix Figure 6)**	• A wide range of service innovations is possible based on shared smartphone sensor pools, which may also complement fixed sensor infrastructures in the likes of roads and buildings.	• No direct inhibitors were obtained. We deduce that connectivity sharing does not lead to new mobile services niches.
***Productivity* (Appendix Figure 7)**	• The ubiquity of smartphones, their increasing numbers of sensors processing power in combination with many idle smartphone resources provide the preconditions for a range of new mobile resource based services. • Bandwidth price decreases and flat fee data subscriptions are expected to eventually make bandwidth a commodity, enabling always-on mobile resource sharing.	• Lack of business problem solved: it is argued that inherent mobile service limitations due to screen size, input methods, network limitations etc. are not addressed by mobile cloud. • Current trend towards data caps and differentiated data usage fees will hamper uptake of mobile cloud services, as sharing a smartphone may be expensive
***Robustness* (Appendix Figure 8)**	• Connectivity sharing could extend the lifecycle of operator networks by improving coverage and bandwidth via the smartphones of end-users, without significant network expenditures.	• Next-generation operator network bandwidth increases and micro network alternatives may disrupt the need to share connectivity. • Current wireless technologies such as Wi-Fi and Bluetooth technologies fold under large numbers of connection requests as may be the case with mobile cloud in crowded areas. • Service providers may at any time disrupt the position of a mobile cloud platform owner by offering similar services via a (web) application.
***Customer value* (Appendix Figure 9 & Figure 10)**	• Shared mobile resource pools could be successful in community environments or personal environments such as homes, schools and offices due to trust and lack of cost sharing concerns • Device owners sharing mobile resources may be rewarded with data, voice, SMS subscription discounts, app store credits or in other ways. • New types of collaborative services may be enabled by mobile clouds. • Connectivity robustness in indoor or remote areas can potentially be improved with shared connectivity. • Mobile clouds resources seamlessly integrating with fixed cloud resources could be advantageous	• Security, legal, privacy concerns may prevent end-users from opting in to mobile cloud. • Limited end-user understanding may hamper opt-in and thus the size of the mobile resource pool • Offloading processing may be limited to non-time critical tasks due to connectivity limitations. • There is a perceived lack of killer applications for offloading processing tasks to other mobile devices due to increasing power on smartphones and the possibility to offload to datacenters. • Perishable nature of mobile resources: battery drain, connectivity interruption cause a lack of availability guarantees. • End-user sharing incentives are unclear. Some

	in cost, connection and availability.	end-users may not benefit from access to the mobile resource pool themselves. Free-rider behavior could occur where end-users profit from others with better subscriptions or hardware.

5.3.1 Performance: Niche Creation

Niche creation was defined as *ecosystem variety* and *adoption of innovation* (section 3.3.1). The combination of both should lead to 'firm, product and technical variety' in an ecosystem. The interview results provide us with an indication of the product (service) variety mobile cloud could result in. Our respondents point to making mobile sensors as a shared resource pool as the prominent source of niche creation. The respondents associated mobile cloud with the following service niches (Figure 26):

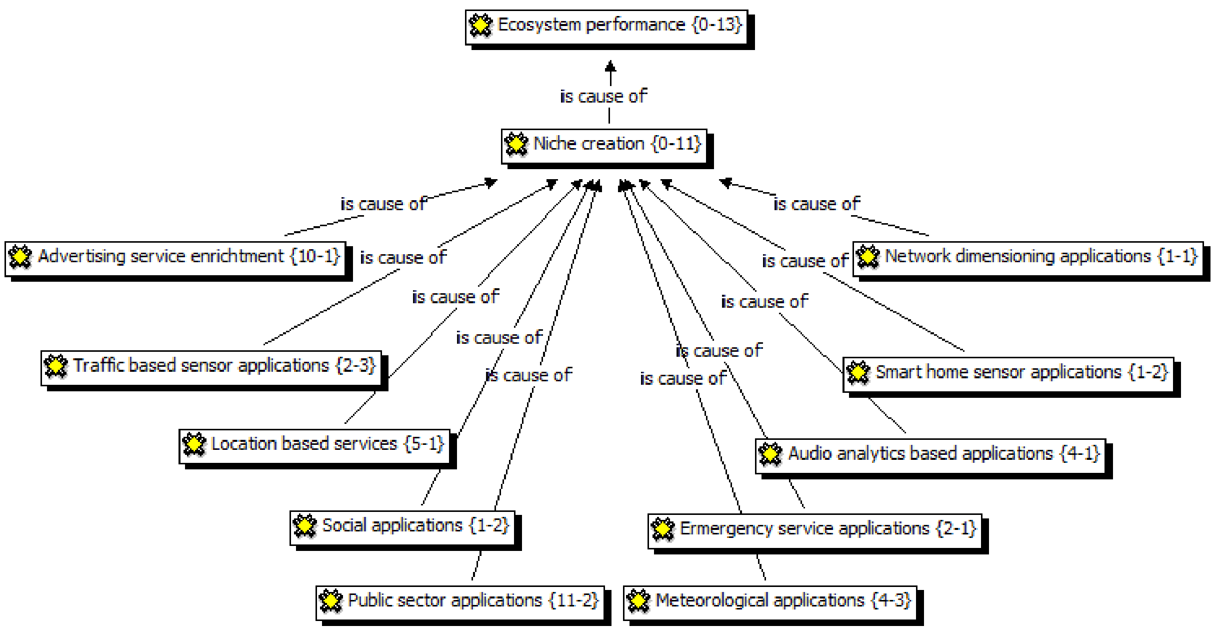

Figure 26 - Niche creation success factors

- *Advertising:* behavior-based, location-based and other types of advertising services are possible based on monitoring the activities of groups of people via their smartphone sensors. Parties such as Google could for example enrich their search and advertising services in real-time with this information.
- *Traffic:* measuring the number of people present at an event; measuring the number and speed of people on the road via combinations of accelerometer, gyroscope and GPS e.g. for traffic jam detection.
- *Location:* extensions of the foursquare concept, not only sharing location data but also for example audio, e.g. allowing for measurement of topics discussed in a certain area.
- *Social:* friend-finder style applications reporting friend location, activities and location properties in detail.
- *Public sector:* predicting earthquakes using gyroscopes collectively; measuring road usage to target infrastructure improvements; crowd tracking at large events.
- *Meteorological:* collective barometer data for local air pressure measurements, enriching the data sources of parties such as meteorological institutes. Many respondents mentioned temperature based applications though these are not yet mainstream in mobile devices.

- *Emergency services:* mobile devices directly being able to communicate with the devices in their vicinity in case the operator network fails (it is debatable whether this still fits the cloud paradigm); orchestrating relief workers and crowds in case of emergencies.
- *Audio analytics:* adapting television advertising based on words often spoken in front of televisions; regularly polling and recording audio from the microphone for reprocessing afterwards e.g. for song lyrics.
- *Smart homes/buildings:* enriching home or office automation by using the mobile devices e.g. to keep tabs on energy consumption by automatically adapting heating based on mobile device temperature measurements.
- *Network dimensioning:* allowing operators to measure where what types of applications are used to optimize their networks.

Many of the mobile cloud service niches stated by our respondents appear to be derived from existing cases regarding location and sensor based applications. It was however acknowledged that in the current market users opt in to just one of such services specifically, while allowing flexible use of the sensors in mobile devices would enable a wider range of services. The lack of connectivity based mobile cloud niche services was expected as shared connectivity is more of an IaaS feature: rather than enabling new services altogether, it serves as the infrastructure for existing services. The lack of shared processing services is more surprising. Our respondents expect increasing mobile device processing power and offloading to datacenters to diminish the need for mobile-to-mobile processing offloading. Having studied the capability of mobile cloud ecosystems to generate variety in innovation we now move to the ecosystem performance category productivity.

5.3.2 Performance: Productivity

In section 3.3.2 productivity was defined as the *delivery of innovations over time* in an ecosystem- in this case, the amount and rate of services potentially delivered based on mobile cloud platforms. As expected the interviews cannot directly tell us how many or how quickly mobile cloud services are delivered. The interviews however do provide feedback on the preconditions for rapid delivery of innovations. Eight success factors and two inhibitors for productivity in mobile cloud ecosystems are identified. We first elaborate on the two inhibitors:

- *Lack of business problem solved:* some of our respondents argue that mobile cloud does not directly solve the inherent limitations of mobile services and mobile devices (memory, screen size, resolution, battery, network bandwidth limitations) and will therefore not lead to major new possibilities.
- *Differentiated data consumption fees:* current developments in mobile data subscriptions indicate a move away from flat fee to limited data subscriptions where after a fixed bundle usage is billed per megabyte. This would discourage end-users from sharing their smartphone as it could lead to high bills. Operators also contest net neutrality. While currently differentiated pricing per service type is not allowed for, operators would like to bill specifically for data-intensive applications such as video. This would also discourage end-users from sharing their data subscription.

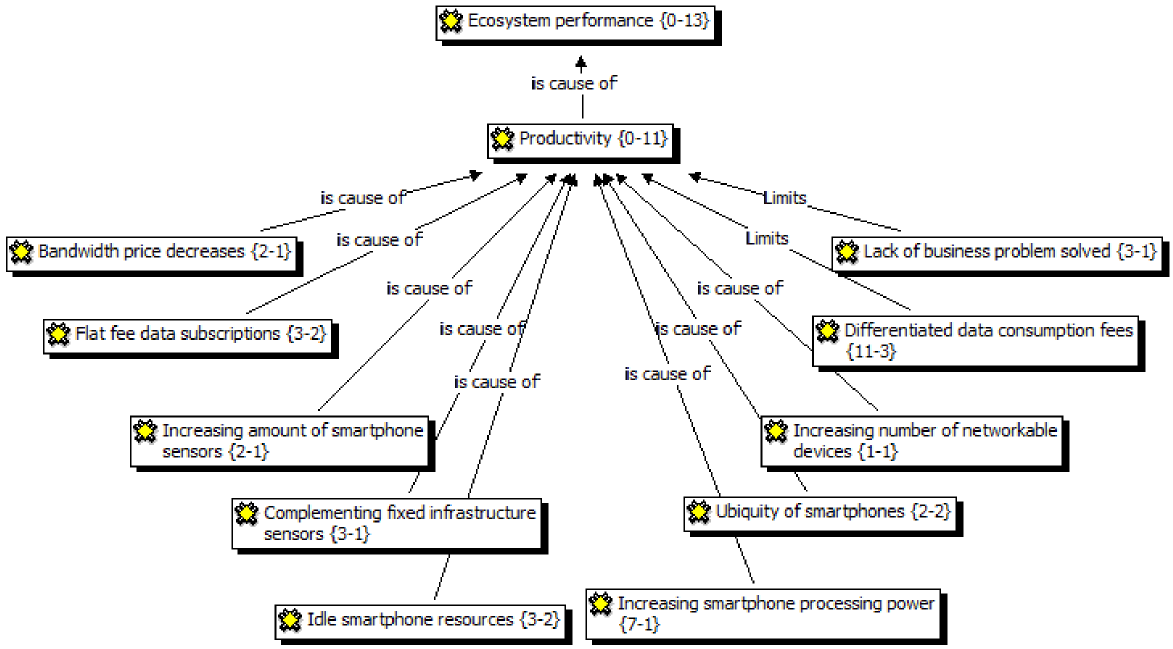

Figure 27 - Productivity success factors and inhibitors

Eight potential success factors enabling productivity in mobile cloud ecosystems were encountered:

- *Bandwidth price decreases:* bandwidth will eventually become a cheap commodity so that data-heavy always-online services will eventually become feasible.
- *Flat fee data subscriptions:* related to the previous factor, when end-users can do as much as they like online, sharing bandwidth is no issue taking away a limitation for mobile cloud services.
- *Increasing amount of smartphone sensors:* upcoming sensors for proximity (RFID, NFC), temperature, barometers and others enable new streams of innovation
- *Complementing fixed infrastructure sensors:* smartphones can complement sensors in roads, buildings etc. which may be flexibly allocated for a wide range of new mobile services.
- *Idle smartphone resources:* active use of smartphones is limited to a small fraction of the day, leaving a large pool of shared resources available to build mobile cloud services on.
- *Increasing smartphone processing power:* with dual core and quad core mobile devices on the rise the range of services possible by combining mobile devices will continuously increase.
- *Ubiquity of smartphones:* this leads a myriad of computing capabilities available ‘everywhere’.
- *Increasing number of networkable devices:* mobile cloud may eventually extend from mobile devices and computers to everyday devices such as cars, household equipment and consumer electronics which could all be connected into a large shared resource pool.

With this we have discussed the factors influencing the potential of mobile cloud platforms to deliver innovations over time. We now move on to the performance of mobile cloud ecosystems in the category robustness.

5.3.3 Performance: Robustness

Robustness was defined in section 3.3.3 with the criteria *continuity of structure* and *lengthy technological lifecycle*. Both criteria go hand in hand as technological disruptions are likely to affect the structure of the ecosystem. Figure 28 visualizes factors influencing the robustness of mobile cloud ecosystems.

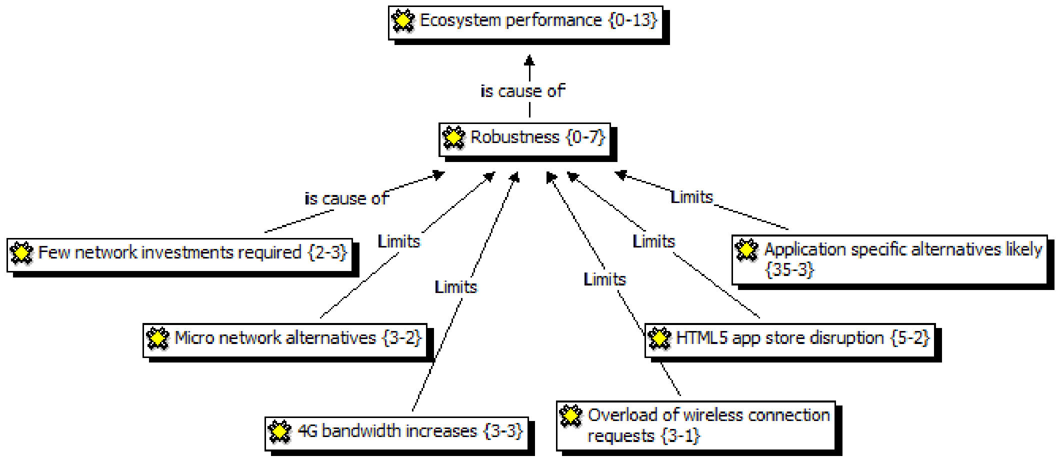

Figure 28 - Robustness success factors and inhibitors

The interviews provide one success factor with regards to technological lifecycle robustness:

- *Few network investments required:* this success factor is related to mobile devices as shared connectivity pools. It was indicated that investments in the operator macro network have practical limitations in cost, coverage and available spectrum. The lifecycle of the existing macro network could be extended by mobile devices sharing connectivity amongst themselves, filling gaps in coverage with limited capital and operational expenditure.

Three robustness inhibitors are noted related to the technological lifecycle of mobile cloud ecosystems:

- *Micro network alternatives:* due to the aforementioned macro cell expansion limitations operators turn to micro network alternatives such as femtocells and picocells. As these already provide better coverage and higher bandwidths the need for mobile connectivity sharing is reduced.
- *4G bandwidth increases:* with upcoming LTE networks mobile devices will be able to enjoy similar bandwidth and latency comparable to fixed line internet connectivity. This reduces the need to combine the bandwidth of multiple mobile devices.
- *Overload of wireless connection requests:* current wireless technologies such as Wi-Fi and Bluetooth are not suited for environments where large numbers of connection requests take place, such as events where large crowds gather. As the technology often stalls when faced with many incoming connection requests it may not be suited to interconnect the general public in a shared resource pool.
- *Application specific alternatives likely:* often cited feedback is that mobile cloud already is already possible through installing applications. Any service provider able to convince end-users to share their smartphone resources through an application can then pool these resources for further use. Any elaborate operator, device or service provider specific platform might therefore be disrupted by a service provider with a successful mobile application.
- *HTML5 app store disruptions:* related to the previous inhibitor, HTML5 -a language to structure and present internet content- is considered to be disruptive for closed mobile service development environments. Currently applications are developed for iOS, Android etc. specifically, creating lock-in for end-users as they would lose their applications when moving to another platform. With HTML5 platform agnostic mobile services are possible. The lock-in created by a specific operator, OS vendor or service provider offering mobile cloud services may therefore be broken by HTML5.

We note that the last two robustness inhibitors are related to both the structural and the technological lifecycle of mobile cloud ecosystems. Having established robustness success factors and inhibitors we now move to performance of mobile cloud ecosystems in the category customer value.

5.3.4 Performance: Customer Value

In chapter 3 customer value was defined as delivering a *compelling value proposition* for the users of a platform. A wide range of feedback regarding success factors and inhibitors for customer value were derived from the interviews. Figure 29 shows the success factors positively influencing customer value of mobile cloud ecosystems.

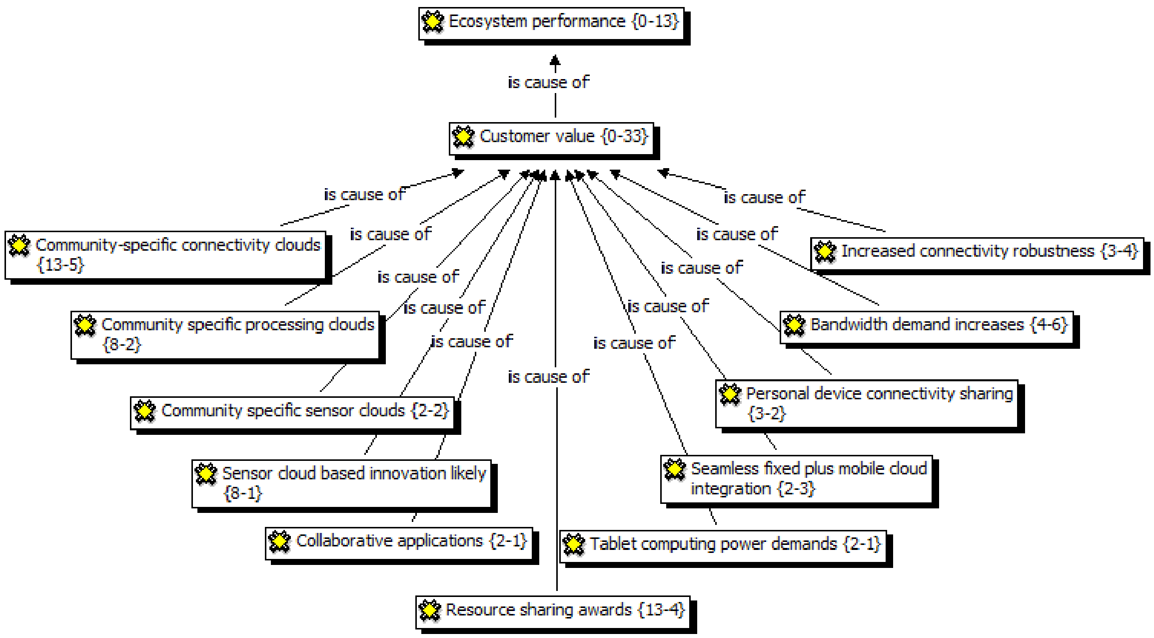

Figure 29 - Customer value success factors

Four categories of success factors for customer value can be derived from our interview feedback:

- *Community specific mobile cloud:* in communities such as offices or homes end-users are stationary leading to a steady amount of additional mobile resources with low installation costs and complexity. Community specific mobile cloud happens in a trusted environment and can be event-based, e.g. to share connectivity in order to view a movie on a beamer together. This also applies for mobile devices on a personal level, e.g. an iPhone supporting the iPad of a single user (tablets were specifically mentioned as one mobile channel which is more power-hungry due to the larger screen and more resource-intensive usage pattern).
- *Mobile service innovations:* our respondents expect that mobile cloud can result in innovations around collaborative applications, where groups of people or devices together can do more than they can do alone. Shared mobile sensor pools are also expected to lead to innovations as they allow access to information which is currently not available.
- *Improved connectivity:* being able to tap into a shared connectivity pool can be advantageous in cases where connectivity is limited for some but fully functional for others, such as remote or indoor areas. Ever increasing bandwidth demands also add to the value of connectivity sharing as factors such as 3D and HD video streaming, music streaming, gaming and the integration of TV and social media

drive bandwidth demand. In related feedback seamless fixed-plus-mobile cloud is considered to add value as it allows for seamless handoff of tasks to nearby mobile devices when a cloud computing provider is offline.

- *Resource sharing awards:* our respondents consider compensation as a key incentive for end-users to share their smartphone in a common resource pool. Award mechanisms mentioned include:
  - Kickback fee for use of device or percentage of data subscription
  - Data subscription fee reductions
  - Reduced voice/SMS bills
  - Billing or trading between end-users sharing resources
  - Credit awards for prepaid users, credit awards for coupons, app stores, virtual wallets etc.

