Department of Communications and Networking

Techno-Economic Analysis of Mobile Peer-to-Peer Systems and Services

Mikko V. J. Heikkinen

Aalto University

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Techno-Economic Analysis of Mobile Peer-to-Peer Systems and Services

Mikko V. J. Heikkinen

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Abstract

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Abstract

Peer-to-peer (P2P) systems are an integral part of many technology and business domains of the Internet. P2P-based services are disrupting established business models, and they are emerging in the mobile domain. The aim of this thesis is to analyze the effect of emerging mobile P2P-based services and systems in the technology and business domains of the Internet by using a multimethod research design.

The contribution of this thesis consists of the following studies: Applying the scenario planning method to decision making related to emerging mobile services in a case study of a novel P2P communications protocol. Developing a framework to analyze the value distribution of ICT services, and conducting case studies on value flows and role constellations of centralized and distributed communications and video streaming. Assessing value in the technology evolution of mobile P2P communications, which potentially disrupts the positions of incumbents by introducing Internet-driven, telecom-driven, and proprietary evolution paths. Operationalizing the Theory of Planned Behavior conceptual model and finding novel mobile P2P communications and content sharing services to have high adoption potential among respondents with advanced handsets. Surveying consumer attitudes towards different aspects of mobile P2P services, such as usage intention, usage satisfaction, revenue models, battery consumption, and social sharing. Measuring mobile P2P usage in Finland during 2005-2007 by analyzing traffic traces from the networks of three major Finnish mobile operators and by investigating the usage log files from a panel of Finnish advanced handset users.

In conclusion, the research contribution of this thesis consists of applying multiple research methods to case studies on novel distributed mobile services, developing frameworks for the analysis of such services, extending existing theories and methods for such analysis, and reporting results from surveys and usage measurements on relevant topics. The main techno-economic challenges in deploying mobile P2P systems and services are related to business models, resources, incentives, usability, security, and policy. Based on value distribution and usage analyses, one can assert that mobile peer-to-peer systems and services are transforming the technology and business domains of the Internet.

Keywords case study, communications, emerging service, mobile, multimethod, peer-to-peer, scenario, techno-economic, usage, value

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Tiivistelmä

Vertaisverkkojärjestelmät ovat olennainen osa Internetin teknologiaa ja liiketoimintaa. Vertaisverkkopohjaiset palvelut muuttavat vakiintuneita liiketoimintamalleja ja vaikuttavat mobiilien teknologioiden kehitykseen. Tämän väitöksen tavoitteena on analysoida mobiilien vertaisverkkopalveluiden vaikutusta Internetin teknologiaan ja liiketoimintaan Internetissä.

Tämä väitös koostuu seuraavista tutkimuksista: Uuden vertaisverkkopohjaisen viestintäprotokollan tapaustutkimus, jossa skenaarioanalyysi havaittiin sopivaksi päätöksentekomenetelmäksi uusiin mobiilipalveluihin liittyen. Viitekehyksen kehittäminen informaatio- ja kommunikaatiopalveluiden arvon jakautumisen arvioimiseen ja siihen liittyvät tapaustutkimukset keskitetystä ja hajautetusta viestinnästä ja videon suoratoistosta. Arvon kehittymisen arviointi mobiilissa vertaisverkkopohjaisessa viestinnässä, jossa on mahdollisesti avoimien, vakiintuneiden ja sulkeutuneiden toimijoiden hallitsemia kehityspolkuja. Käsitemallin operationalisointi, minkä perusteella mobiileilla vertaisverkkopohjaisilla viestintä- ja sisällönjakopalveluilla havaittiin hyvät menestymismahdollisuudet älypuhelimien käyttäjien keskuudessa. Kuluttajien asenteiden selvitys mobiilivertaisverkkopalveluihin liittyviin seikkoihin, kuten käyttöaikomuksiin, käyttötyytyväisyyteen, ansaintamalleihin, akun kulutukseen ja sosiaaliseen jakamiseen. Mobiilin vertaisverkkokäytön mittaus Suomessa vuosina 2005-2007 sekä kolmen johtavan operaattorin matkaviestintäverkoissa että älypuhelinkäyttäjien paneelitutkimuksella.