Aside from the abovementioned success factors of mobile cloud customer value, an even larger range of customer value inhibitors was acquired during the interviews. Five categories of customer value inhibitors are identified (Figure 30):

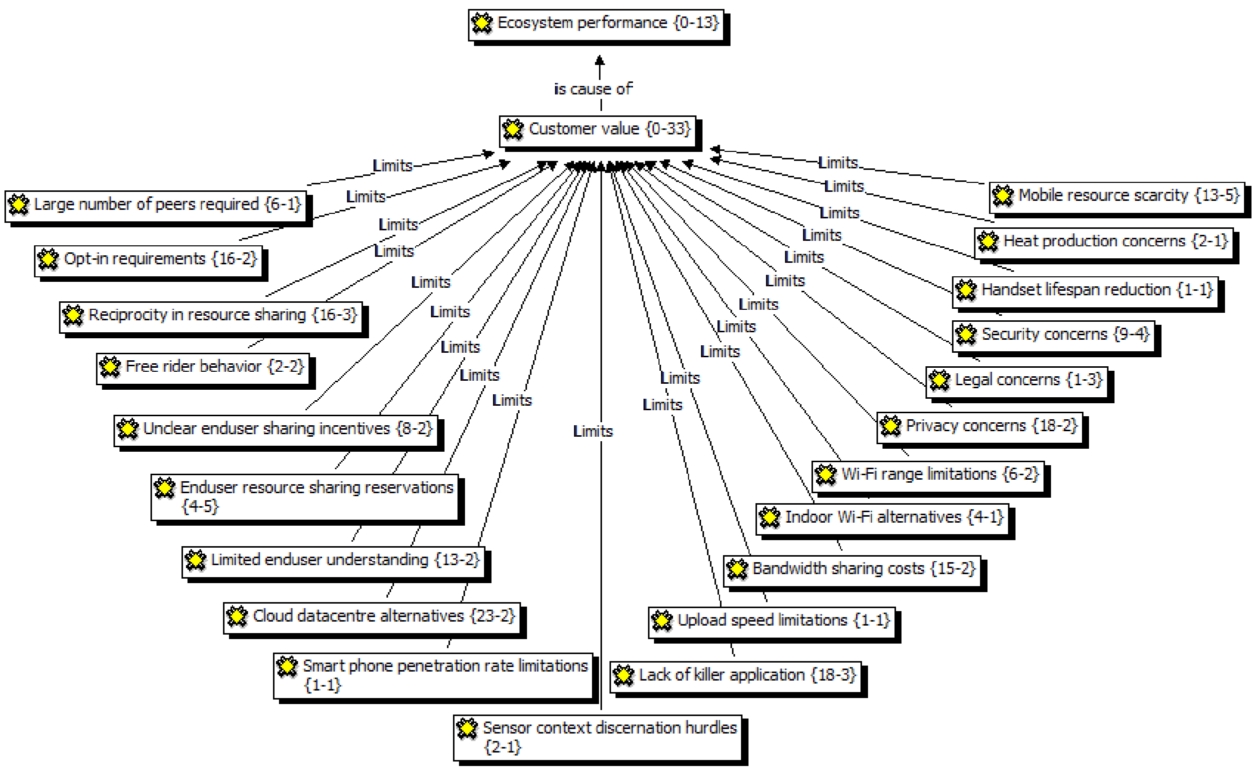

Figure 30 - Customer value inhibitors

- *Security, legal and privacy issues:* security is an issue as end-users may end up running unknown code on their smartphone. This introduces issues as the end-user may not know whether this code is legal, especially in cross-border situations. It may also introduce the risk of running malicious code such as with botnets, or code of which the results have been manipulated. Furthermore allowing third parties access to a personal smartphone can lead to very privacy-sensitive situations, especially when sensor information such as that of the microphone and location is shared. This is an issue when end-users are not aware of how their smartphone will be used when part of a flexible resource pool.

- *Scarce mobile resources:* smartphones drain their battery life quickly when under load of processing or sensors such as camera or GPS. At the same time, they run hot under load which may uncomfortable for those carrying smartphones in their pockets. It was also indicated that smartphones are not built for continuous loads and their lifespan may be reduced by the continuous strain of a shared resource pool. Generally mobile resources are perishable, either because a smartphone moves out of connectivity range, runs out of battery of because the owner of the smartphone may suddenly require the device at full capacity. This may limit the amount of resources available for mobile cloud services.
- *Connectivity limitations:* upload speeds and response time are a limitation with current wireless connections. This limits the scope of processing tasks which can be offloaded to other mobile devices to non-time critical mobile services. The range limitations of Wi-Fi (estimated up to 50 meters) also and Bluetooth are also inhibiting for mobile cloud. Though architectures such as AggreGATE support multiple simultaneous connections and seamless handoff between devices there is still a risk of multiple sharing devices moving out of range and thus interrupted service when using direct device-to-device connections. The costs of bandwidth are another connectivity limitation as sharing mobile resources entails continuous uploading/downloading and thus incurring costs created by third parties.
- *Limitations in value added:* our respondents point to a general lack of what they consider to be a killer application for mobile cloud computing. Devices do not need to be interconnected as datacenters are to become part of a cloud construct- for most services, this could happen via the operator network. This can be enabled via applications installed on the mobile device. A second major limitation in the value delivered is because of the presence of a coordinating server in the mobile cloud architectures. Our respondents argue that once a processing request goes through a fixed server, it may as well be processed on that server or forwarded to another fixed server rather than forwarding the task to another smartphone via the bottlenecked operator network. Cloud computing datacenters are less resource-constrained and considered a more efficient and effective place to offload processing to than mobile devices.
- *Limited end-user resource sharing incentives:* several issues around convincing users to opt-in to a shared mobile resource pool are noted. First, due to implications for battery life, billing and privacy explicit user opt-in is likely to be legally required whether this is operator, OS, or application based. This may limit the amount of users that actually participate in the shared resource pool- while a ‘dense’ mobile cloud is required to provide value for service developers and end-users. Convincing users to opt-in may be difficult as our respondents indicate that end-users have very limited understanding of the working of mobile devices and mobile services. Selling a high-tech mobile resource concept which may or may not provide additional resources depending on the conditions will therefore be difficult. End-users who do understand the concept may have several mobile resource sharing reservations as shown in Figure 31. Furthermore, the value proposition for those sharing mobile resources is unclear. People are unlikely to share due to altruism, while the device owner sharing may not get or want other mobile resources back in return. Mobile cloud may also lead to free-rider incentives: those with prepaid or limited data subscriptions profit from those paying more for their subscriptions. Respondents suggest some kind of reciprocity in resource sharing as seen in peer-to-peer file sharing protocols is required, where those who share proportionally receive more resources.

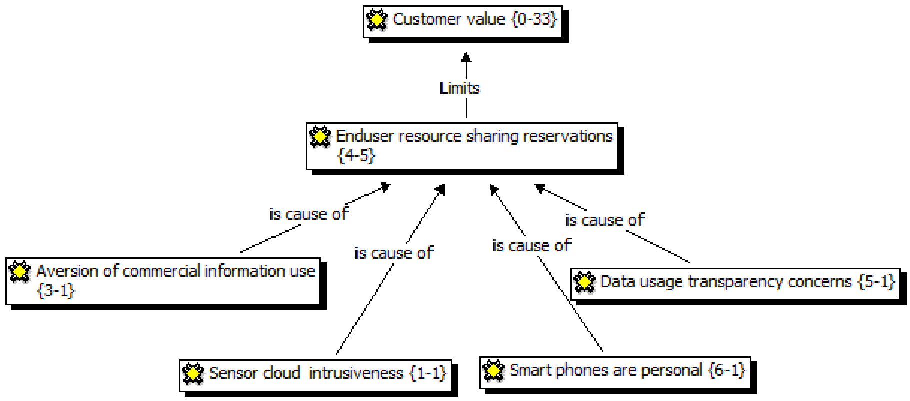

Figure 31 - End-user resource sharing reservations limit customer value

With this we have concluded our discussion of the interview results in the categories members, network and performance. In the performance category the interview results were split in niche creation, productivity, robustness and customer value as specified in our theoretical framework from chapter 3. The interview results are applicable to mobile cloud in general/ We will now move on to interview results which are specific to the use cases presented during the interview, that is connectivity, processing and sensor sharing, which are separate technical architectures in literature.

5.4 Use Case Specific Results

In this section we discuss the specific interview results from the connectivity, processing and sensor use cases. The detailed codes and relations can be consulted in the appendices.

5.4.1 Connectivity Cloud

Table 16 summarizes the interview results from the connectivity (mobiles as resource for IaaS) use case which was based on AggreGATE (Ananthanarayanan & Zats, 2009). The results indicate that operator network capacity can limit the value added by connectivity sharing. As Wi-Fi or Bluetooth are used to connect devices this entails that users are near each other and thus in one coverage cell, which has finite bandwidth. Operator billing is another issue when sharing data subscriptions. Handset OS vendors can support the feature natively in their OS but may have reservations as connection sharing would increase base operator load, while handset OS vendors which also sell devices depend on operators for device subsidies. The results indicate that the architecture with central coordination is likely to be contested: mobile devices might as well locally poll which devices are present to share resources with. Our respondents are also mixed with regards to the performance of connectivity ecosystems: network improvements may disrupt connectivity sharing needs, while customer value is uncertain with the current trend towards expensive, non-flat fee data subscriptions and uncertain reciprocity in connection sharing.

Table 16 - Success factors and inhibitors of connectivity cloud ecosystems

Category	Success factors	Inhibitors
Members	• Handset OS support possible and likely due to handset differentiation incentives	Operator support unlikely: • Bandwidth scarcity • Mobile cell capacity limitations • LTE bandwidth increases • Complexity of billing shared subscriptions • Lack of service availability guarantees • Handset OS support possibly prohibited due to dependency on operator subsidies for handsets
Network	• An intermediary interconnect service provider can deal with billing the traffic shared connectivity causes between operators	• Inter-operator interconnect and data handoff causes billing complexity • Desirable P2P alternatives circumvent central coordination and operator networks and thus ways to monetize
Performance	*Productivity* • Bandwidth price decreases and flat fee data subscriptions may over time make bandwidth a commodity, enabling connectivity sharing *Robustness* • Can extend the lifecycle of existing networks by improving coverage via end-users with few capital and operational investments *Customer value* • Convenient automatic sharing of connectivity on personal or trusted community level • Increased connectivity robustness for indoor and remote areas • Can aid with high-bandwidth applications such as HD video and audio streaming • Resource sharing awards via subscription discounts, app store credits etc.	*Robustness:* • Application specific connection sharing alternatives possible • Wireless technology unable to deal with large numbers of connection requests • Disruptive operator network bandwidth improvements • Disruptive operator micro cell alternatives for coverage and bandwidth improvements *Customer value:* • Battery life limitations • Uncertain reciprocity in connection sharing; costs of sharing bandwidth with possible free-rider behavior • Limited end-user understanding plus opt-in requirement may limit user base

5.4.2 Processing Cloud

In the 'processing cloud' use case based on MapReduce (Elespuru, et al., 2009) we discussed mobile devices as PaaS which can be approached by developers to run applications on or by the mobile devices of end-users to boost computing tasks. The focus was on offloading via a coordinating server which segments computation tasks. The general feedback obtained during interviews is that mobile-to-mobile offloading of processing tasks is not efficient or required. Datacenters are faster, have near-infinite resources and less complexity in compensation end-users for usage of their device and data subscription. Several discussions regarding direct device-to-device offloading lead to the conclusion that increasing device capabilities may take away much of the need to offload processing tasks. However, it was noted that there are opportunities for seamless fixed-plus-mobile cloud integration as seen in the Elastic Weblets architecture (Zhang, et al., 2009). This could provide multiple options to offload: depending on the cost and quality of connections available a datacenter or nearby devices may be used. It was indicated that existing PaaS vendors may extend their offerings in this way. Table 17 summarizes the interview results specific to processing clouds.

Table 17 - Success factors and inhibitors of processing cloud ecosystems

Category	Success factors	Inhibitors
Members	• The handset OS is a likely platform position for processing PaaS due to handset differentiation incentives and the existing user base of developers and end-users.	• Operator support unlikely due to the connection overhead created by offloading via a coordinating server
Network	• Possibility exists to offer aggregated mobile processing power to developers as an alternative to datacenter-based PaaS	• Recurring inhibitor: application specific alternatives or HTML5 challenge the position of a central coordinating platform owner
Performance	*Productivity* • Preconditions for shared processing based services available due to increasing smartphone processing power, ubiquity and idle resources *Customer value* • Seamless fixed-plus-mobile cloud integration would ensure availability of processing power, reducing dependency on datacenter • Community or event specific processing clouds can add value through collaborative applications • Resource sharing awards can tempt users to opt-in	*Customer value* • Due to upload and latency limitations only non-time critical applications can be offloaded via the network • General lack of killer application for coordinated offloading to mobile devices as cloud computing datacenters are readily available and non-perishable • Unclear end-user sharing incentives for those who do not require additional processing themselves • Reduced handset battery performance • Bandwidth costs incurred by downloading/uploading processing segments of others

5.4.3 Sensor Cloud

The sensor cloud use case was not based on a specific architecture but derived from the PaaS architecture as seen in the processing use case: mobile devices combined into a shared sensor resource pool via a coordinating server. The sensors could be consulted by service providers or by applications running on the devices of end-users in the shared sensor pool, representing a PaaS environment. It was left open whether this could occur in real-time or with certain intervals. The interview results show that aggregating this much sensor information would enable a wide range of service innovations and that especially social media platforms and the handset OS could be coordinators. However, convincing users to opt in to a shared sensor pool where they will not know when, how, why and by whom their device information is used is considered challenging. The uproar in the Netherlands when it was discovered that TomTom sells traffic speeding information based on mobile devices to the police is an example of this opt-in hurdle. This means that event-based, location-based or application based sensor clouds may be more viable unless privacy is guaranteed in some way.

Table 18 - Success factors and inhibitors of sensor cloud ecosystems

Category	Success factors	Inhibitors
Members	• Natural extension for service providers with existing developer community and end-users familiar with sharing status, media and location • Easily integrated in the handset OS and existing communities of end-users and developers • Possible role for operators as a trusted intermediary for privacy guarantees	• Unlikely to be operator-centric due to lack of innovation power, earlier failed attempts with selling location-based services and operator user base limitations
Network	• Platform owner can sell high-level aggregated or real-time sensor information	• Recurring feedback of fragmented user bases & possible cross-platform development undermining central coordination
Performance	*Productivity* • Increasing amount of smartphone sensors and the potential to integrate with fixed infrastructure sensors enable a range of new services *Niche creation* • Wide range of location based, audio based, advertising based and public sector possible *Customer value* • Wide ranges of service innovations possible on personal/community/public level	*Robustness* • Application specific alternatives are likely and more transparent for end-users *Customer value* • Perceived current lack of killer apps for directly connection devices for sensor sharing • Opt-in hurdles with privacy, security, legal concerns, especially with possible international access to sensors. Aversion of commercial information use. • Hurdles to determine sensor context: indoor, outdoor, in pocket etc.

This concludes our discussion of the interview results regarding mobile cloud in general and connectivity, processing and sensor specific mobile cloud computing. We now move on to the chapter conclusions.

5.5 Chapter Conclusion

This chapter discussed the interview results, focusing on the question: *what are success factors and inhibitors which determine the real-world feasibility and viability of mobile cloud platforms?*

We identified success factors and inhibitors for mobile cloud platforms in the three categories of our theoretical framework: members, network and performance.

The results of the member category mainly indicate where mobile cloud platforms can be positioned. Our respondents consider platforms with existing strong ecosystems such as those of the handset OS or internet based service providers as the most likely position for mobile cloud platforms, these have an established large base of end-users, mobile service providers and because of their capability to innovate. Operators lack such communities or innovation power but may still complement mobile cloud platforms with resources such as billing.

The results in the network category indicate that the platform owner which pools and shares smartphone resources can not only return these to end-users or device owners, but also sell access to this smartphone resource pool to third parties. However, third parties and internet-based service providers may circumvent any platform owners by sharing and pooling mobile devices themselves via cross-platform applications installed on smartphones, omitting eventual OS or operator dependencies (Figure 32).

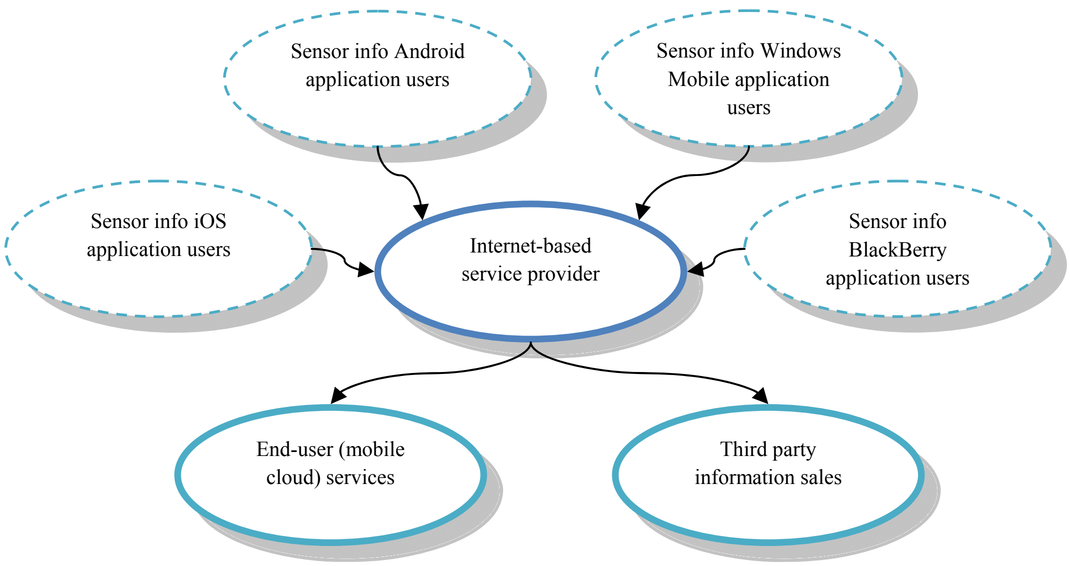

Figure 32 - Cross-platform access to smartphone resources

The results in the performance category indicate that a wide range of new service opportunities is possible around mobile sensor clouds. However, many privacy, security and legal issues arise when end-users opt-in to a shared resource pool. Furthermore, convincing end-users to opt-in may be challenging due to limited end-user understanding and an as yet ill-defined incentives to share resources. The current state of smartphone batteries and operator networks are also considered inhibiting

With regards to the applicability of the theoretical framework we note that even though the governance category of criteria was omitted during interviews, we can still observe the importance of governance around mobile cloud ecosystems. A mobile cloud platform may for example be located at the handset OS. Third parties requesting access to devices would then have to go through the OS, sharing revenues with the OS vendor. They may however circumvent the OS by creating a platform agnostic web-based application, gaining a larger customer base of multiple OS users in the process. The OS developer may discourage such behavior via their license agreements or by disabling access to certain hardware features, yet this may have the negative impact of reducing service innovation. This illustrates the balancing act of providing platform flexibility versus keeping control over a platform.

Having discussed the interview results we now move on to the conclusions, limitations and recommendations following from this research.

6 Conclusions, Limitations and Recommendations

This research began with the objective to: *identify factors influencing the feasibility and viability of mobile cloud platforms within their ecosystem in order to provide input for defining mobile cloud business models.* This objective followed from various technical papers which discuss the possibility to use the ever more ubiquitous, powerful and feature-rich smartphones as a cloud computing resources. While research discusses various architectures and prototypes to engage smartphones collaboratively in computing tasks, there is a lack of insight in the practical business feasibility and viability of sharing smartphone resources. In this final chapter we conclude our research by discussing conclusions, the limitations of this research and recommendations for future research. To this end we answer the main research question:

> *What is the feasibility and viability of mobile cloud computing platforms from an ecosystems perspective, with regards to their positioning, enabling networks and their ability to deliver streams of mobile cloud services?*

We answer this question by first combining the answers to the three sub-questions. After drawing our conclusions, we discuss the limitations of this research. Next, we suggest several areas for follow-up research for practitioners and academics. Finally, we reflect on the research project.

6.1 Conclusions

We first aimed to distinguish mobile cloud computing from the numerous other mobile resource sharing concepts in order to clarify the concept of a mobile cloud platform.

> The first research question therefore focuses on: *what is mobile cloud computing and how is it related to cloud computing?*

To answer this first sub-question we first conducted a literature review towards existing definitions of cloud computing. The NIST (2011) definition of cloud computing was found to contain the common elements found in a number of often-cited cloud computing definitions in literature. We apply the NIST definition to define mobile cloud computing as it is comprehensive, was recently updated (January 2011) and provides guidelines to break down mobile cloud computing into component parts: *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models."*

Using the NIST definition we answered our first sub-question by defining mobile cloud computing in two parts: *mobile devices as a channel to obtain cloud computing resources with via the network and/or mobile devices together as (part of) a shared pool of computing resources.*

The second part of this definition demarcates the focal area of the research: mobile devices themselves as the cloud computing resource. In this perspective mobile devices can offer the traditional resources of storage and processing, but also mobile-unique resources found in smartphones such as multiple connectivity methods and a range of sensors. The three service models in this definition define the type of resources shared with mobile cloud computing:

- Mobile Software as a Service (mSaaS) entails acquiring services which are hosted on other mobile devices. Acquiring these services may happen by manual prompts e.g. to share an application or multimedia. Mobile SaaS may also be invoked automatically with devices sharing services, settings and applications to align with their environment: machine-to-machine services.

- Mobile Platform as a Service (mPaaS) entails using mobile devices as a multi-sided platform to deploy and acquire a range of compatible services from.
- Mobile Infrastructure as a Service (mIaaS) entails providing mobile resources as a general purpose infrastructure to deploy and run arbitrary software on.

Mobile Platform as a Service is in part a technical service of common and compatible components to develop and deploy mobile cloud services on, and can therefore be considered as a Machine-to-Machine service (H. Bouwman, et al., 2010). mPaaS however also entails matchmaking between multiple customers of a mobile cloud platform: smartphone owners sharing their device, mobile service providers and end-users of mobile cloud services. This coordinating position between the supply and demand sides around a mobile cloud platform mPaaS is considered as a multi-sided platform, which can both enable and drive creation and sales of mobile services by connecting customers on different sides of the platform, while the platform owner may extract value from all sides. The next sub-question focuses on the way the feasibility and viability of such multi-sided mobile cloud platforms can be studied with the perspective of business ecosystems.

> We now focus on the second sub-question: *what are the ecosystems around platforms and how can these be analyzed?*

This sub-question was answered with a literature review towards ecosystems theory and critical success factors for ICT services. The core components of business ecosystems definitions answer the first part of this sub-question: ecosystems consist of a network of interrelated firms or individuals around a core technology which are mutually dependent on each other for their performance and survival (Den Hartigh & Van Asseldonk, 2004; Peltoniemi, 2005). Ecosystems can be analyzed in four categories, which answers the second part of this sub-question: the strength of the members of the ecosystem, the acceptability of the network of relations between these members, the performance of the ecosystem in delivering a range of new products and persisting over time, and governance in the ecosystem (Anggraeni, et al., 2007). These categories result in more detailed ecosystems feasibility and viability criteria for qualitative analysis of ecosystems.

When evaluating mobile cloud platforms with these criteria one thus seeks ecosystems with the properties of: strong members that possess unique resources and have large amounts of customers; acceptable arrangements to divide roles and revenues between the platform owner, providers of smartphone resources, service providers and end-users; a long expected lifecycle; enabling and driving large and varied streams of mobile cloud services which are attractive for service providers and end-users. With the exception of governance due to time limitations, the ecosystems feasibility and viability criteria were applied during a series of interviews the results of which are discussed in the next section.

> Next, we focus on the third sub-question: *what are success factors and inhibitors which determine the real-world feasibility and viability of mobile cloud platform?*

This third sub-question was answered using the theoretical framework of ecosystems criteria during fourteen interviews with industry experts resulting in a range of success factors and inhibitors in the categories members, network, and performance. We combine the answers to this third sub question in the answer to our main research question:

> *What is the feasibility and viability of mobile cloud computing platforms from an ecosystems perspective, considering their positioning, enabling networks and their ability to deliver streams of mobile cloud services?*

We conclude that a future of smart phones as a shared ubiquitous resource pool still faces some practical feasibility and viability hurdles due to the current limitations in network connectivity, data subscriptions, mobile resource scarcity and end-user incentives to share. However, these hurdles apply to the current market and are expected to be alleviated with developments such as next-generation operator networks and increases in smartphone battery life. On the short term, rather than a general-purpose smartphone resource pool for the public, the mobile cloud concept may well be feasible and viable when applied on a personal or community-based level. In such environments trust and costs are less of an issue and appliances are more transparent.

We further answer the second part of the main research question by separately discussing the positioning, networks and the performance of mobile cloud ecosystems.

Positioning or member feasibility and viability: platform positioning in the mobile domain can be categorized as operator centric, device centric and service provider centric (De Reuver, et al., 2011). From our research it is concluded that mobile cloud platforms are most likely to be positioned at the handset OS or internet-based service providers. Both parties posses a strong existing ecosystem of end-users and service developers. Internet based service providers have further advantages in acquiring the largest possible smartphone resource pool as they are not tied to specific hardware, operators or geographical area and consequently more capable of rapid service innovation. While internet based service providers may eventually try and circumvent the handset OS to enable mobile cloud services, it is to be expected that handset OS developers will try and protect their mobile service platforms either by bounds on low-level application programming interfaces or by changing the terms and conditions regarding the use of their hardware. It remains to be seen how such measures hold with the rise of cross-platform development tools such as HTML5. Operators are considered as unlikely owners of mobile cloud platforms due to limited user bases and service provider communities. They do however control the connectivity which facilitates mobile resource sharing in non local environments. As smartphone owners which share their device may incur data subscription costs through mobile resource sharing, there may still be room for the operator to facilitate mobile cloud services through billing mechanisms. This can entail both billing between end-users sharing smartphones and billing between operators themselves, as smartphone resource sharing could entail cross-operator connections. As operators would still need device support such as applications or firmware we conclude that operators, device (OS) producers and internet based service providers all boast unique resources which may need to be combined for mobile cloud platforms.

Network feasibility and viability: the central mobile cloud platform owner combines smartphone resources and subsequently offers these to both end-users and third party service providers. From the interview results we conclude that this role can add great value by making smartphone sensors collectively available. Third party service providers may then poll any desired group of smartphone sensors for their own purposes or mobile services. The mobile cloud platform owner is then compensated for access to real-time sensor information, while the smartphone owner may be compensated for delivering resources. Such ‘sensor clouds’ are promising in drawing creativity from service developers for new streams of mobile services. A similar approach may apply for processing, though we conclude that offloading to a cloud computing datacenter may often be more efficient in such cases, though direct smartphone-to-smartphone connections may be an exception.

An inhibitor of network viability is that any internet-based service provider may convince end-users to opt-in for a similar service via standard smartphone applications rather than elaborate mobile services, e.g. Foursquare. The advantage of such specific-purpose applications is that smartphone owners may have less concerns regarding the security, privacy and legal implications of sharing their device as they can predict the appliance of their device.

Performance feasibility and viability: the performance of mobile cloud platforms is currently considered to be hampered in several ways. Scarcity in smartphone resources and limited but expensive bandwidth and lack of clear end-user sharing incentives are the most visible hurdles. While these may be addressed over time with technical and network improvements, these same improvements may disrupt the need for smartphone resource sharing. Faster operator networks diminish the need for shared connectivity, while increasing smartphone power and cheaper cloud computing datacenters reduce the need to offload computing tasks to other smartphones. This impression of mobile cloud may change when more collaborative services making use of multiple devices are conceived, rather than considering mobile devices as a straightforward resource pool akin to cloud datacenters. Similarly, palpable business models which provide smartphone users with enticing rewards for sharing their device are required.

6.1.1 Theoretical Contribution

This research has contributed to theory by further developing the definition of mobile cloud computing. It has been made explicit that definitions of cloud computing vary but still contain a large number of common elements, which are integrated in the NIST definition of cloud computing (NIST, 2011). This NIST definition has been used to categorize different aspects of mobile cloud computing, which may be used in follow-up research to categorize different mobile resource sharing concepts or as input to further develop the mobile cloud concept.

The theoretical insight gained by this research further includes increased knowledge of ecosystems as an analytical approach for multi-sided platforms. Financial indicators to express ecosystem performance and health (Iansiti & Levien, 2004a) have been shown to be applicable as qualitative criteria to evaluate ecosystems with. Furthermore is was shown that many Critical Success Factors for ICT business models (De Reuver, et al., 2006) are also applicable when evaluating ecosystems and multi-sided platforms rather than business models. Furthermore, the classification of operator centric, device centric and service provider centric ecosystems (De Reuver, et al., 2011) was applied during interviews, resulting in a range of success factors and inhibitors for platform positioning, confirming known issues in these ecosystems and providing input for further development of these generalized ecosystem models.

6.1.2 Implications for Practitioners

The objective of this research was to *identify factors influencing the feasibility and viability of mobile cloud platforms within their ecosystem in order to provide input for defining mobile cloud business models.* Business models are considered to be blueprints to create and capture customer and network value (H. Bouwman, et al., 2005).

Business models could focus on seamless fixed plus mobile integration. Mobile devices are increasingly intertwined with cloud computing services. These services are acquired via cloud computing datacenters, usually accessed via the operator network. This client-server style cloud computing model creates dependency on the cloud computing provider and the operator network. As the cloud computing paradigm entails acquiring heterogeneous resources via the network, mobile cloud computing could extend from cloud computing resources in datacenters to mobile devices providing cloud computing resources. Mobile devices can provide the traditional processing and storage resources, supplemented with the mobile-unique resources of sensors and connectivity. In combination with the ubiquity of mobile devices this can aid in reducing the dependency on cloud computing datacenters.

On the topic of platform positioning it was noted that silo's of device or operator specific mobile cloud platforms may not be able to hold on the long term due to the cross-platform capability of internet based service providers. Collaborative platform business models may therefore be sought e.g. between operators and OS developers or OS developers with internet based service providers.

With regards to end-user acceptance of mobile cloud services business models and technology should alleviate the security, privacy and legal concerns which may inhibit smartphone owners from opting in to a shared mobile resource pool. These issues may especially apply in cross-border mobile resource sharing cases. The business models should also in some way take into account that smartphone owners are compensated for the usage of their device and subscription fee.

6.2 Limitations of this Research

Some limitations are noted in the research scope and in the theoretical approach. We start with limitations regarding the research scope. First, we were unable to interview the major handset operating system developers and cloud computing service providers. This limits our knowledge of mobile cloud platform support in the smartphone operating system and of the future opportunities regarding the integration of fixed and mobile cloud computing. The handset operating system developers and cloud computing providers were difficult to contact due to having R&D centers situated outside of the Netherlands. When contacting their Dutch sales and distribution channels some employees commented that mobile cloud may be part of their ongoing R&D, possibly reducing willingness to share strategically sensitive information.

Secondly, though most of our interview results can be generalized to mobile cloud services globally, the specific Dutch perspective of the respondents may have influenced their attitude towards smartphone resource sharing. The Dutch culture is comparatively privacy-sensitive, which means that our respondents may have been negative regarding the willingness of end-users to share smartphone sensor information. Similarly, the perspective of our Dutch respondents may have been biased as during the interview period Dutch mobile network operators changed their subscription offerings to step away from flat fee models. The costs incurred with connectivity or other kinds of resources were consistently mentioned as inhibitors for smartphone resource sharing. These costs may vary depending on the reigning subscription model per country. Additionally, the need for sharing connectivity between smartphones in the Netherland may have been considered less desirable due to a high population density, base station density and flat terrains, when compared to countries with larger geographical areas.

The third limitation entails the way interview results were coded into variables influencing the feasibility and viability of mobile cloud ecosystems. A degree of subjectivity exists in recognizing a pattern in interview responses, selecting a code for this pattern and matching this code to the theoretical framework of ecosystems criteria. While this results in a rich perspective on factors influencing the feasibility and viability of mobile cloud ecosystems, our research did not extend to a validation of the codings by the respondents or other experts due to the time constraints for this project.

Fourth, to maintain a focus on the mobile telecom domain we demarcated our use cases to smartphones as a shared resource pool, based on use cases found in technical papers. However, several enabling architectures for mobile cloud are flexible enough to involve both smartphones and non-mobile devices. This could extend mobile cloud ecosystems to non-mobile actors and resources, such as internet service providers.

Limitations in the theoretical approach are noted in the definition of mobile cloud, the selection of criteria and the qualitative judgment of ecosystems with these criteria. The selection of ecosystems feasibility and viability criteria used in this research may not be exhaustive depending on the research perspective taken. The selected criteria were derived from ecosystems theory and selected critical success factors for ICT business models (De Reuver & Faber, 2008). It is conceivable that additional business model criteria may apply when conducting a more practically oriented feasibility study, such as such as time to market and cost divisions.

As we dealt with qualitative ecosystems criteria, factors influencing the criteria were split into success factors and inhibitors, leaving no difference in the weight of the various criteria. Alternative approaches such as multi-criteria decision analysis or statistics allow for an indication of the relative importance of criterion or the strength of relations between influencing factors and criteria. The chosen approach however allows for breadth in acquiring relevant factors and gives an indication of the relevance of a success factor or inhibitor through the amount of quotations and relations with other variables.

Finally, with regards to the definition of mobile cloud computing we note that our chosen definition was derived top-down working from cloud computing definitions to technical architectures. A bottom-up approach eliciting common elements in technical architectures may lead to different or supplementary results as there is an overwhelming amount of research towards mobile resource sharing, mobile resource pooling and variants in-between.

In the next section several of these limitations are used as a starting point towards recommendations for future research.

6.3 Recommendations for future Research

Based on our conclusions, the limitations discussed above and the remarks of our interview respondents we provide several suggestions for further research:

1. In this research the respondent base was selected on diversity in expertise for breadth in the interview results. As most respondent types were interviewed just once the interview results cannot extrapolated to a general perspective for specific industry roles. Research could be extended to multiple interviews per role to increase the reliability of the findings and allow for categorization of perspectives.
2. Interviews were conducted without explicitly involving end-users. While research such as that of Wijngaert & Bouwman (2009) explores factors influencing the willingness to share resources, this concerns sharing on the level individuals and specific applications. It is recommended that end-user willingness to opt in to a general purpose shared resource pool is explored as well.

3 Following from the previous point mobile cloud research could extends its scope to award or compensation mechanisms for sharing smartphone resources. Analysis could be geared towards different awards for the type, scope and duration of resources shared as well as mechanisms to discourage free-rider behavior in a shared resource pool.
4 Billing mechanisms for smartphone connectivity sharing may be explored as customers of multiple operators sharing connectivity can cause skewed network loads. During interviews it was suggested that operators could deal with these skewed loads in a similar way as with voice and SMS: by inter-operator billing of data handoff. This may also provide a means to deal with the inter-operator traffic caused by future mobile internet based services such as Voice-Over-IP.
5 The success factors and inhibitors found in this research can be applied to specify operator centric, device centric and service provider centric (De Reuver, et al., 2011) mobile cloud ecosystems in more detail with specific roles, customer relations, shared platform assets and governance of these relations. The platform categorization of Ballon (2009) may provide guidance in further specifying mobile cloud platforms in these positions as enablers, brokers, system integrators or neutral platforms.
6 Respondents noted peer-to-peer style mobile resource sharing to be of interest as it circumvents the operator network, which implies cost and network overhead. Mobile cloud research could explore mechanisms which select the appropriate channel to obtain cloud computing resources with, based on connection requirements and cost.
7 Our research focused on sharing resources between smartphones or mobile devices. Future research could explore business models which seamlessly integrate mobile and non-mobile cloud computing resources such as datacenters and personal computers. A possible starting point for such research could be the Platform as a Service providers which also develop mobile operating systems, such as Microsoft and Google which may be in a position to combine mobile and non-mobile cloud resources, end-users and development communities.

6.4 Reflection on the Graduation Project

I finish this chapter by looking back on the work I have delivered during this graduation project. During the project it has become apparent to me that mobile cloud computing is a new label on existing mobile resource sharing approaches. Connectivity sharing is also known as ad-hoc networks, mesh networks, liquid bandwidth or peer-to-peer networks while shared processing is also known as mobile distributed, grid or cluster computing. The way I have approached sensor cloud also is a rebranding of existing wireless sensor network concepts. Using the omnipresent smartphones as a shared resource pool is also akin to the concept of ubiquitous computing, in which people have computing resources available regardless of location and the device used. Nevertheless, the mobile cloud paradigm has allowed me to take a specific perspective on smartphones as shared resource pool for end-users as well as mobile service providers, whereas many earlier approaches focus on ad-hoc local resource sharing between individuals. Allowing service developers access to a shared pool of mobile resources may lead to both mobile and non-mobile service innovations, for example when information aggregators can access smartphone sensors.

For the theoretical approach I turned to ecosystems theory. At the beginning of this research I wondered whether to try and design the ecosystems around mobile cloud platforms or whether to analyze conceptual mobile cloud ecosystems. Both approaches proved challenging. I found ecosystems theory to be focused on ex post analytical tools to map or study existing ecosystems, with analytical tools geared towards financial indicators. Furthermore there appears to be limited guidance for those seeking to design rather than analyze ecosystems. Bouwman et al (2010) note that business models describe which resources and capabilities have to be made available in an ecosystem from a service innovation perspective, which implies that ecosystems may be designed using business models. However, ecosystems theory does differ from business model theory in that it explicitly takes the multi-sidedness of platforms into account. In the end I decided go forward with an analytical approach to provide input for future business model and ecosystem designs rather than trawling the large number of design variables around the abstract concept of mobile cloud.

In my approach to analyze ecosystems I derived a large number of feasibility and viability criteria from ecosystems theory in four categories: members, network, performance, governance. In retrospect I formulated too many criteria, as the results from the interviews can often be linked to the overarching category rather than individual criteria. The sheer amount of success factors and inhibitors obtained from the interviews may also indicate that using just one the four categories of ecosystems criteria as an analytical perspective may yield sufficient in-depth results when evaluating the feasibility and viability of an ecosystem.

For the nearby future I am curious to see how mobile cloud computing may eventually be realized. During this project I have experienced a glimpse of sharing smartphones by participating in research performed by Zokem, which collected information from my smartphone using an application which monitors device usage and location. Interestingly, the application at times caused me worries much in line with some of the results of this research: the appliance of the information collected is unclear, causing a privacy worries while several times I wondered about the application costs at times it used my data subscription when near or across the border.

Reflecting on my graduation project as a whole I can say that I have learned in many areas, conducting research on my own, dealing with unpredictable setbacks and seeking answers to satisfy my curiosity. I am pleased to have studied at the faculty of Technology, Policy and Management and to have finished the study by combining my knowledge in this thesis.

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A. Appendix: Scientific Article

Mobile Cloud Ecosystems
Evaluating the feasibility and viability of Smartphones as a Shared Resource Pool

Soebhaash Dihal - 1048902
spm5910, SEPAM Master's Thesis Project
Delft University of Technology, Faculty of Technology, Policy and Management
August 2011

Abstract
The increasing ubiquity of smartphones provides opportunities to perform mobile tasks collaboratively by combining smartphone processing power, connectivity and sensors into a shared resource pool for end-users and mobile service providers. Several conceptual technological architectures exist in which clusters of mobile devices serve as such a flexible mobile cloud resource. However, business perspectives on this technology are limited. This paper empirically evaluates the mobile cloud concept with industry practitioners. Using an ecosystems perspective. semi-structured interviews provide input on platform positioning, customer value and opportunities for innovation. Handset operating systems and internet based service providers are considered to be the most likely centre of mobile cloud ecosystems due to their existing scale, developer relations and innovation capabilities. The main hurdles for smartphone resource sharing include capped mobile data subscriptions, application-specific alternatives and limited end-user resource sharing incentives. Opportunities are noted around sensor sharing innovations and for shared mobile resource pools on a community-specific or personal level.

Keywords: mobile cloud computing, mobile ecosystems, platform as a service, multi-sided platforms

1. Introduction: inverting the cloud paradigm
In the cloud computing paradigm computing resources are placed outside of devices into the network (Hayes, 2008). Computing resources such as storage, processing power, development platforms and applications are acquired as a service rather than purchased or deployed locally. Cloud computing is gaining popularity as it can offer its users benefits such as ubiquitous online access to data or services and seemingly infinite computing resources available on demand, only paid for when needed (Armbrust et al., 2010). Cloud computing vendors benefit from economies of scale and increased resource utilization through the principle of multi-tenancy, a software architecture in which multiple customers share a large resource pool, while perceiving only their currently required part (Bezemer, Zaidman, Platzbeecker, Hurkmans, & 't Hart, 2010). For mobile devices cloud computing can allow access to services which would otherwise be limited by device constraints. Mobile devices vary in processor capabilities, operating system, form factor, input methods, connectivity speed, display, storage and memory capacity as well as battery lifetime. This restricts and causes fragmentation in the tasks which can be performed on mobile devices, as mobile service providers can only support so many devices. With cloud computing resource-intensive mobile computing tasks can be moved to the network and accessed via standard web interfaces (Kumar & Lu, 2010), allowing for access to mobile services regardless of the device used.

In the established perspective on cloud computing mobile devices serve as the clients in a client-server architecture, where collections of servers in datacenters provide the computing resources. Mobile devices then act as a consumption channel for cloud computing resources. However as mobile devices become ever more ubiquitous, powerful and feature-rich hardware and software advances and integration of sensor functionality in smartphones, researchers have started exploring the possibilities to offload computing tasks to other smartphones rather than cloud computing datacenters (Shanklin, 2009). In these new mobile cloud computing approaches smartphones become part of a larger cloud construct, collaboratively handling computing tasks with other smartphones (Warner & Karman, 2010).With such cloud constructs smartphones can acquire nearby computing resources via local ad-hoc connections (Want, Pering, Sud, & Rosario, 2008) or remote resources via the operator network (Elespuru, Shakya, & Mishra, 2009). The resources acquired can include processing power and storage (Marinelli, 2009) but also extend to smartphone-specific resources such as connectivity (Ananthanarayanan & Zats, 2009) and sensors (Beng, 2009; McKnight, Howison, & Bradner, 2004). Ongoing research approaches towards mobile cloud constructs include:

- *Dynamic Composable Computing*: mobile device capabilities seamlessly extended with (multiple) nearby computing resources (Want, et al., 2008).
- *Cloudlets*: computing sources in the environment available for use by nearby mobile devices (Satyanarayanan et al., 2009).
- *Clone Cloud*: one or more clones of a smartphone created 'in the cloud' to circumvent limitations on the device itself (Chun & Maniatis, 2009).
- *Elastic weblets:* applications consisting of weblets launched on and migrated between (non) mobile devices depending on environment and user preferences (Zhang, Schiffman, Gibbs, Kunjithapatham, & Jeong, 2009).
- *MapReduce:* processing tasks distributed across a mobile device pool while scaling with the number of devices available (Elespuru, et al., 2009).
- *Dynamic Virtual Machine Migration*: computation tasks offloaded from mobile devices to nearby desktop computers (Sud et al., 2011).