Väitöksessä sovelletaan useita tutkimusmenetelmiä tapaustutkimuksiin uusista hajautetuista mobiileista palveluista, kehitetään viitekehyksiä, laajennetaan metodeita ja teorioita, sekä raportoidaan kyselytutkimuksien ja verkkomittauksien tuloksia. Pääasialliset tekno-ekonomiset haasteet mobiilien vertaisverkkopohjaisten palvelujen ja järjestelmien käytössä liittyvät liiketoimintamalleihin, resursseihin, kannustimiin, käytettävyyteen, turvallisuuteen ja menettelytapoihin. Arvon jakautumisen ja käytön analyyseihin perustuen voidaan väittää että mobiilit vertaisverkkopohjaiset palvelut muuttavat Internetin teknologiaa ja liiketoimintaa.

Avainsanat arvo, ilmaantuva palvelu, käyttö, mobiili, monimetodi, skenaario, tapaustutkimus, tekno-ekonominen, vertaisverkko, viestintä

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Preface

Der Weg ist das Ziel. –Confucius

This journey would not have started without my supervisor Prof. Heikki Hämmäinen who continuously supported me and trusted me to reach this point on the way. I am especially grateful to Heikki for giving me the freedom to find my own path and for securing the necessary resources to make this an interesting and rewarding journey.

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I did the work for this thesis while participating in the research projects DECICOM, FICNIA, MoMI, MoMI II and MoMIE during the years 2007–2011. I thank the project members, especially Nicklas Beijar, Heikki Kokkinen, and Timo Smura, for productive collaboration. I am grateful to TEKES and the corporate partners for supporting the projects. I am also grateful to the Emil Aaltonen Foundation, the HPY Foundation, the Marcus Wallenberg Foundation, the Nokia Foundation, the TeliaSonera

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Helsinki, March 18, 2012,

Mikko V. J. Heikkinen

Contents

List of Publications

This thesis consists of an overview and of the following publications which are referred to in the text by their Roman numerals.

I M. V. J. Heikkinen, M. Matuszewski, and H. Hämmäinen. Scenario planning for emerging mobile services decision making: Mobile peer-to-peer session initiation protocol case study. *International Journal of Information and Decision Sciences*, vol. 1, no. 1, pp. 26–43, Aug. 2008.

II M. V. J. Heikkinen, T. Casey, and F. Hecht. Value analysis of centralized and distributed communications and video streaming. *Info*, vol. 12, no. 5, pp. 42–58, Aug. 2010.

III M. V. J. Heikkinen and S. Luukkainen. Value in technology evolution: Case mobile peer-to-peer communications. *Info*, vol. 12, no. 5, pp. 59–78, Aug. 2010.

IV M. V. J. Heikkinen and J. Töyli. Modeling intention to use novel mobile peer-to-peer services. *International Journal of E-Business Research*, vol. 7, no. 1, pp. 23–38, Jan. 2011.

V M. V. J. Heikkinen and J. K. Nurminen. Consumer attitudes towards different aspects of mobile peer-to-peer services. In *Proceedings of the First International Conference on Advances in P2P Systems*, pp. 132–137, Oct. 2009.

VI M. V. J. Heikkinen, A. Kivi, and H. Verkasalo. Measuring mobile peer-to-peer usage: Case Finland 2007. In *Passive and Active Network Measurement*, ser. Lecture Notes in Computer Science. Springer-Verlag Berlin Heidelberg, vol. 5448, pp. 165–174, Apr. 2009.

Author's Contribution

Publication I: "Scenario planning for emerging mobile services decision making: Mobile peer-to-peer session initiation protocol case study"

Heikkinen was the head author of the publication and wrote the bulk of it. Heikkinen designed and executed the group interview sessions and the questionnaire study. Heikkinen, Matuszewski, and Hämmäinen did the analysis. Matuszewski and Hämmäinen reviewed and edited the publication.