Current mobile cloud research approaches focus on the technical enablers to offload tasks from a mobile device or smartphone to other devices, such as middleware and wireless technologies. Comparable work is found in earlier mobile resource sharing concepts under titles such as ad-hoc or mesh networks, mobile clusters and wireless grids (e.g. McKnight, et al., 2004). Some researchers such as Wijngaert & Bouwman (2009) have explored the factors influencing end-user willingness to share smartphone resources. Knowledge gaps are noted around business models for mobile cloud computing and the possible impact of mobile business models on the proliferation of mobile services. We consider business models to be a blueprint to describe how organizations can co-operate to create and capture value from technical innovations (Faber et al., 2003). Mobile services are enabled and driven by platforms, which according to Gawer (2009) are *"technological building blocks (which can be technologies, products, or services) that act as a foundation on top of which an array of firms, organized in a set of interdependent firms (or ecosystem) develop a set of inter-related products, technologies and services"*. Business models around mobile cloud platforms may be unique as unlike traditional cloud computing datacenters, a shared smartphone resource pool may have many individual resource owners which could be compensated for using their device. The mobile cloud platform owner may be responsible for combining or pooling mobile resources, making these available to mobile service developers and compensating smartphone owners. Such interactions between platform enablers and platform customers can also be labeled as an ecosystem (Basole, 2009; Gawer, 2009). Business models thus describe how value is created and captured in an ecosystem.

While existing prototypes lead us to assume that it is technically feasible to bring mobile cloud platforms to market, there are uncertainties regarding the feasibility of their ecosystem. This includes issues such as the various possible arrangements for the role of mobile cloud platform owner, compensation for sharing and the relation with mobile service providers. Similarly, the subsequent business chances of mobile cloud platforms in various arrangements are unknown. This can be expressed as a question of viability, which stands for to the potential value delivered for customers and enabling networks (Bouwman, Haarker, & De Vos, 2005). The objective of this paper is therefore to identify success factors and inhibitors influencing the feasibility and viability of future mobile cloud ecosystems. To this end we focus on the following research question: *what is the feasibility and viability of mobile cloud platforms, considering their positioning, enabling networks and ability to result in streams of mobile cloud services?*

We answer this question by evaluating the mobile cloud platform concept in a range of interviews with various experts in the mobile industry, using a number of use cases which illustrate the mobile resource sharing concept. The interviews and interview results are structured using ecosystems theory, which provides guidance in establishing criteria for feasible and viable platforms in the mobile domain. Chapter 2 presents the three use cases illustrating the mobile cloud concept which are discussed during the interviews. Chapter 3 discusses ecosystems theory, focusing on criteria with which mobile cloud platforms can be evaluated. Chapter 4 provides the interview setup. Chapter 5 presents the success factors and inhibitors elicited during interviews. Chapter 6 discusses the results, limitations and viewpoints on possible future research.

2. Mobile Cloud Computing

Cloud computing is an ill-defined concept in both literature and practice, due to a diversity of evolving technologies associated with cloud computing and marketing practices. When extended to mobile cloud computing, confusion can arise as conceptual overlap with earlier mobile resource sharing research is noted. We clarify our approach of mobile cloud using the recently updated NIST (2011) definition of cloud computing: *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models."* The key part of this definition for mobile cloud is that of a shared resource pool. Mobile cloud computing can therefore entail two aspects: mobile devices as a channel to obtain cloud computing resources with via the network, and/or mobile devices together as (part of) a shared pool of computing resources (Elespuru, et al., 2009; Shanklin, 2009). We will now further clarify the concept of mobile devices as a shared resource pool with three use cases based on smartphone connectivity, processing and sensors. We have omitted the smartphone as a shared resource pool for storage as few architectures for this purpose are available, most likely because the perishable nature of smartphone resources such as connectivity and battery can be a showstopper for accessing storage.

2.1 Connectivity case

In this example based on the AggreGATE architecture (Ananthanarayanan & Zats, 2009) mobile devices become part of a shared pool of connectivity resources. The user requests a bandwidth-demanding video stream. The request is sent via a central coordinating server which then simultaneously invokes multiple connectivity options (e.g. 3G, Bluetooth and Wi-Fi) of nearby smartphones to improve the download speed for the end-user. The smartphone of the end-user seamlessly migrates from multiple connectivity options to a single operator connection and vice-versa depending on the number of smartphones available. The coordinating server takes into account factors such as utilization rates, battery levels and interruption tolerance to determine which smartphones are engaged (Figure 1).

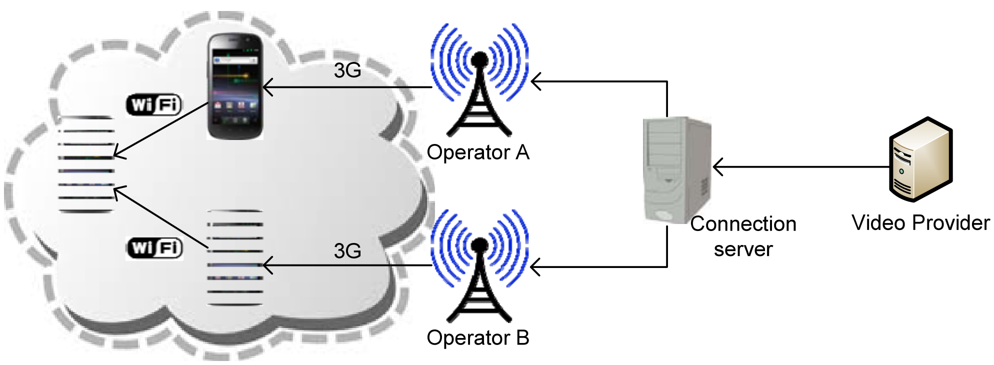

Figure 1 - Mobile connectivity cloud example based on AggreGATE (Ananthanarayanan & Zats, 2009)

2.2 Processing case

This use case is based on the MapReduce algorithm (Elespuru, et al., 2009). A smartphone offloads a computation task via a central coordinating server, which segments the tasks and distributes it across multiple mobile devices. The server combines the processed results and sent these back to the requesting device potentially saving processing time and energy (Figure 2). Examples of tasks which could be offloaded include background virus scans, video encoding or face recognition. Some alternative architectures allow for direct device-to-device offloading of computing tasks (Marinelli, 2009), potentially circumventing operator network bottlenecks.

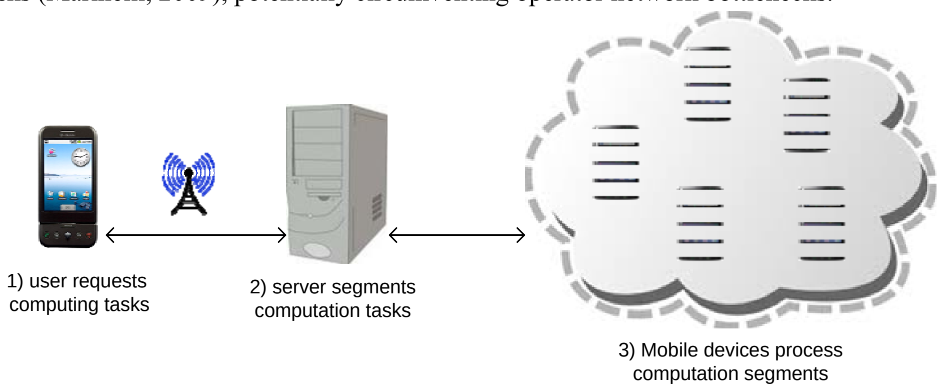

Figure 2 - Mobile processing cloud example based on MapReduce

2.3 Sensor case

The sensor use case is a theoretical extension from connectivity and processing use case, based on the same architecture consisting of an application layer at the device plus a coordinating server which distributes sensor requests. In this case a smartphone can consult the sensors in other smartphones as needed. An example application would be to obtain traffic information via the GPS, accelerometers and gyroscopes of large groups of smartphones. (Figure 3). Alternatively, third parties can access the shared smartphone sensor resource pool to collect information such as noise levels on the highway and traffic density trends.

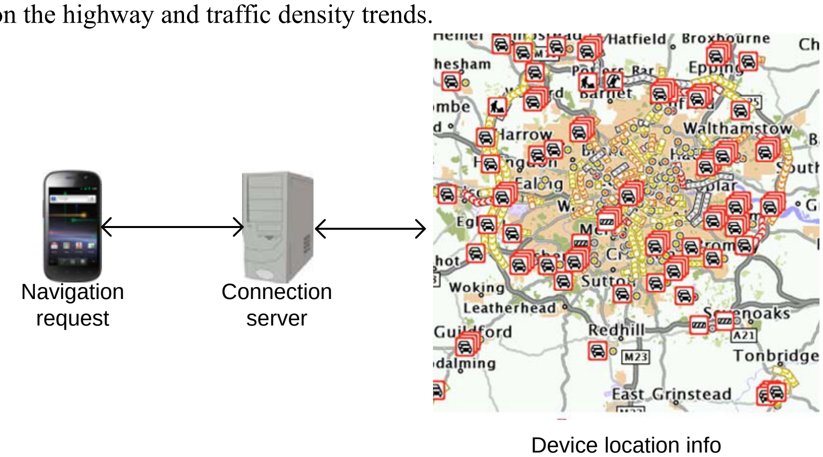

Figure 3 - Mobile Sensor Cloud example inspired by TomTom HD Traffic

2.3 Mobile cloud platforms

The connectivity, processing and sensor use cases all include a server which coordinates the shared smartphone resource pool. The question rises who will 'own' the server coordinating devices. In the sensor and processing use case it is possible that not only smartphone owners, but also third party service providers tap into the shared mobile resource pool. The owner of the coordinating server and possibly the handset code, is in charge of matching the smartphone supply side to smartphone resource demand from end-users and third party service providers and can be considered as a platform owner. This platform owner is potentially in a position to acquire and distribute revenues from both supply and demand sides. This can be labeled as a multi-sided platform (Evans, Hagiu, & Schmalensee, 2008). The business dynamics around such multi-sided platforms can be studied using ecosystems theory, which is discussed in the next chapter.

3. Theoretical approach

In the previous chapter we concluded that mobile cloud platforms can have multi-sided properties. In the mobile domain these multi-sided platforms are prominently visible as 'app stores', which serve as matchmakers between developers on one side and end-users on the other side of the platform. Service developers benefit from a critical mass of users, whereas end-users are attracted by the many applications and a long tail of niche products (Anderson, 2006). Multi-sided platforms build audiences and reduce costs through shared facilities for their customers, including software programming tools, quality control, billing and update functionality.

Ecosystems are a frequently used perspective to study the interactions around multi-sided platforms in the mobile domain. The business ecosystem analogy is an evolution of earlier approaches to study inter-organizational networks, such as value chains (Porter, 1985) and value networks (Haglind & Helander, 1998). Business ecosystems differ from value networks as they include both competition and cooperation at the same time and are centered around platforms, which both enable and drive the creation of a wide range of new products and services (Basole, 2009). Business ecosystems also have lifecycle dynamics over time: the roles or lifespan of actors in the ecosystem can change over time, whereas members of a value network have more predefined tasks and usually only compete when the members of the value network are chosen (Peltoniemi & Eng, 2004).

Multi-sided platforms depend on the ecosystems, or networks of enablers and complementary service or product providers they enable (Basole, 2009). There appears to be a lack of clear-cut qualitative analytical tools to evaluate the feasibility and viability of conceptual ecosystems (Adomavicius, J., Gupta, & Kauffman, 2006). Many ecosystems analysis methods are geared towards financial indicators, simulation or social network analysis which require the availability or creation of databases around existing ecosystems (Basole, 2009; Iansiti & Richards, 2005). We thus seek guidance in evaluating ecosystems with the categorization proposed by Anggraeni et al (2007) which breaks down ecosystems theory in four parts:

- the members of the ecosystem;
- the network of interactions in the ecosystem;
- the performance of the ecosystem;
- governance of the ecosystem.

In line with the research question we focus on ecosystem members, network and performance, assigning criteria to evaluate the feasibility and viability of ecosystems within these three categories.

3.1 Ecosystem member criteria

Iansiti and Levien (2004) define three role-based for ecosystem members: keystone, niche player/complementor and physical dominator. *Keystones* are platform providers and actively foster the ecosystem health by facilitating interactions around the platform and removing unwanted ecosystem members. In the mobile domain the keystone role is centered around operators, handsets or service providers (De Reuver, Bouwman, Prieto, & Visser, 2011).
The position of keystone in an ecosystem is a desired position due to the possibility of high rewards when the platform becomes dominant (Shapiro & Varian, 1999). Platforms can provide competitive advantages such as economies of scale, barriers to entry and persistence over time (Bresnahan, 1999). Such lasting platform advantages can be gained with valuable, rare, inimitable and non-substitutable resources (Barney, 1991). This is an incentive for complementors to collaborate with the platform as they are mutually dependent on its resources (Pfeffer & Salancik, 1978). *Niche players* or c*omplementors* make up the largest portion of the ecosystem in quantity and diversity, making use of and complementing the facilities offered by the platform provider with specialized capabilities. In the mobile domain niche players often include application developers, service and content providers. In the case of mobile cloud one could possibly even consider end-users providing heterogeneous mobile resources as niche players. *Dominators* are extreme variants of keystones and extract maximal value from the ecosystem for own gain rather than for the network. The dominator strategy may limit innovation and may therefore be more suited to mature ecosystems (Basole, 2008) and thus not mobile cloud. We therefore derive three ecosystem criteria from the category members:

- The presence of platform leaders, to connect ecosystem members and promote ecosystem performance
- The presence of platform complementors, to complement the platform in numbers and derivative products
- The presence of unique resources, as a barrier to entry for competing platforms

3.2 Ecosystem network criteria

The ecosystem analogy is built on a large theoretical foundation regarding inter-firm relationships and collaboration, inter-organizational network analysis, and complexity theory (Basole, 2008; Moore, 1996; Peltoniemi & Vuori, 2004) In these networks firms both compete and co-operate simultaneously, engaging in co-opetition (Brandenburger & Nalebuff, 1997) to develop the ecosystem. The abundance of literature discussing the network properties of ecosystems can roughly be divided in two parts: structure and dynamics. *Structure* can entail role divisions and revenue sharing arrangements (Bouwman, et al., 2005). Role divisions are relevant due to competition for the position of keystone or control over the customer relation and platform assets (De Reuver, et al., 2011), while revenue sharing is relevant due to the share of revenue taken by the platform owner versus the share of revenue going to suppliers. Ecosystem *dynamics* are caused by network externalities. When end-users leave the network, the value of the platform declines for the platform owner, end-users and suppliers. Similarly when suppliers of complementary products adopt the platform, the value of the platform rises for all parties (Katz & Shapiro, 1985). From network theory we therefore derive the following three criteria:

- Acceptable division of roles
- Acceptable division of revenues
- Strong network externalities

3.3 Ecosystem performance criteria

Iansiti & Richards (2005) provide a number of financial measures which can express the health or performance of an ecosystem: niche creation, productivity and robustness. *Niche creation* stands for firm, product and technical variety and adoption of innovation in the ecosystem. *Productivity* entails the rate of delivery of innovations (or new products) in an ecosystem over time. *Robustness* is a measure of the persistence of an ecosystem, which can depend on the technical lifecycle of the underlying platform technology or the continuity of the inter-firm relations in the ecosystem. We convert these measures to qualitative set of criteria expressing ecosystem *performance*. The performance of an ecosystem also depends on the straightforward value proposition the platform offers to its customers: service providers and end-users (Bouwman, et al., 2005). We therefore add customer value as an additional performance criterion, resulting in the following criteria:

- Ecosystem variety
- Delivery of innovations over time
- Continuity of structure
- Lengthy technological lifecycle
- Customer value

With this we have defined a number of theoretical criteria for ecosystem members, networks and performance as listed in Table 1. The next section will discuss the interview setup around these criteria.

Table 1 - Overview of selected ecosystem feasibility and viability criteria

Category	Relevance	Criteria
Members	Availability of resource-rich members	• Presence of platform leaders (keystones) • Presence of complementors • Presence of unique resources
Network	Network value & network dynamics	• Acceptable division of roles • Acceptable division of revenues • Strong network externalities
Performance	Niche creation *Firm, product, technical variety*	• Ecosystem variety
	Productivity *Rate of delivery of innovations*	• Delivery of innovations over time
	Robustness *Resistance to environmental changes*	• Continuity of structure • Lengthy technological lifecycle
	Customer value	• Compelling value proposition

4. Methodology

To empirically validate the mobile cloud concept we interviewed 14 respondents in semi-structured interviews using the three smartphone sharing cases introduced in chapter 2: connectivity, processing and sensor sharing, explaining the basic architecture of a coordinating server and an application programming layer at the mobile device. The three use cases are discussed one by one with the same questions to elicit a broad range of success factors and inhibitors depending on the type of smartphone resource shared. This allows us to generalize the results of each case to conclusions regarding the feasibility and viability of mobile cloud platforms. The interview questions are derived from the ecosystem criteria as shown in Table 2. Interviews lasted one hour, in two select cases reduced to 45 and 30 minutes to fit the agenda of the respondent. Prior to the appointment the respondents were sent an introductory document containing the research objective and use cases for mobile cloud. With the consent of the respondent the interview was recorded for processing into a transcript afterwards.

4.1 Processing interview results

Interview transcripts have been interpreted using the ATLAS.ti software tool for qualitative analysis of textual data. ATLAS.ti aids in systematically categorizing interview feedback. Recurring quotations in the interview transcripts are coded into success factors or inhibitors of mobile cloud ecosystems. Coding allows us more convenience in the analysis of interview results by grouping comparable codes to our theoretical criteria of members, network and performance. ATLAS.ti indicates the amount quotations underlying a code, giving a possible hint towards the importance of a code. Furthermore, ATLAS.ti is used to construct visual relations between codes and criteria.

Table 2 - Interview questions in relation to theoretical framework of ecosystems criteria

Category	Criteria	Questions
Members	• Presence of platform leaders • Presence of platform complementors • Presence of unique resources	4. Which organizations would be 1) capable of and 2) willing to attain ownership of a mobile cloud platform? 4.1. Operator, device, service provider centric? 4.2. What would be the critical assets to determine platform ownership? 4.3. Which complementors would the platform require?
Network	• Acceptable division of roles • Acceptable division of revenues • Strong network externalities	5. Which role divisions would be acceptable for the parties enabling the mobile cloud platform service? 5.1. Which revenue sharing models are likely to be supported between these parties? 5.2. Is the user base in these models sufficient to provide enough smartphones to connect with?
Performance	• Ecosystem variety • Delivery of innovations over time • Continuity of structure • Lengthy technological lifecycle • Compelling value proposition	6. Is the core mobile cloud service platform proposition attractive enough to attract a wide range of customers and innovations to the platform: smartphone owners, service providers, end-users? 6.1. Which type of services or applications would you expect to drive demand for this mobile cloud platform? 6.2. In what ways would end-users be a) attracted and b) retained? 6.3. Which telecom market developments could have an impact on the lifecycle of a mobile cloud platform? (e.g. LTE-A, HTML5)

4.2 Selection of respondents

Interview candidates (N=14) were acquired via the network of industry guest lecturers at Delft University of Technology, at the Capgemini and Exact cloud computing conferences of September 2010 in the Netherlands as well as the client network of the Dutch branch of KPMG Advisory. Table 3 presents an overview of respondents. Diversity in respondents was sought to acquire a wide range of perspectives on mobile cloud platforms.

Table 3 - Overview of respondents

Respondent	Organization	Function	Expertise
Hugo Huis in't Veld	KPN Fixed plus mobile network operator, internet service provider	Senior Innovation Manager	Mobile innovations
Patrick Steemers	Capgemini Consultancy/system Integrator	Principal consultant telecom, media, entertainment	SaaS/PaaS for mobile, infrastructure implementations, mobile strategy
Bart Bastiaans	KPMG Consultancy	Manager IT infrastructure & architecture	Wireless technology, architectures, mobile security
Mick Coulson	Acision Messaging platform provider	Product manager mobile data services	Mobile messaging platforms
Frank Berkers	TNO Research institute	Researcher business innovation & modeling	Technology trends & stakeholder analysis
Ignas Niemegeers	Delft University of Technology	Professor wireless & mobile communications	Collaborative device applications, personal networks
Joost van der Plas	Hyves Mobile virtual network operator & social media platform	Manager Mobile	Mobile plus social media platform convergence
Patrick Blankers	Ericsson Infrastructure provider	Manager Strategy & Regulation	Mobile telecom infrastructures
Jose Santiago Nunez	TomTom Navigation solutions	Product labs manager	Multi-platform application development, device-to-device applications, location services
Arjen de Vet and Lassi Kurkijärvi	Sanoma media Content & media provider	Manager ICT Manager mobile development	Mobile marketing and content, mobile video
Fred Herrebout	T-Mobile Mobile Network Operator	Strategy manager	Operator centric strategy
Rene Witjes	Service2media Application & software provider, development platform provider	International business developer	Cross-platform application development and sales
Marcel Wendt	Golden Bytes Billing & infrastructure provider	CTO, founder	Mobile technology innovations, operator interconnect infrastructure
Dennis Kokkelink	Samsung Handset manufacturer	Mobile telecom content manager	Handset and OS differentiation, handset marketing and sales

5. Results

We present the interview results in the categories members, network and performance in two ways. First the main success factors and inhibitors per category are summarized in a table. Second, the visual constructs of codes in ATLAS.ti showing the factors influencing feasibility and viability per category are presented. The codes in these visualizations are accompanied with two numbers within brackets. The left number shows the amount of times a code was quoted. The number on the right indicates the amount of relations with other codes in total. We have labeled success factors as causes of feasibility and viability, while inhibitors are labeled as limiters of feasibility and viability. To preserve the clarity of our overviews the codes in ATLAS.ti were linked to the main category of members, network and performance rather than the numerous underlying criteria, which are addressed in the table if applicable.

5.1 Member results

We evaluate ecosystem members with three criteria: presence of platform leaders, presence of complementors and presence of unique resources. The interview results highlight the connection between these three criteria: the most likely platform leaders are those with an existing ecosystem of complementors and strong resources such as handset OS software development kits, or a specific customer relation such as internet service providers with end-users accustomed to sharing smartphone information. The results are shown in Table 4 and Figure 4.

Table 4 - Main success factors and inhibitors in the category members

Category	Success factors	Inhibitors
Members	• Platforms with already large ecosystems of service providers and mobile end-users are considered most likely to become mobile cloud platform owners due to existing network effects. • Handset OS vendors may extend their app store service offerings with mobile cloud services, making devices more attractive. At the same time they can sell access to the shared mobile resource pool to third party service providers. • Internet based service providers may gather large audiences of end-users and service developers which are not bound to a single operator or OS.	• Parties which lack the capability to innovate or mobilize innovation are unlikely to become mobile cloud platform owners. Operators are therefore considered less likely to be the platform owner in mobile cloud ecosystems. • Operators are considered to be less likely to support mobile cloud platforms as mobile cloud services increase the load on their (currently) strained networks. Operators may actively discourage mobile cloud services, possibly exploiting the mutual dependencies between operators and handset vendors in handset subsidies.

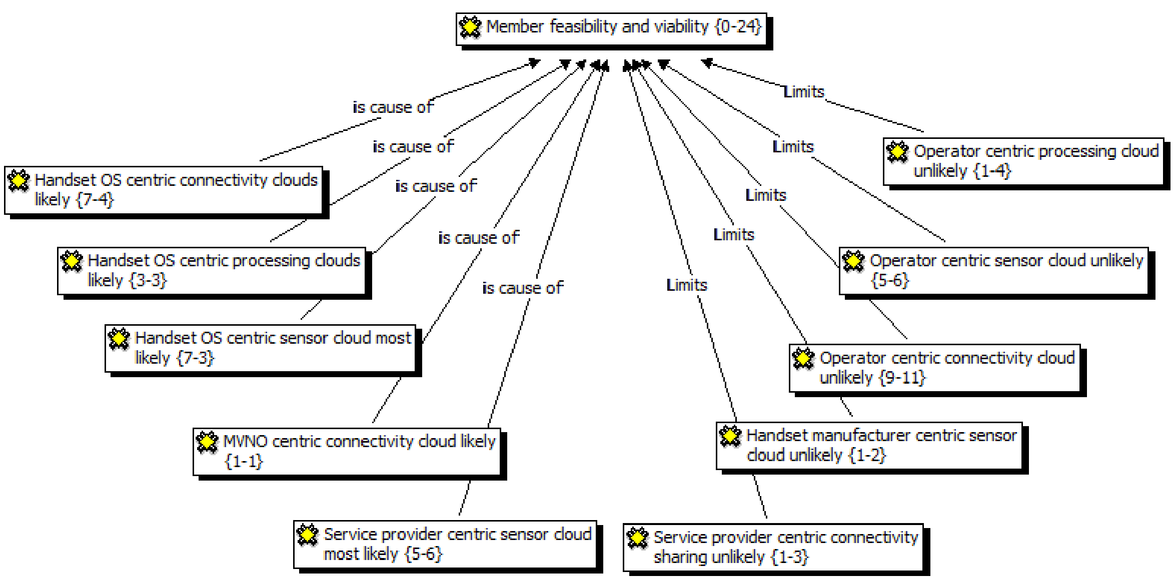

Figure 4 - Member success factors and inhibitors

5.2 Network results

We evaluated mobile cloud networks with three criteria: acceptable division of roles, acceptable division of revenues and strong network externalities. With regards to role divisions it was indicated that the role of pooling and sharing mobile resources can be attractive, as mobile service providers are considered to be likely to pay for access to unique smartphone resources. However this role may be subject to strong competition, as any internet-based service provider may take in this position with via an application on a smartphone- which may circumvent existing app stores and thus revenue sharing arrangements by using cross-platform web interfaces. Network externalities were already addressed in the responses regarding ecosystem members, where respondents indicated that mobile cloud platforms are more likely to be placed in ecosystems with existing network externalities. The results are shown in Table 5 and Figure 5.

Table 5 - Main success factors and inhibitors in the category network

Category	Success factors	Inhibitors
Network	• Selling access to a shared smartphone pool is considered valuable. The platform owner may acquire revenues for allowing access to the sensors or sensor data acquired in the shared mobile resource pool. • To allocate the costs caused by smartphone resource sharing, intermediary service providers may take in the role of facilitating billing between operators, e.g. when end-users of multiple operators share connectivity resources.	• Sharing resources between smartphone is considered to cause billing complexity as end-users consume each other's data subscriptions and tilt network loads towards multiple operators. • HTML5 and application specific alternatives challenge mobile cloud platform ownership silo's at the handset OS or operators. Internet service providers can potentially engage all smartphone owners. • The focal use case architecture of a coordinating server which distributes tasks across a shared mobile resource pool is considered limiting, due to the need to engage the operator network. Peer-to-peer alternatives which allow smartphones to connect directly to resources in their environment are considered attractive.

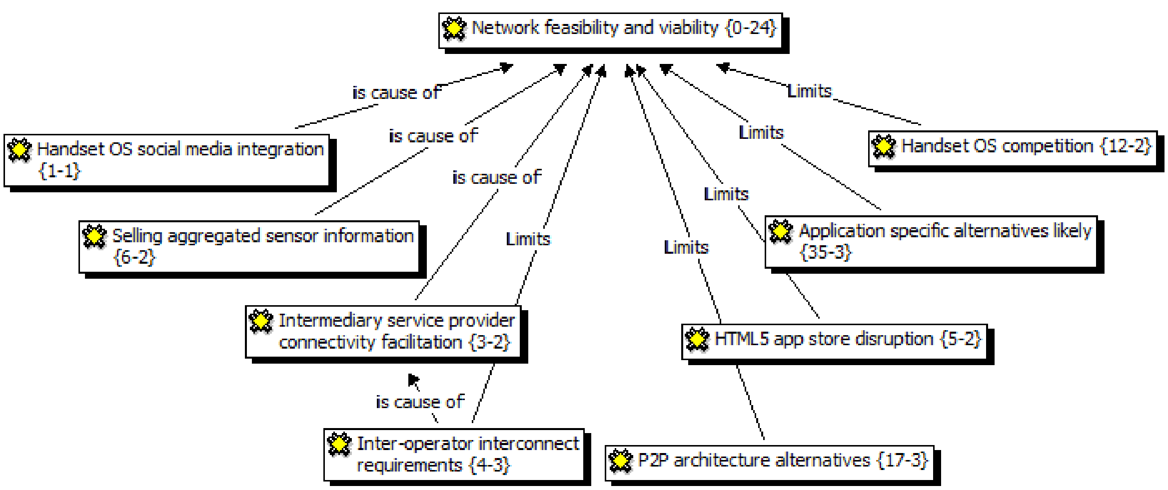

Figure 5 - Network success factors and inhibitors

5.3 Performance results

Mobile cloud ecosystems performance was evaluated with criteria regarding niche creation, productivity, robustness and customer value. Due to the large volume of feedback received in these categories the ATLAS.ti visuals with the interview results can be consulted in the appendices. Table 6 presents the summarized performance results, which address all the criteria formulated in the theoretical approach. The responses regarding performance are quite mixed, partly due to current state of the market and technology in the mobile domain, such as data caps and battery life limitations. Many factors influencing the feasibility and viability of mobile cloud may thus change over a currently unknown time period.

Table 6 - Main performance success factors and inhibitors

Performance Category	Success factors	Inhibitors
Niche creation (Appendix Figure 6)	• A wide range of service innovations is possible based on shared smartphone sensor pools, which may also complement fixed sensor infrastructures in the likes of roads and buildings.	• No direct inhibitors were obtained.
Productivity (Appendix Figure 7)	• The ubiquity of smartphones, their increasing numbers of sensors processing power in combination with many idle smartphone resources provide the preconditions for a range of new mobile resource based services. • Bandwidth price decreases and flat fee data subscriptions are expected to eventually make bandwidth a commodity, enabling always-on mobile resource sharing.	• Lack of business problem solved: it is argued that inherent mobile service limitations due to screen size, input methods, network limitations etc. are not addressed by mobile cloud. • Current trend towards data caps and differentiated data usage fees will hamper uptake of mobile cloud services, as sharing a smartphone may be expensive
Robustness (Appendix Figure 8*)*	• Connectivity sharing could extend the lifecycle of operator networks by improving coverage and bandwidth via the smartphones of end-users, without significant network expenditures.	• Next-generation operator network bandwidth increases and micro network alternatives may disrupt the need to share connectivity. • Current wireless technologies such as Wi-Fi and Bluetooth technologies fold under large numbers of connection requests as may be the case with mobile cloud in crowded areas. • Service providers may at any time disrupt the position of a mobile cloud platform owner by offering similar services via a (web) application.
Customer value (Appendix Figure 9 *&* Figure 10*)*	• Shared mobile resource pools could be successful in community environments or personal environments such as homes, schools and offices due to trust and lack of cost sharing concerns • Device owners sharing mobile resources may be rewarded with data, voice, SMS subscription discounts, app store credits or in other ways. • New types of collaborative services may be enabled by mobile clouds. • Connectivity robustness in indoor or remote areas can be potentially be improved with shared connectivity. • Mobile clouds resources seamlessly integrating with fixed cloud resources could be advantageous in cost, connection and availability.	• Security, legal, privacy concerns may prevent end-users from opting in to mobile cloud. • Limited end-user understanding may hamper opt-in and thus the size of the mobile resource pool • Offloading processing may be limited to non-time critical tasks due to connectivity limitations. • There is a perceived lack of killer applications for offloading processing tasks to other mobile devices due to increasing power on smartphones and the possibility to offload to datacenters. • Perishable nature of mobile resources: battery drain, connectivity interruption cause a lack of availability guarantees. • End-user sharing incentives are unclear. Some end-users may not benefit from access to the mobile resource pool themselves. Free-rider behavior could occur where end-users profit from others with better subscriptions or hardware.

Having presented the interview results we now discuss the conclusions and limitations of this paper and provide an outlook to future research.

6. Conclusions

Reflecting on this research it is apparent that mobile cloud computing is a new label on existing mobile resource sharing approaches. Connectivity sharing is also known as ad-hoc networks, mesh networks or peer-to-peer networks while shared processing is also known as distributed, grid or cluster computing. Our approach of sensor cloud is a rebranding of existing wireless sensor networks. Nevertheless, the cloud paradigm allows for a specific perspective on smartphones as shared resource pool for both end-users and mobile service providers, whereas many earlier approaches focus on ad-hoc local resource sharing for end-users. Using the omnipresent smartphones as a shared resource pool is akin to the concept of ubiquitous computing, in which people have computing resources available regardless of location and the device used.

This paper focused on the research question: *what is the feasibility and viability of mobile cloud platforms from an ecosystems perspective, considering their positioning, their networks and their ability to result in streams of mobile cloud services?* We approached this question by evaluating the possible members, network and performance of the ecosystems around mobile cloud platforms with a range of industry experts. The results show that a future of smart phones as a ubiquitous shared resource pool still faces some practical feasibility and viability hurdles due to the current limitations in connectivity, data subscriptions, and end-user incentives. Rather than a general-purpose smartphone resource pool for the public, the concept may first be applied on a personal or community-based level where trust and cost are less of an issue and appliances can be more palpable.

Members: platform positioning in the mobile domain can be categorized as operator centric, device centric and service provider centric (De Reuver, et al., 2011). Our respondents consider mobile cloud platforms most likely to be positioned at the handset OS or internet-based service providers. Both parties are coupled with a strong existing ecosystem of end-users and service developers. Internet based service providers may have further advantages in acquiring the largest possible smartphone resource pool as they are not tied to certain hardware, operators or geographical area and consequently more capable of rapid service innovation. While internet service providers may eventually try and circumvent the handset OS to enable mobile cloud services, it is to be expected that handset OS developers will try and protect their mobile service platforms either by bounds on low-level application programming interfaces or by changing the terms and conditions regarding the use of their hardware. It remains to be seen how such measures hold in the light of cross-platform development tools such as HTML5. Operators are considered as unlikely owners of mobile cloud platforms due to limited user bases and service provider communities. They do however control the connectivity which facilitates mobile resource sharing on larger scales. As smartphone owners sharing their device may incur data subscription costs through mobile resource sharing, there may still be room for the operator to facilitate mobile cloud services, possibly through billing mechanisms. This can entail both billing between end-users sharing smartphones and billing between operators themselves, as smartphone resource sharing could entail cross-operator connections. As operators would still need device support such as applications or firmware we conclude that operators, device (OS) producers and internet based service providers all boast unique resources which may need to be combined for mobile cloud platforms.

Network: the central mobile cloud platform owner pools smartphone resources and subsequently offers these to end-users and third party service providers. The interview results indicate that this role can add value by making smartphone sensors available. Third party service providers may then ‘poll’ any desired group of smartphone sensors for their own information applications. The mobile cloud platform owner is then compensated for access to real-time sensor information. Such ‘sensor clouds’ are considered promising in drawing creativity from service developers for a new generation in mobile services. The downside is that any internet-based service provider may convince end-users to opt-in for a similar service via standard smartphone applications rather than elaborate mobile services. The advantage of such specific-purpose applications is that smartphone owners may have less concerns regarding the security, privacy and legal implications of sharing their device as the purpose is more transparent, e.g. Foursquare.

Performance: the performance of mobile cloud platforms is currently considered to be hampered in several ways. Scarcity in smartphone resources and limited but expensive bandwidth and lack of clear end-user sharing incentives are the most visible hurdles. While these may be addressed over time with technical and network improvements, these same improvements may disrupt the need for smartphone resource sharing. Faster operator networks diminish the need for shared connectivity, while increasing smartphone power and cheaper cloud computing datacenters reduce the need to offload computing tasks to other smartphones. This impression of mobile cloud may change when more collaborative services making use of multiple devices are conceived, rather than considering mobile devices as a straightforward resource pool akin to cloud datacenters. Similarly, palpable business models which provide smartphone users with enticing rewards for sharing their device are required.

6.1 Limitations and future research

We note three limitations in our research. First, the specific Dutch perspective of the respondents may influence their attitude towards smartphone resource sharing as the Dutch culture is relatively privacy-sensitive. Second, we were unable to consult the major handset operating system developers and cloud computing service providers for our interviews. This may limit our knowledge of positioning a mobile cloud platform in the smartphone OS and that of the opportunities for fixed-plus-mobile cloud integration. The third limitation is that we demarcated our use cases to smartphones as a shared resource pool, focusing on the mobile telecom domain. However, some enabling architectures for mobile cloud are flexible enough to involve both smartphones and non-mobile devices. This could extend the members of a mobile cloud ecosystem to the likes of fixed line internet service providers.

Future research towards mobile cloud computing could focus on five areas. First, the opportunities to seamlessly integrate datacenter cloud computing resources with unique mobile cloud computing resources are of interest, in part because major mobile OS developers such as Microsoft and Google are at the same time cloud computing vendors. Secondly, mobile cloud research could extend its scope to award mechanisms for smartphone sharing, which can possibly vary depending on the type, scope and duration of resources shared and may discourage free-rider behavior. Third, billing mechanisms for inter-operator handoff of traffic may be explored as smartphone connectivity sharing was noted to lead to potential skewed operator loads. Fourth, peer-to-peer style mobile resource sharing circumventing the operator network was noted to be of interest. Research in this area may extend to optimizing the type of connection and resource used depending on service requirements and costs. Finally, the ecosystems approach to mobile cloud in this paper can be further developed by specifying operator centric, device centric and service provider centric (De Reuver, et al., 2011) mobile cloud ecosystems in detail with their specific roles, customer relations, shared platform assets and the governance of these relations. The platform categorization of Ballon (2009) may provide guidance in classifying mobile cloud platforms in these positions as enablers, brokers, system integrators or neutral platforms.

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Appendix: Interview results for mobile cloud ecosystem performance