Publication II: "Value analysis of centralized and distributed communications and video streaming"

Heikkinen was the head author of the publication and wrote the bulk of it. Heikkinen and Casey constructed the analysis framework and did the analysis. Casey reviewed and edited the publication. Hecht assisted in the analysis of video streaming services and reviewed the publication.

Publication III: "Value in technology evolution: Case mobile peer-to-peer communications"

Heikkinen was the head author of the publication and wrote the bulk of it. Heikkinen and Luukkainen constructed the analysis framework and did the analysis. Heikkinen designed and executed the questionnaire study and did the statistical analysis; Luukkainen reviewed them. Luukkainen reviewed and edited the publication.

Publication IV: "Modeling intention to use novel mobile peer-to-peer services"

Heikkinen was the head author of the publication and wrote the bulk of it. Heikkinen designed the questionnaire study and did the statistical analysis; Töyli reviewed them. Töyli reviewed and edited the publication.

Publication V: "Consumer attitudes towards different aspects of mobile peer-to-peer services"

Heikkinen was the head author of the publication and wrote the bulk of it. Heikkinen designed the questionnaire study and did the statistical analysis; Nurminen reviewed them. Nurminen reviewed and edited the publication.

Publication VI: "Measuring mobile peer-to-peer usage: Case Finland 2007"

Heikkinen was the head author of the publication. Heikkinen did the literature study and decided on the traffic and application identification criteria, and wrote the corresponding sections of the publication. Kivi did the traffic trace measurements and wrote the corresponding sections of the publication. Verkasalo did the handset monitoring measurements and wrote the corresponding sections of the publication. Heikkinen, Kivi, and Verkasalo reviewed and edited the publication.

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List of Abbreviations

AoR	Address of Record
AS	Application Server
CDN	Content Distribution Network
CPU	Central Processing Unit
DHT	Distributed Hash Table
DRM	Digital Rights Management
EU	European Union
FTP	File Transfer Protocol
GSM	Global System for Mobile Communications
HTTP	Hypertext Transfer Protocol
ICN	Information-Centric Networking
ICT	Information and Communications Technology
IETF	Internet Engineering Task Force
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IS	Information System
ISP	Internet Service Provider
IT	Information Technology
LTE	Long Term Evolution
MANET	Mobile Ad-hoc Network
MP2P	Mobile Peer-to-Peer
NAT	Network Address Translation
NGN	Next Generation Network
P2P	Peer-to-Peer
P2P-IMS	Peer-to-Peer IP Multimedia Subsystem
P2PSIP	Peer-to-Peer Session Initiation Protocol
PSTN	Public Switched Telephone Network
RELOAD	REsource LOcation And Discovery

RTP	Real-time Transport Protocol
SIP	Session Initiation Protocol
SMS	Short Message Service
TAM	Technology Acceptance Model
TCP	Transmission Control Protocol
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
US	United States
USB	Universal Serial Bus
VoIP	Voice over IP
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
XMPP	Extensible Messaging and Presence Protocol

1. Introduction

Peer-to-peer (P2P) systems are an integral part of many technology and business domains on the Internet. P2P-based file-sharing applications generate a significant portion of the traffic on the Internet [Cis11] by enabling rapid transport of vast amounts of data. P2P-based communications services have enabled ubiquitous international voice calls over the Internet. Concurrently, P2P-based services are disrupting established business models. The media industry claims it has lost a significant portion of its revenue due to digital sharing of movies and music on P2P-based file-sharing networks [Env11, IFP11], although these claims are criticized [CM11, Kar11]. Telecommunications operators are losing revenue due to the proliferation of P2P-based communications services where calling and messaging across the globe can be free of charge. Currently, P2P-based services are emerging in the mobile domain: they are being introduced to mobile devices with access to the Internet. Motivated by these phenomena, the aim of this thesis is to analyze the effect of emerging mobile peer-to-peer services and systems in the technology and business domains on the Internet.