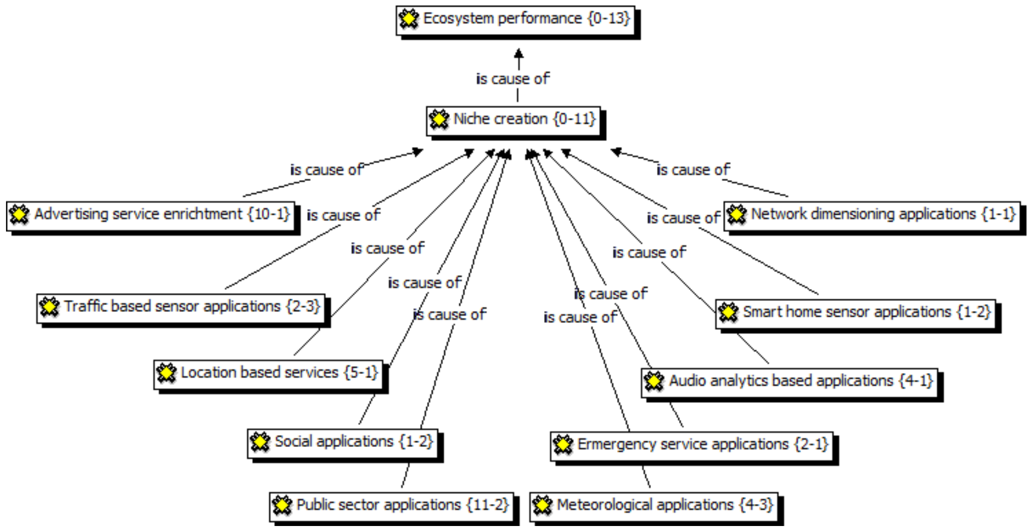

Figure 6 – Niche creation success factors and inhibitors

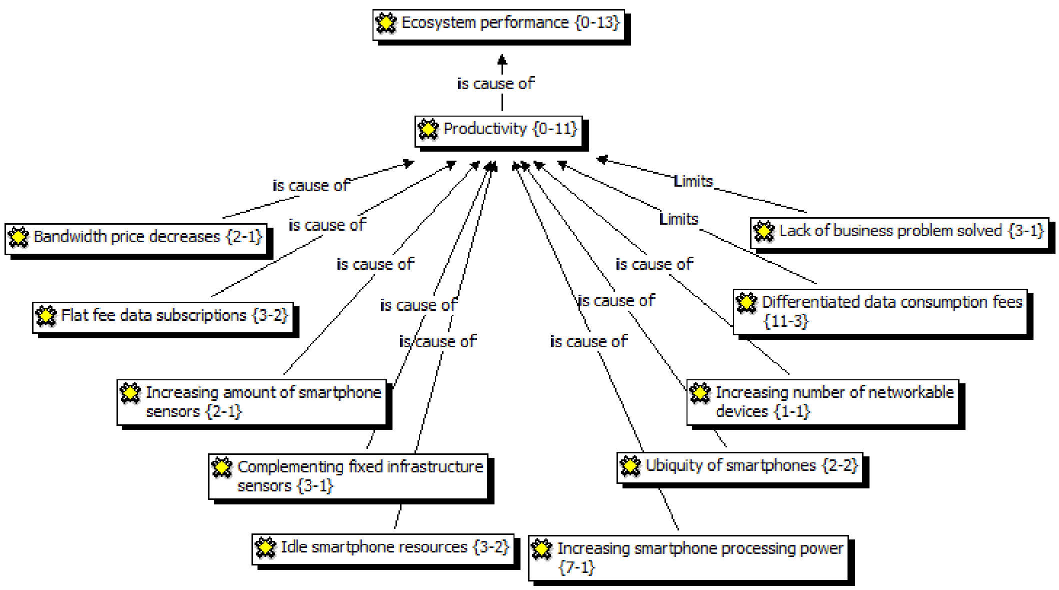

Figure 7 – Productivity success factors and inhibitors

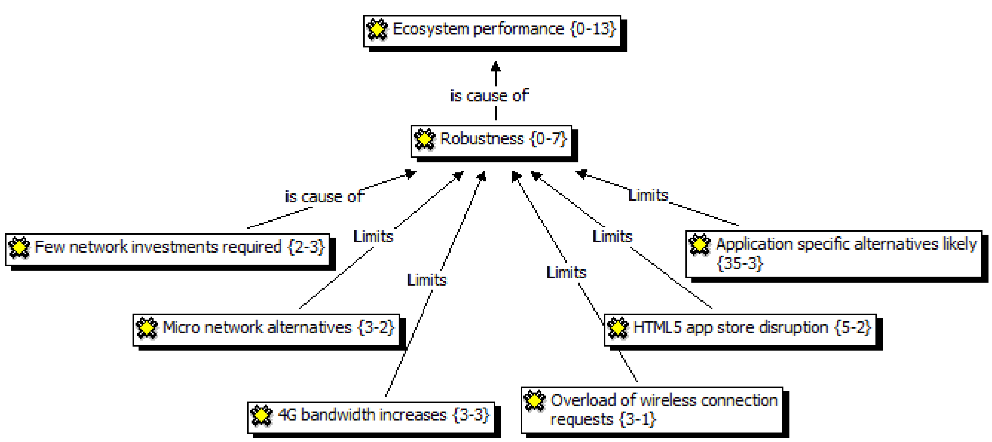

Figure 8 – Robustness success factors and inhibitors

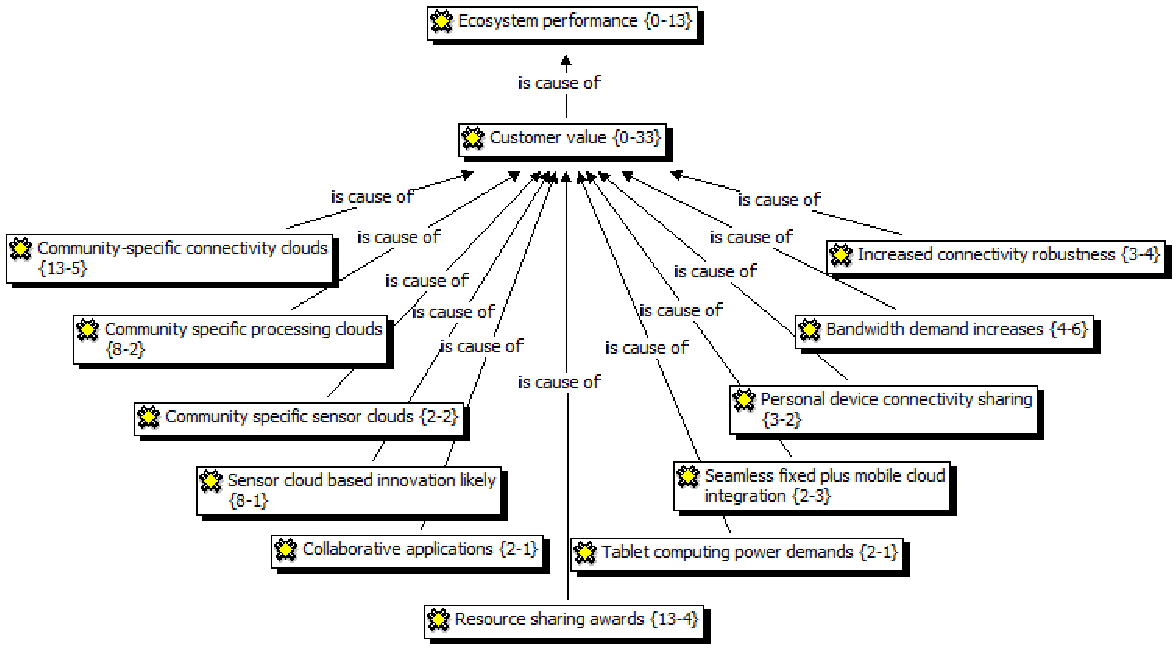

Figure 9 – Customer value success factors

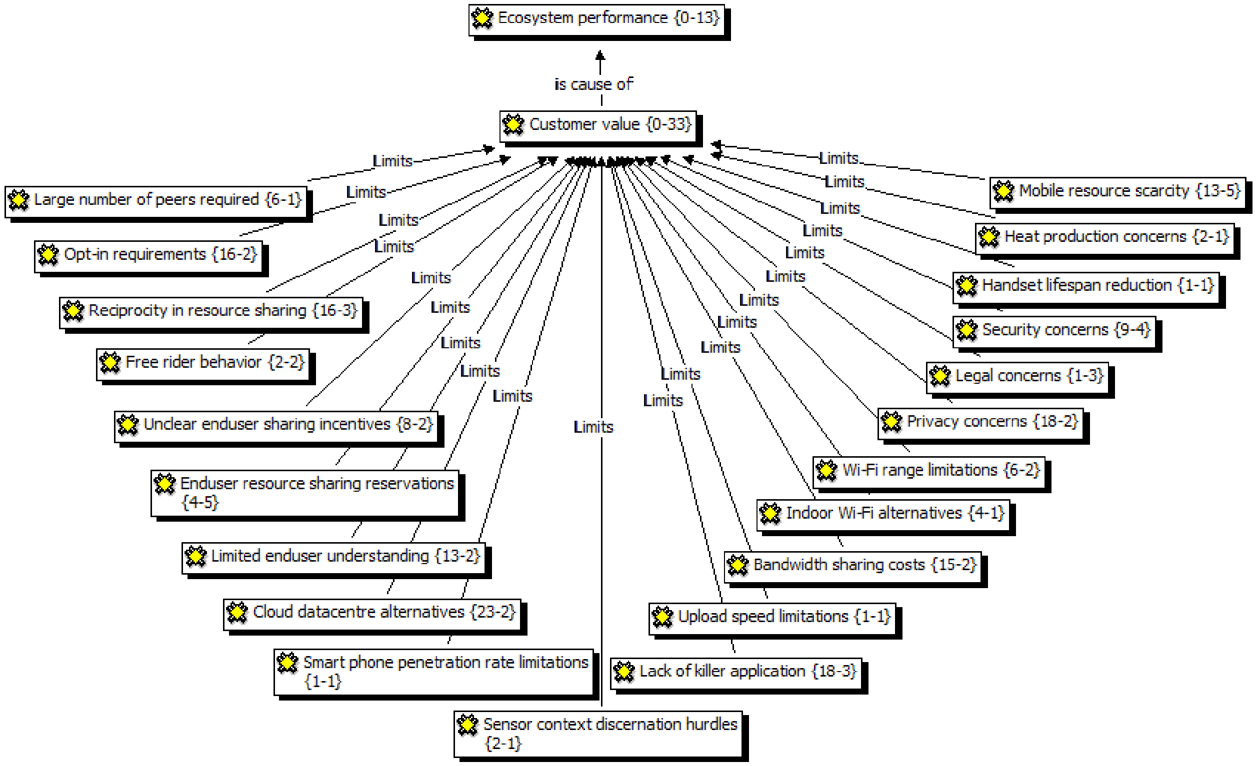

Figure 10 – Customer value inhibitors

B. Appendix: quick scan of mobile cloud definitions and architectures

Table 19 serves as reference material for the interpretations of mobile cloud computing as discussed in chapter 2. The table provides a non-exhaustive overview of mobile cloud research, definitions provided and type of research conducted, empirical or conceptual.

Table 19 – Examples of mobile cloud computing related research

Article	Mobile Cloud Definition	Unit of analysis / Type of analysis	Description
(Chun & Maniatis, 2009)	Not available	• Architecture & use cases • Conceptual	Architecture that addresses application limitations in terms of computation, memory, and energy reserves via seamless partial-off-loading of execution from the smartphone to a computational infrastructure hosting a cloud of smartphone *clones*
(Christensen, 2009)	Combination of smart mobile devices, context enablement using sensors on the device, and Cloud Computing with RESTful web-services	• Architecture • Conceptual	Using the ability of modern mobile to use multiple connection channels at once and the context information delivered by sensors on mobile devices, the RESTful architecture aims to offload processing capabilities, storage, and security to cloud computing via web-services, allowing for applications that exceed the capabilities of traditional mobile devices.
(Elespuru, et al., 2009)	Conceptually similar to existing cloud computing, but where computation and storage resources happen to be mobile devices, or they interoperate between traditional cloud and a new set of mobile cloud resources	• Architecture • Prototype	The MapReduce system contains a coordinating server which receives computation tasks, distributes them to nodes, aggregates results and returns the results. A client for mobile devices receives processes and transmits solutions to subtasks. A browser interface allows the user to submit tasks and view results (Shanklin, 200x)
(Kumar & Lu, 2010)	Not available	• Architecture • Classification of services • Conceptual	Defines several advantages of mobile cloud: -battery life extended by offloading intensive applications; -potential solution for the fragmented mobile OS market; -increased security levels by centralized software monitoring and maintenance; -new tech opportunities through location, context personalization
(Samimi, et al., 2006)	Automatic service configuration for mobile consumers as they move between different 'mobile service clouds' and internet service providers. Nodes form virtual overlay network on top of physical communication networks (handsets, Wi-Fi hotspots, 3G networks)	• Architecture • Prototype	Mobile Service Clouds enable dynamic instantiation, composition, configuration, and reconfiguration of services on an overlay network to support mobile computing
(Shanklin, 2009)	Cloud computing is the trend in which resources are provided to a local client on an on-demand basis, usually by means of the internet. Mobile cloud computing (MCC) is cloud computing in which at least some of the devices involved are mobile.	• Architectures • Conceptual	Distinguishes between general-purpose mobile cloud computing (GPMCC) which alleviates the limitations of mobile devices and application-specific mobile cloud computing (ASMCC) which allows for new mobile use cases through cloud computing.

(Song & Yoon, 2010)	Mobile cloud allows device independency, avoiding hardware failures because of continuous service availability in the Cloud. Cloud allows mobile phones to have larger storage than their own, use augmented reality service and find location by GPS. This differs from the past mobile services which only worked inside the phone in non-interactive ways.	• Architecture • Conceptual	Introduces a 'smart cloud' model which intelligently meets user's needs through collecting user's behaviors, prospecting, building, delivering, and rendering steps. Collects user behavior information via sensors mounted on always-online smartphones. Mobile services are automatically pushed or pulled by continuously reading the information provided by the numerous sensors present in mobile devices.
(Zhang, et al., 2009)	Not available	• Architecture • Conceptual	Aims to build elastic applications which augment resource-constrained platforms, such as mobile phones, with elastic computing resources from clouds. An elastic application consists of one or more *weblets*, each of which can be launched on any mobile or nonmobile device or cloud, and can be migrated between them according to dynamic changes of the computing environment or user preferences on the device.
(Ananthanarayanan & Zats, 2009)	Not available	• Architecture • Prototype	AggreGATE consists of an application programming layer at the mobile device and a network proxy which enables mobile devices to seamlessly and simultaneously use their different connectivity options
(Marinelli, 2009)	Not available	• Architecture • Prototype	Hyrax combines distributed storage and distributed computation uses Google MapReduce distributed programming algorithm to distribute workloads in small pieces across clusters of computers. This allows client applications to use combined networks of smartphones to distribute computing tasks, scaling with the number of devices available
(Niemegeers & Groot, 2002)	Not available	• Architecture • Prototype	Personal Networks consist of connectivity, network and service abstraction layers maintained by a network proxy which enable uninterrupted connection and context aware services to 'simplify the daily life of the user'

C. Appendix: * as a Service examples

Table 20 - *as a Service variations (Slater, 2010)

Abbreviation	Service
AaaS	Authentication as a Service; Application as a Service; Anything as a Service; Architecture as a Service; Analytics as a Service; Aggregation as a Service; Accounting as a Service; Anti Virus as a Service; Auctions as a Service;
BaaS	Business as a Service; Backup as a Service; Banking as a Service; Bandwidth as a Service; Blog as a Service; Business Process Management as a Service;
BBaaS	Black boxes as a Service
BIaaS	Business Intelligence as a Service;
BLaaS	Blog as a Service;
BPaaS	Business Processes as a Service;
CaaS	Computing as a Service; Communication as a Service; Connectivity as a Service; Cells as a Service; Compliance as a Service; Crimeware as a Service; Content as a Service; Capability as a Service
CRMaaS	CRM as a Service
DaaS	Datacentre as a Service; Database as a Service; Desktops as a Service; Data as a Service; Datacentre as a Service
DBaaS	Database as a service;
EaaS	Ethernet as a Service; Everything as a Service; Environments as a Service
ERPaaS	ERP as a Service
FaaS	Firewall as a Service; Frameworks as a Service; Finance as a Service;
GaaS	Grid as a Service; Globalization as a Service; Governance as a Service
HaaS	Hardware as a Service; Humans as a Service
IaaS	Infrastructure as a Service; Identity as a Service; Information as a Service;
ITaaS	Information Technology as a Service
IDaaS	Identity as a Service
JaaS	Java as a Service;
KaaS	Knowledge as a Service
LaaS	Lending as a Service
MaaS	Mashups as a Service;
NaaS	Network as a Service;
OaaS	Organization as a Service; Operation as a Service
PaaS	Platform as a Service; Process as a Service;
PRaaS	Processes as a Service
QaaS	Query as a Service; Quality as a Service;
RaaS	Resources as a Service; Reporting as a Service; Research as a Service; Restore as a Service
SaaS	Software as a Service; Service as a Service; Security as a Service
SEaaS	Service Ecosystems as a Service;
STaaS	Storage as a Service;
TaaS	Testing as a Service; Technology as a Service; Tools as a Service; Trust as a Service
UaaS	Utilities as a Service;
VaaS	Voice as a Service; VMware as a Service; Video as a Service
WaaS	Web as a Service
XaaS	Anything (X) as a Service
ZaaS	Zimbra as a Service

D. Appendix: background document for respondents

Background information on Mobile Cloud Computing

Soebhaash Dihal: sbdihal@gmail.com
SEPAM Master's Thesis Project
Delft University of Technology, Faculty of Technology, Policy and Management
April 2011

Smart phones as a shared resource pool

Cloud computing in the current market is typically enabled by large data centers in which multiple connected servers are virtualized to function as a large and flexible shared resource pool. Existing cloud computing services however ignore the resources which mobile devices can offer. With a quickly rising number of smartphones, there is potential in applying these smartphones as a shared resource pool as well.

Aside from processing power, the smart phone resource pool includes resources unique to mobile devices such as multiple simultaneous connectivity options (3G, Wi-Fi, Bluetooth) and sensors (light sensors, cameras, microphones, GPS, accelerometers, gyroscopes, barometers). With smart phones becoming ever more ubiquitous this provides opportunities for them to perform tasks collaboratively by combining their resources.

During this research we explore the viability of a 'mobile cloud' service platform in which smart phones view their connectivity, processing and sensor resources collectively and use them simultaneously depending on the service requirements. This mobile cloud platform could enable a range of enhanced applications by presenting this pool of mobile resources to developers, service providers and content providers.

The basic mobile cloud platform architecture consists of a server which acts as a central node to coordinate computing, bandwidth and sensors across multiple mobile devices and an application programming layer at the mobile device which allows acquisition, processing and distribution of segments of tasks to and from the coordinating server.

Research objective

Several mobile cloud prototypes are available in research. We aim to complement experimental and conceptual research by acquiring industry standpoints on mobile cloud. The main question to be answered is whether mobile cloud platforms are feasible and viable from an ecosystems perspective: is the platform an attractive matchmaker for platform enablers, end-users and application, service or content providers?

For discussion purposes this document contains the following background information on mobile cloud:

- Discussion points regarding the core service proposition and platform ownership
- Three conceptual use cases which illustrate potential applications based on the mobile cloud platform

Discussion points

Platform attractiveness

The value a mobile cloud platform represents for its customers is currently unidentified. Customers include both supply and demand sides: developers, service providers, content providers and end users.

- End-users might require opt-in due to issues such as battery drain and data subscription requirements.
- Suppliers of end user content might offer comparable services via the current app stores, as seen with wireless hotspot applications or applications which connect smart phones to existing distributed computing networks.

Platform ownership

An open issue is which industry parties would be willing and capable of taking ownership over the mobile cloud platform.

- Platform ownership is usually founded on a set of core assets, e.g. customer relation, billing, application programming interfaces or network infrastructure.
- The core assets for mobile cloud however appear to be distributed amongst handset producers, operators and service providers, e.g. billing and OS integration.

Collaboration structures

For maximal user density and thus resource availability, collaboration between multiple handset providers, operators and/or service providers would be required.

- Alternatively, mobile operating system specific support, operator specific support or service provider specific support (e.g. Facebook) with fragmented user bases could come to exist as well (Figure 33).
- Within possible collaboration structures ownership over the coordinating server and the handset code has to be determined, along with the revenue models for this collaboration.

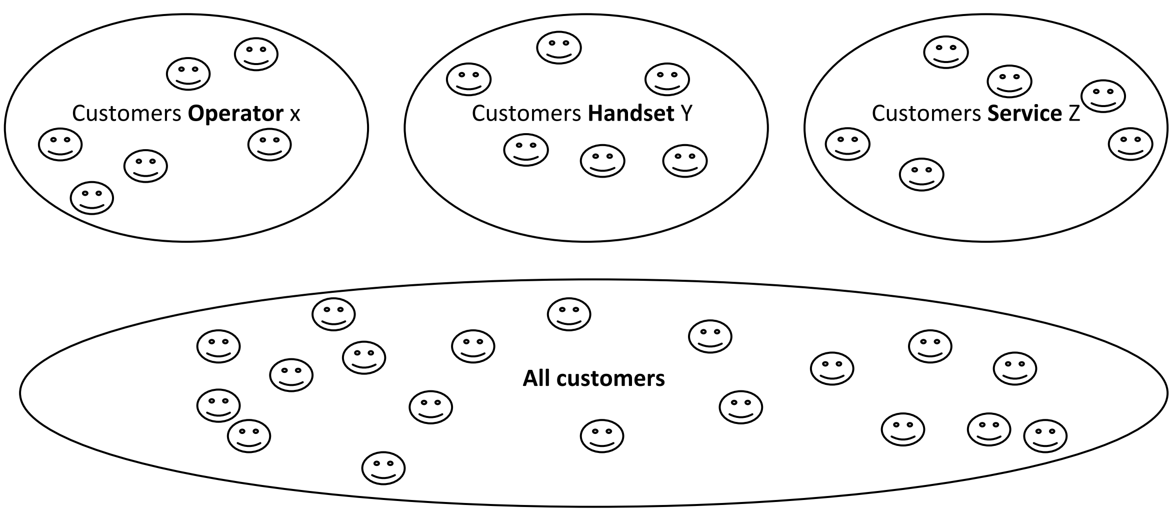

Figure 33 - Mobile cloud density and possible fragmented user bases

Conceptual use cases for Mobile Cloud

Three conceptual use cases demonstrate possible application and service designs for the mobile cloud platform. The use cases are centered around connectivity, sensors and processing. Each use case presents a model in which a central server approaches a group of mobile devices as a virtual whole to augment the experience of an end-user.

Local connectivity clouds: video streaming

In this example the user requests a bandwidth-demanding video stream. The application uses multiple connectivity options of nearby handsets simultaneously to improve throughput. The handset seamlessly migrates from multiple connectivity options to a single 3G connection and vice-versa depending on the number of devices available (Figure 34).

- The user request a High-Definition video stream from his video application;
- The application sends the request to the video provider via the central server;
- The central server identifies nearby handsets which all download a fragment of the video in parallel;
- The user receives the stream via multiple handsets using multiple connection methods, e.g. 3G, Bluetooth and Wi-Fi, depending on availability, utilization, battery levels and interruption tolerance of the application.

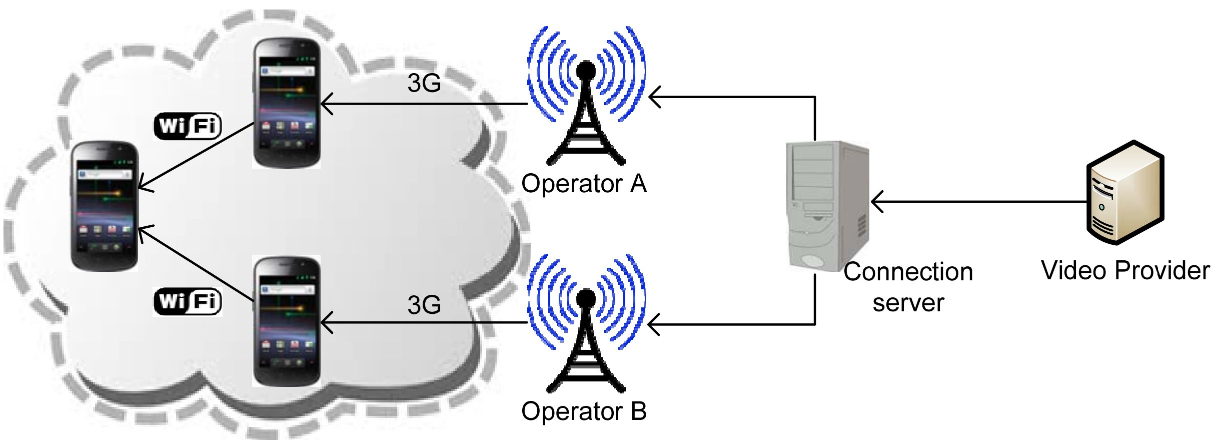

Figure 34 - Parallelized downloads through ad-hoc collaboration with nearby devices

Mobile processing clouds: photo face detection

In this example a computation task which would normally drain the mobile device battery or take a long time to process is outsourced to other mobile devices. The task of matching faces in pictures to known contacts in the address book is segmented, distributed amongst a number of mobile devices and then recompiled by the central server (Figure 35).

- The user requests face detection on a number of pictures from his photo application;
- The application sends the processing request to the central server;
- The central server identifies and segments the computation tasks amongst available handsets;
- The handsets each process their computation segment and send the result back to the central server;
- The central server recompiles the face detection results and returns them to the application.

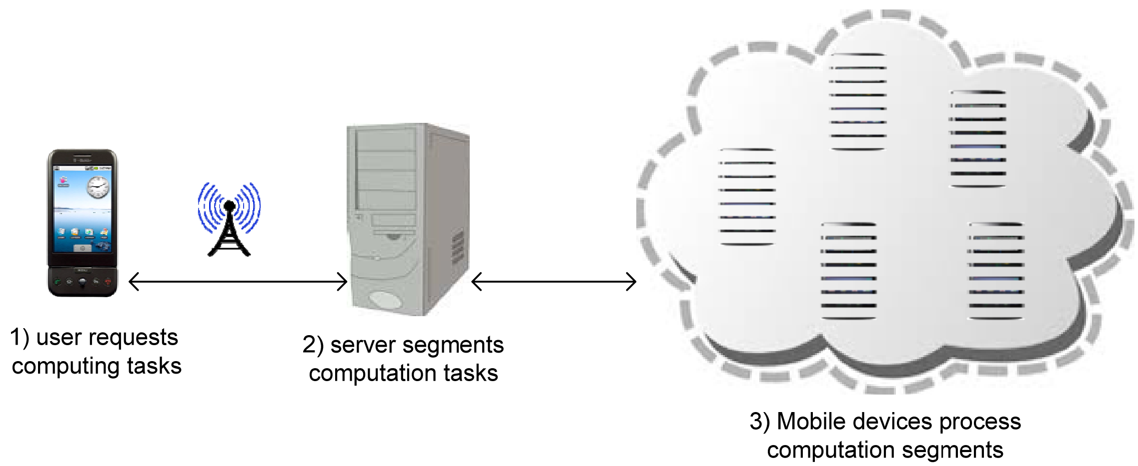

Figure 35 - Offloading segmented computation tasks to other mobile devices

Wireless sensor clouds: traffic detection

In this example the user requests navigation information from his handset, which is augmented using traffic forecasts based on other mobile devices. Using a mixture of GPS, accelerometers, compasses and gyroscopes the service polls the movement speed, direction and location of mobile devices on route to calculate a travel time prediction (Figure 36).

- The user enters a destination;
- The application calculates a route and sends a traffic density request via the central node;
- The central server identifies handsets on the calculated route and provides these to the application;
- The user receives a travel time prediction taking into account the density of traffic on the route.

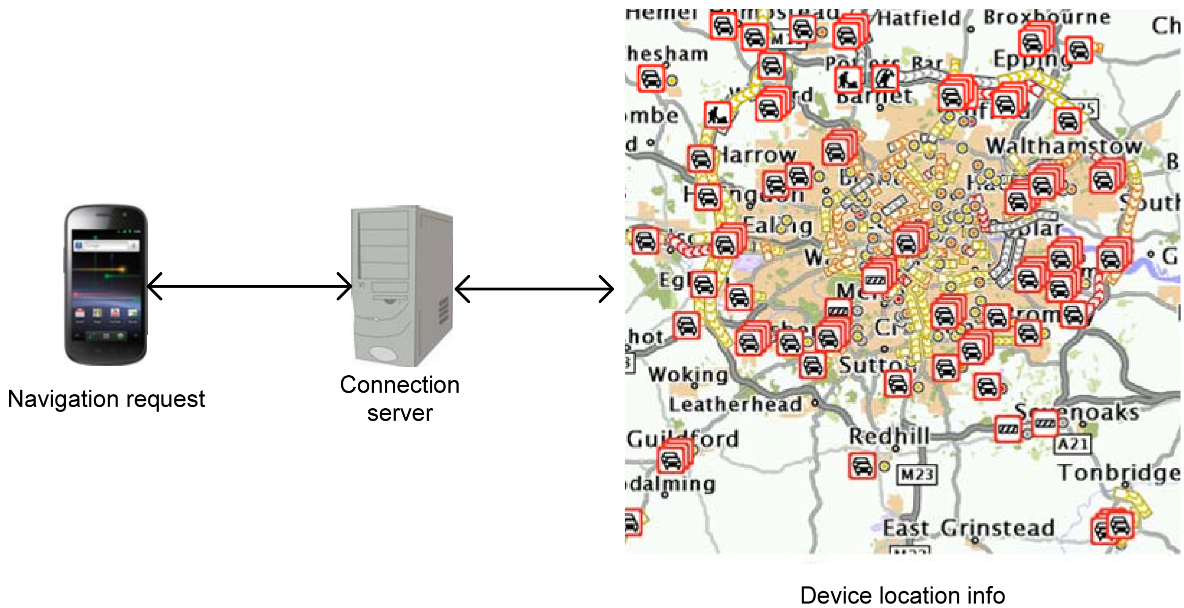

Figure 36 - Polling device sensors for traffic density information and navigation services

E. Appendix: interview protocol

Introduction

1. Introduction:
    1.1. Is audio recording allowed for?
    1.2. Introduction to the background of the respondent
    1.3. Research objective
    1.4. Conversation structure

Questions regarding ecosystem members

2. Which organizations would be 1) capable of and 2) willing to attain ownership of this platform?
    2.1. Operator, Device, Service provider centric?
    2.2. What would be the critical assets to determine platform ownership?
    2.3. Which technological complementors would be required?

Questions regarding ecosystem network structure

3. Which role divisions would be acceptable for the parties enabling the platform service?
    3.1. Which revenue sharing models are likely to be supported between these parties?
    3.2. Would sufficient users be attracted to provide enough smartphones to connect with?

Questions regarding ecosystem performance

4. Is the core service platform proposition attractive enough to attract customers to the platform: end-users, developers, service and content providers?
    4.1. Which type of services or applications would you expect drive demand for this mobile cloud platform?
    4.2. In what ways would end-users be a) attracted and b) retained
    4.3. Which telecom market developments could have an impact on the lifecycle of a mobile cloud platform? (LTE-A, HTML5)

5. Wrap-up

6. Follow-up agreements
    6.1. Is the respondent available for further questions or validation initiatives?
    6.2. May the respondent be mentioned by name in the thesis or article?
    6.3. Does the respondent wish to receive any follow-up material after the interview?

F. Connectivity cloud interview results

F.1 Connectivity cloud members and network success factors

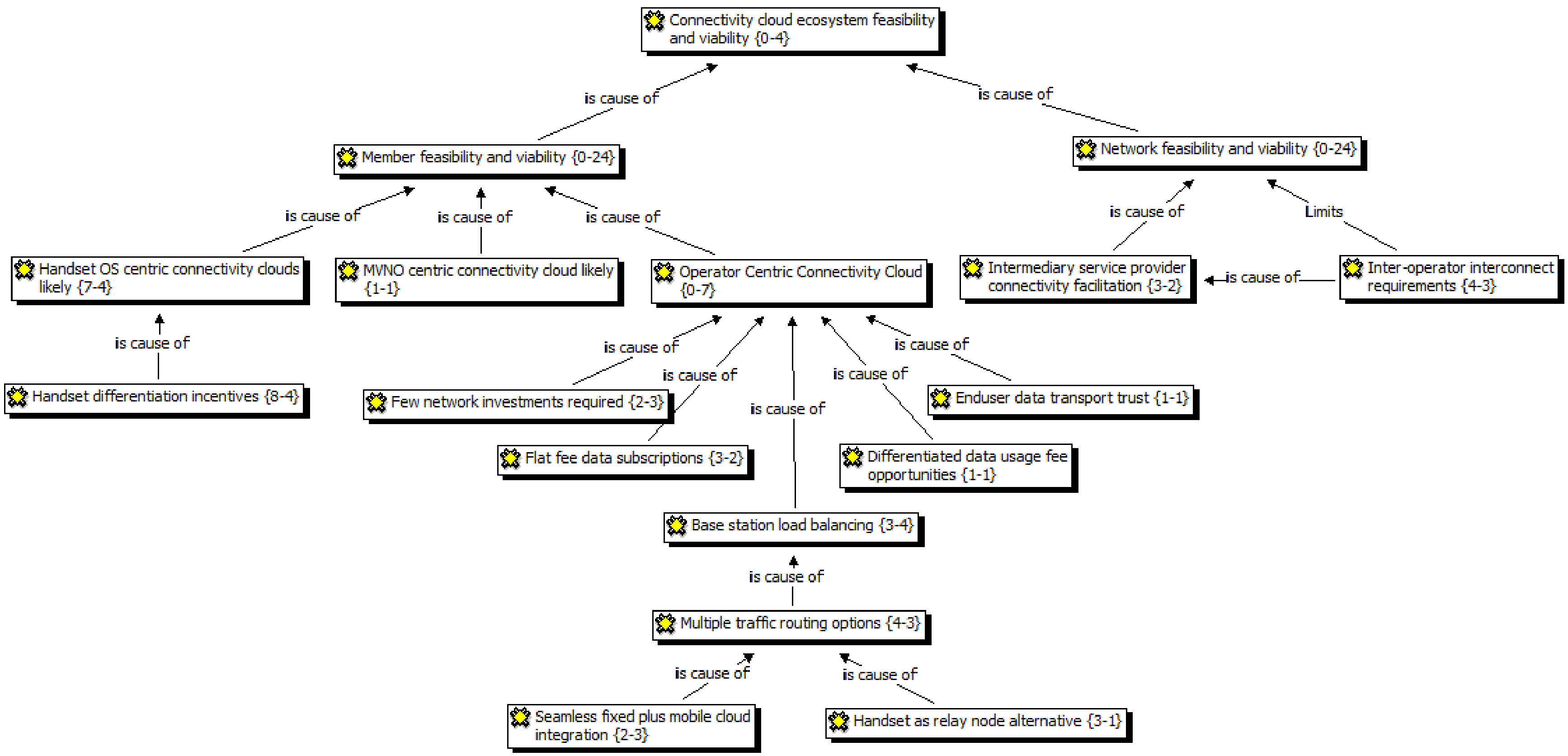

Figure 37 - Connectivity cloud: member and network success factors

F.2 Connectivity cloud members and network inhibitors

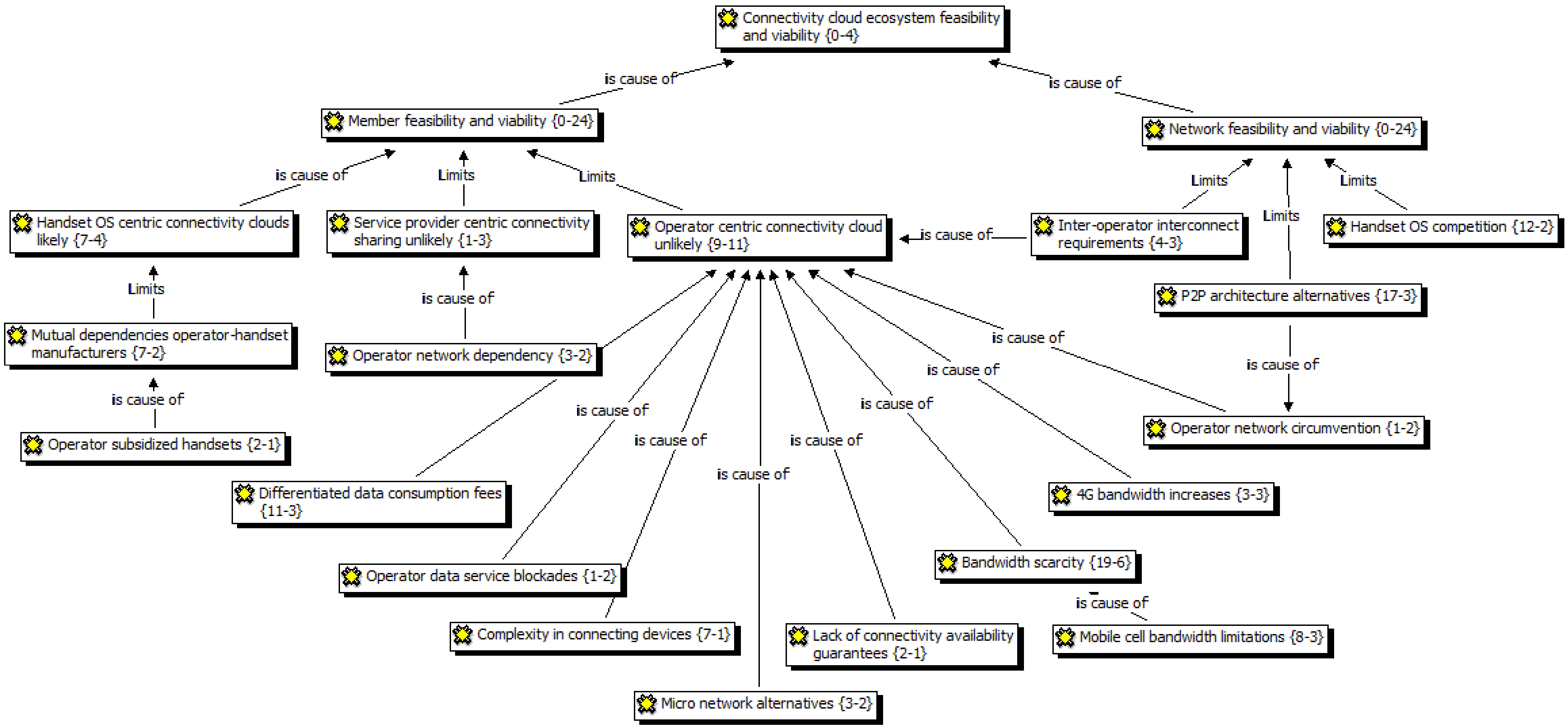

Figure 38 - Connectivity cloud: member and network inhibitors

F.3 Connectivity cloud performance success factors

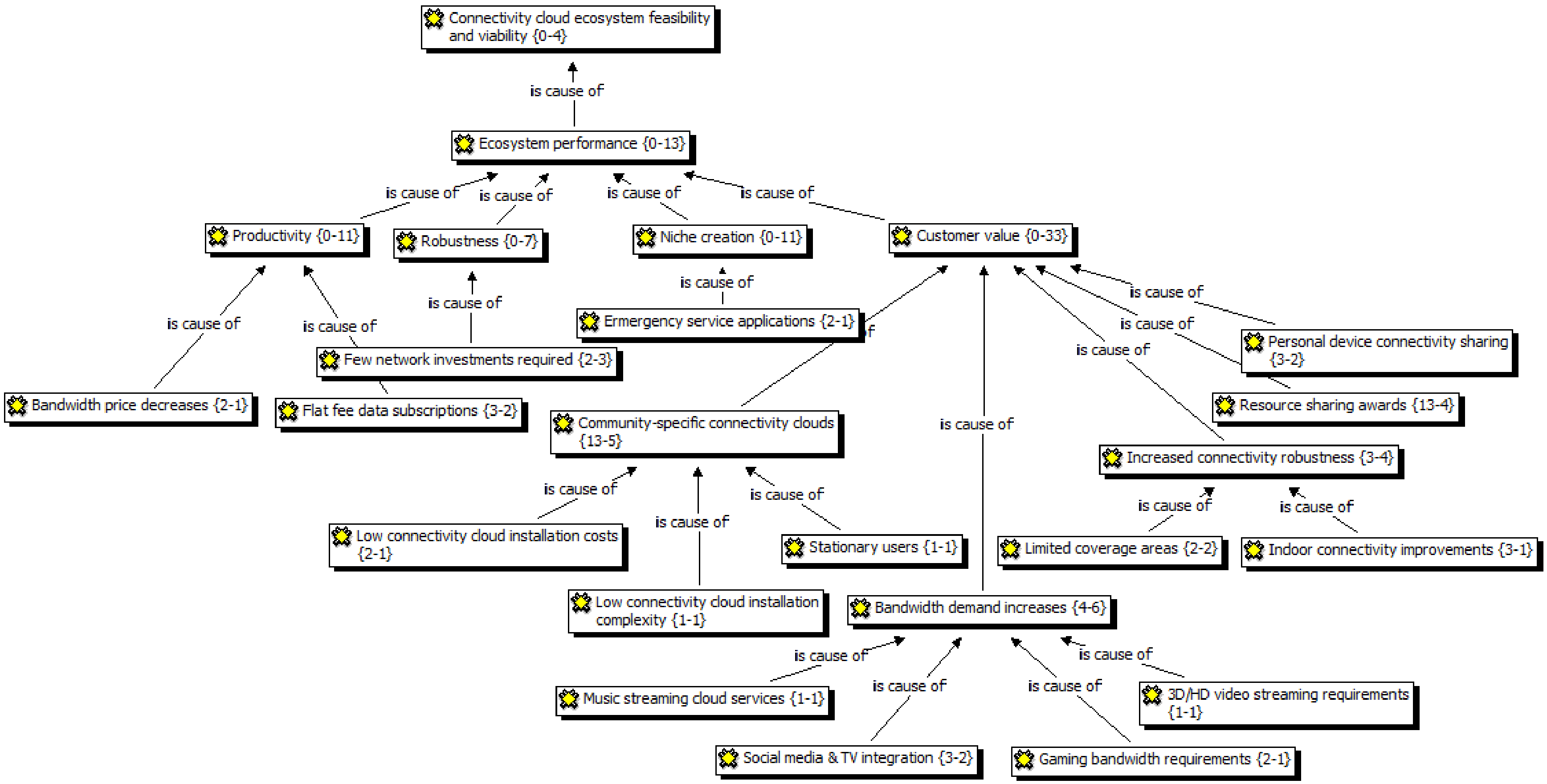

Figure 39 - Connectivity cloud: performance success factors

F.4 Connectivity cloud performance inhibitors

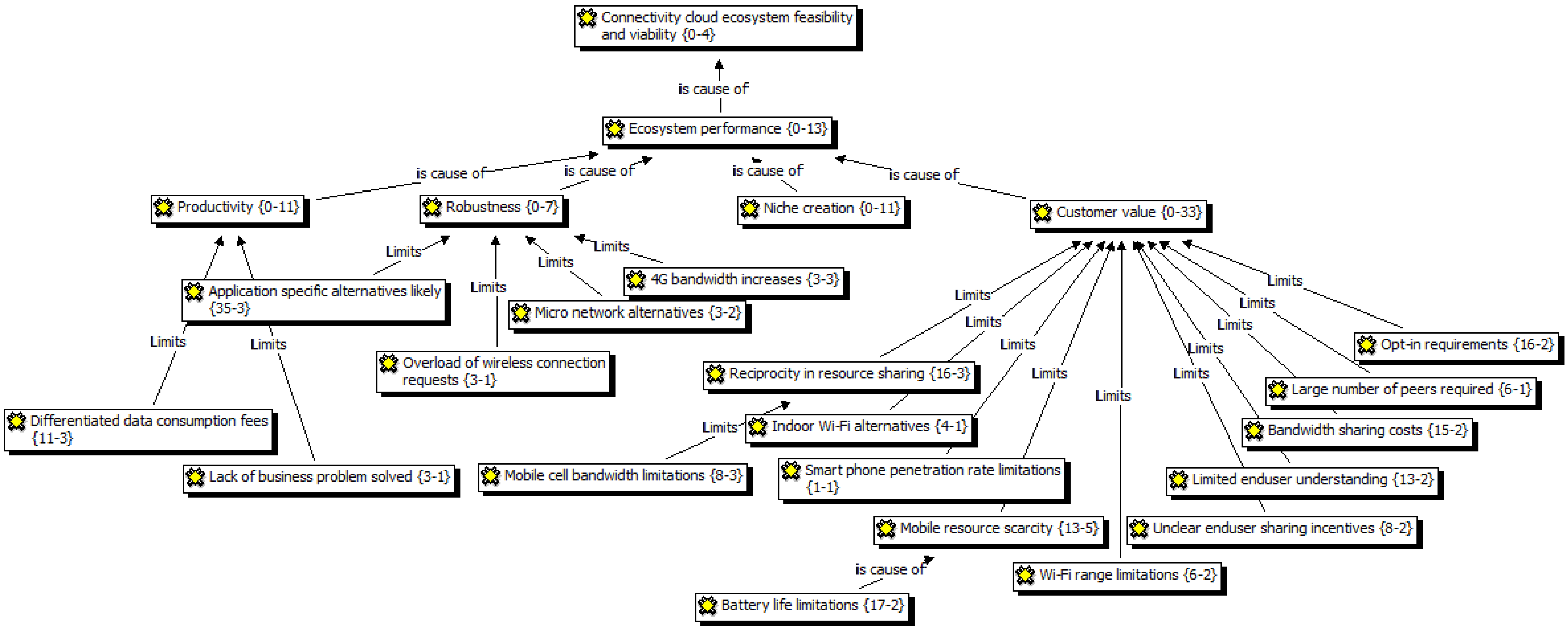

Figure 40 - Connectivity cloud: performance inhibitors

G. Processing cloud interview results

G.1 Processing cloud member, network, performance success factors

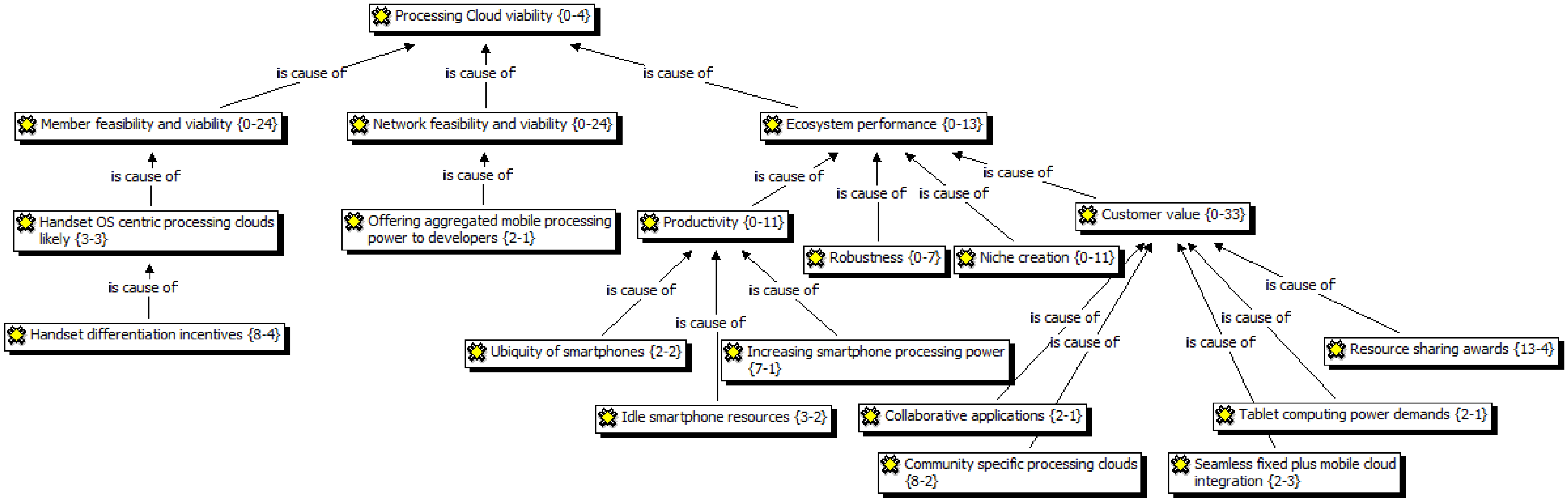

Figure 41 - Processing cloud: member, network, performance success factors

G.2 Processing cloud member and network inhibitors

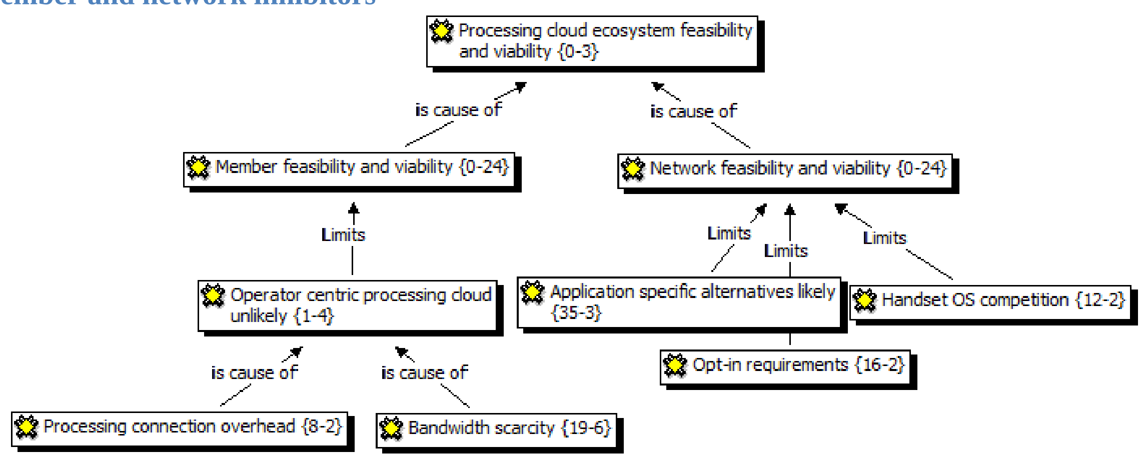

Figure 42 - Processing cloud: member and network inhibitors

G.3 Processing cloud performance inhibitors

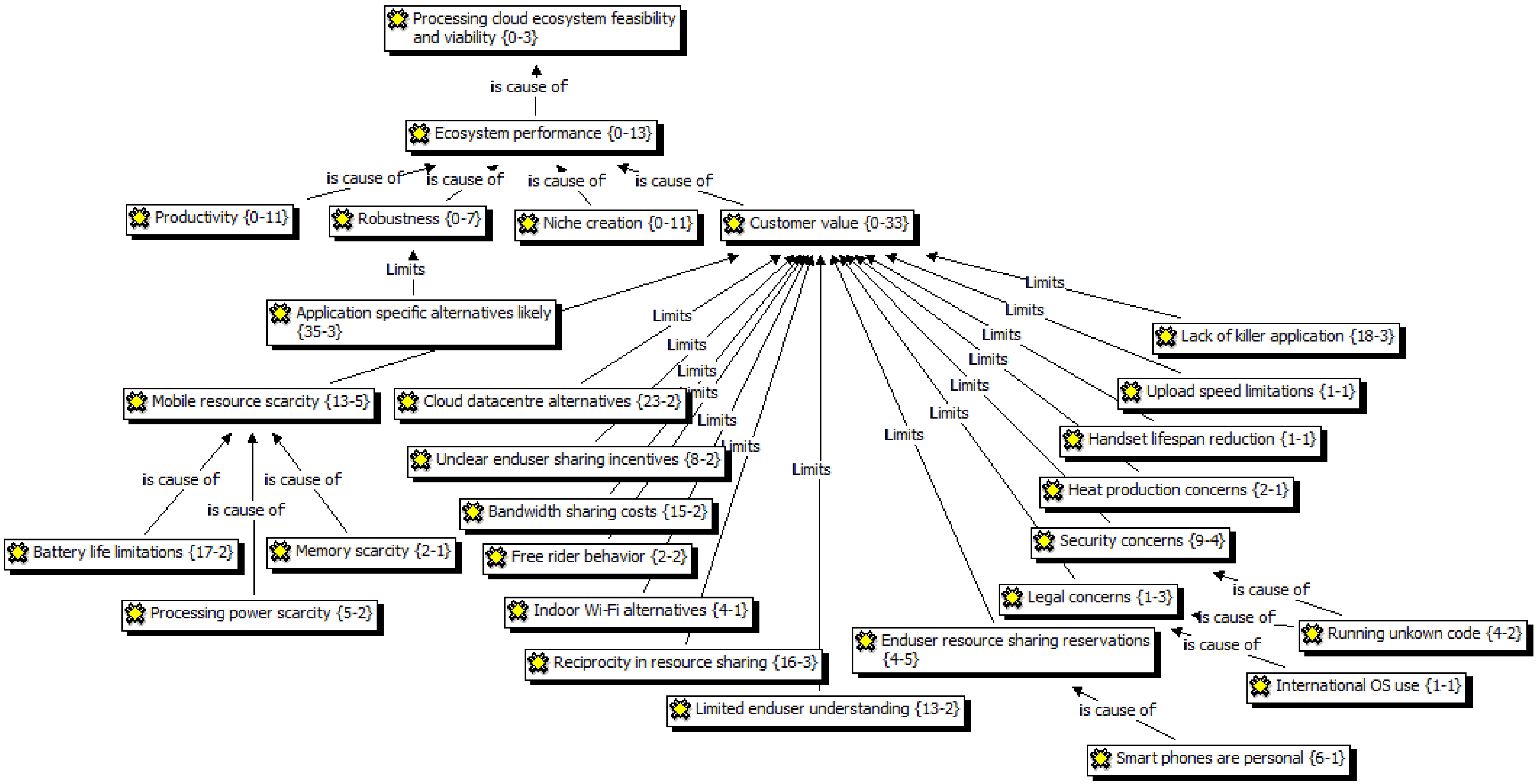

Figure 43 - Processing cloud: performance Inhibitors

H. Sensor cloud interview results

H.1 Sensor cloud member and network success factors

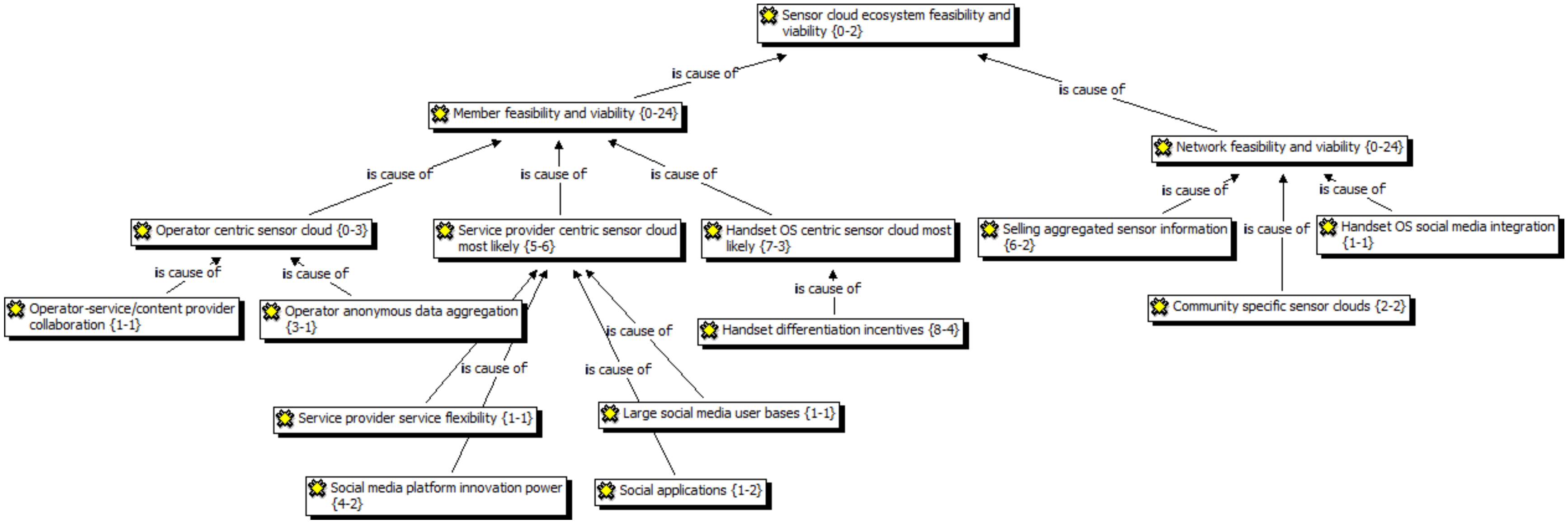

Figure 44 - Sensor cloud: member and network success factors

H.2 Sensor cloud member and network inhibitors

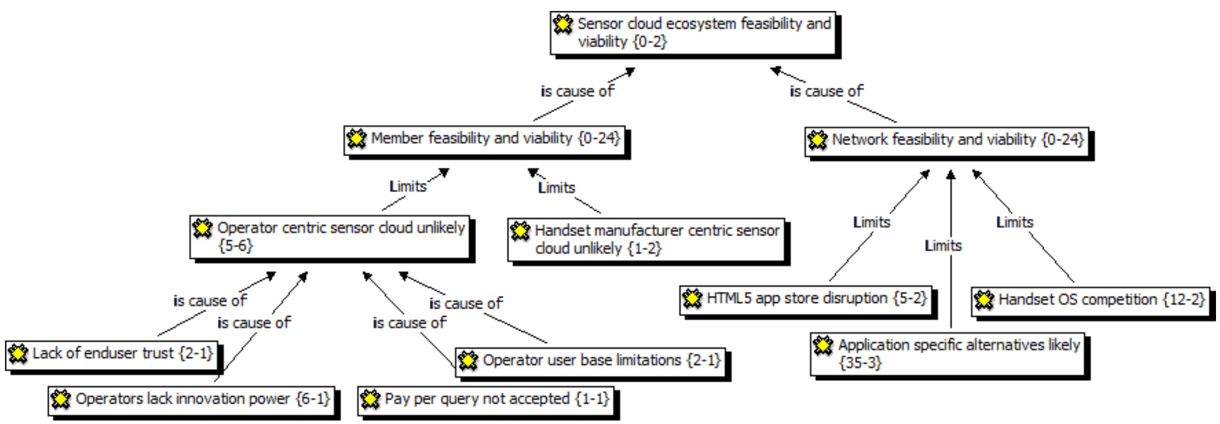

Figure 45 - Sensor cloud: member and network inhibitors

H.3 Sensor cloud performance success factors

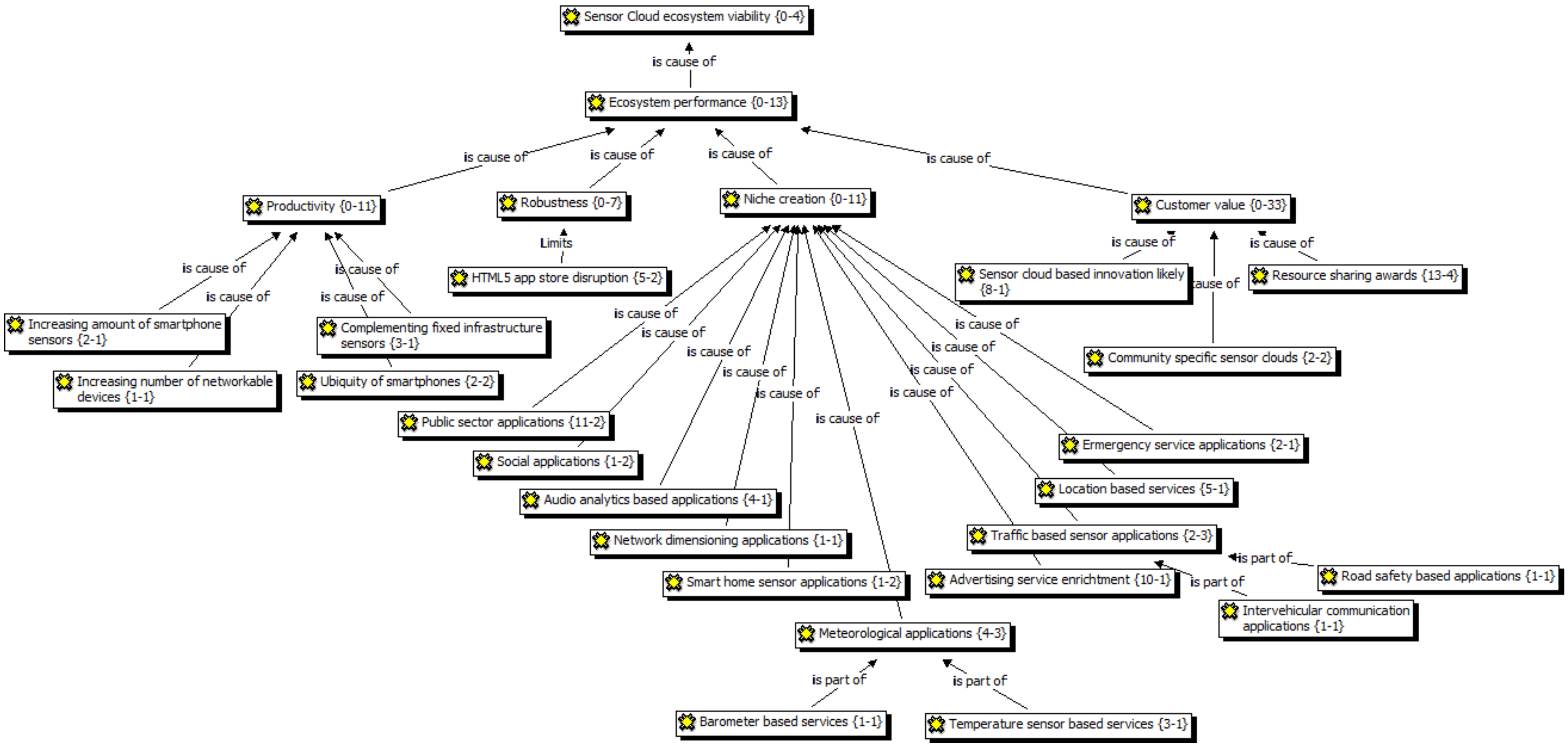

Figure 46 - Sensor cloud: performance success factors

H.4 Sensor cloud performance inhibitors

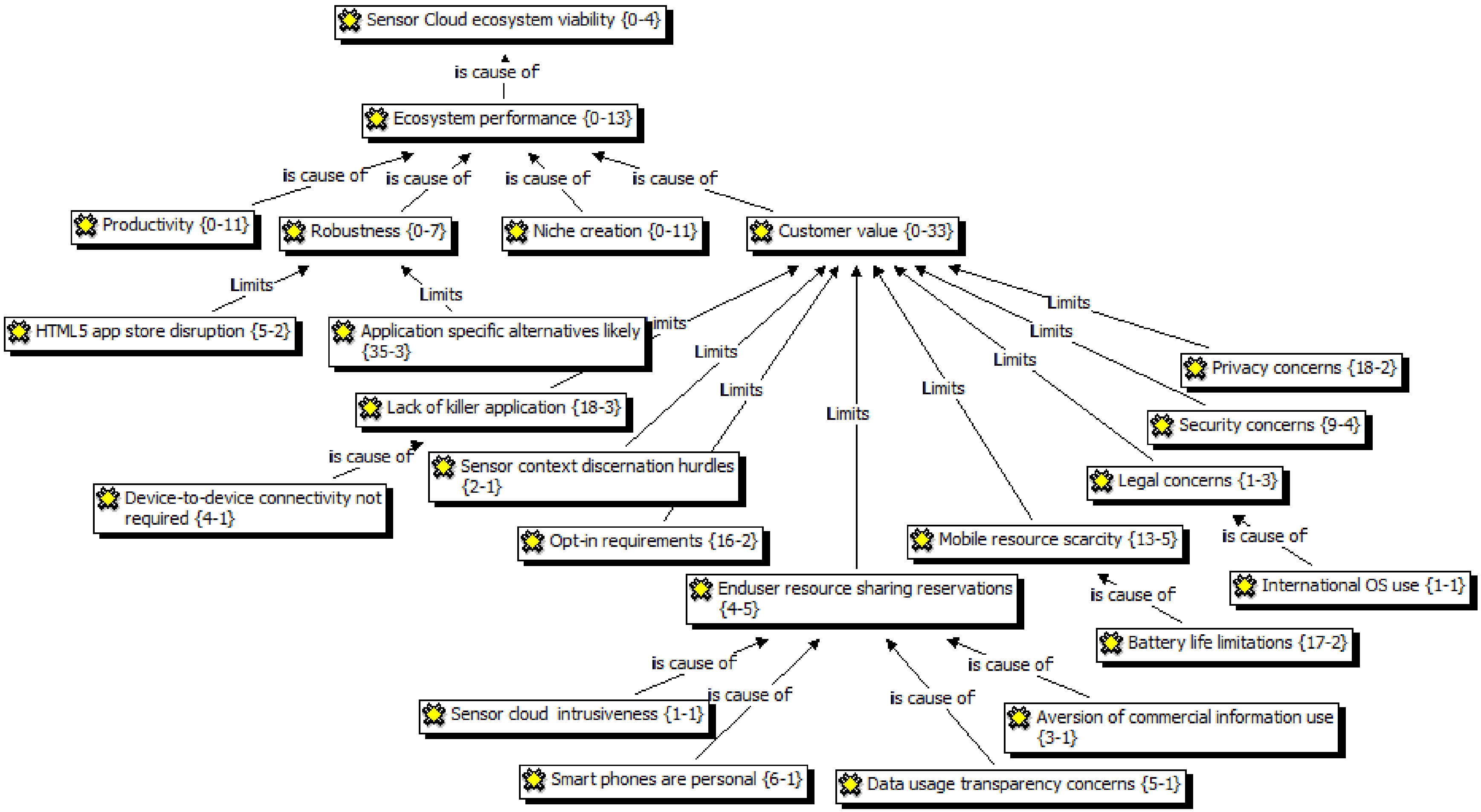

Figure 47 - Sensor cloud: performance inhibitors