The groundwork for current P2P systems started during the 1960s, when the predecessor of the Internet, the ARPANET, was being designed. The aim of the ARPANET was to guarantee connectivity even in the event of failures across the network. One of the design principles was host-to-host connectivity [Cro69], which can be seen as a precursor for peer-to-peer connectivity. Decentralization of control functions was a core design principle also in some of the services in the ARPANET, such as USENET [Hor83]. P2P-based service designs emerged into the mainstream in the beginning of the 21st century along with the rise of the Internet.

On a broader societal level, the notion of egalitarian sharing of resources has emerged in other domains. Commons-based peer production of in-

formation [Ben02], the creative commons licensing model,[1] and the free software movement [Sta85] are examples of processes, legal frameworks, and social movements, respectively, where individuals on a peer-to-peer manner commit a part of their resources[2] for a common good, disrupting the incumbent notion of authoritarian and centralized business and social structures.

Applying economic theory to engineering problems is challenging due to different goals and mindsets of economists and engineers [Bau08, Chapter 7]. Nevertheless, techno-economic methods emerged to study the economic impact of novel technologies and services realized with them. In the telecommunications domain, quantitative methods such as calculating the sensitivity of the net present value of various deployment scenarios of technologies,[3] and real options,[4] have been used in techno-economic analyses.

In this thesis, the term "techno-economic analysis" is used more broadly to encompass both qualitative and quantitative methods to analyze and to evaluate emerging technologies, and the applications and services based on them, from the viewpoints of various stakeholders, including developers, deployers, and users of a new technology. Related terms to techno-economics are "socio-economics" [HNF+09] which emphasizes societal aspects in techno-economic analysis, and "business ecosystems" [NND+07] which applies biological principles of ecosystems to techno-economic analysis.

1.1 Objectives and Scope

The aim of this thesis is to analyze the mobile P2P phenomenon by using multiple research methods to investigate distinct areas of interest within the phenomenon (*i.e.*, the technology and business domains of the Internet).[5]

The overall research question of this thesis is:

Q0: How can one analyze and characterize the effect of emerging mobile peer-to-peer systems and services on the technology and business domains

[1] `http://creativecommons.org/`

[2] *e.g.*, a part their effort, time and wealth

[3] See for example [Ims98, OKV+06, RVK+09, HKH+09, Smu12]

[4] See for example [AN00, dFV02, BF03, Rii09]

[5] Policy and regulatory issues related to the mobile P2P phenomenon are out of scope for this thesis.

of the Internet?

Hence, the title of this thesis is: Techno-Economic Analysis of Mobile Peer-to-Peer Systems and Services.

The keywords in the title are defined as follows:[6]

Techno-economic analysis is analysis of systems created by engineers, taking into account economic arguments.

Peer-to-peer system is a system which does not rely on any centralized system infrastructure, *i.e.*, a peer-to-peer system has no or little centralized infrastructure (*e.g.*, servers).

Peer-to-peer service is a beneficial set of processes enabled by a peer-to-peer system (*e.g.*, communications and content distribution) accessible by users having a suitable application, device, and data network connection.

Mobile systems and services are accessible with a portable device and a mobile data network connection not bound to a certain location (for example, with a handset and a cellular connection to the Internet).

This thesis consists of six publications. Each publication has its own theoretical foundation and corresponding research contribution.[7]

The publications are based on the following research questions:

Q1: What are the most relevant scenarios related to mobile Peer-to-Peer Session Initiation Protocol communications usage in a hypothetical Western European country during 2008–2012?

Q2: How can value distribution be analyzed in *service configuration* scenarios?

Q3: How can value distribution be analyzed in *technology evolution* scenarios?

Q4: What is the adoption potential of mobile peer-to-peer communications and content sharing services among Finnish users of advanced handsets?

Q5: What are the attitudes towards different aspects of mobile peer-to-peer services among Finnish users of advanced handsets?

Q6: What was the level of usage of peer-to-peer applications in Finnish mobile networks during 2005–2007?

[6] At the time of writing, in March 2011, no consensus was over these definitions in the literature. Therefore, the author took the liberty of developing his own definitions.

[7] See Chapters 2 and 4, respectively

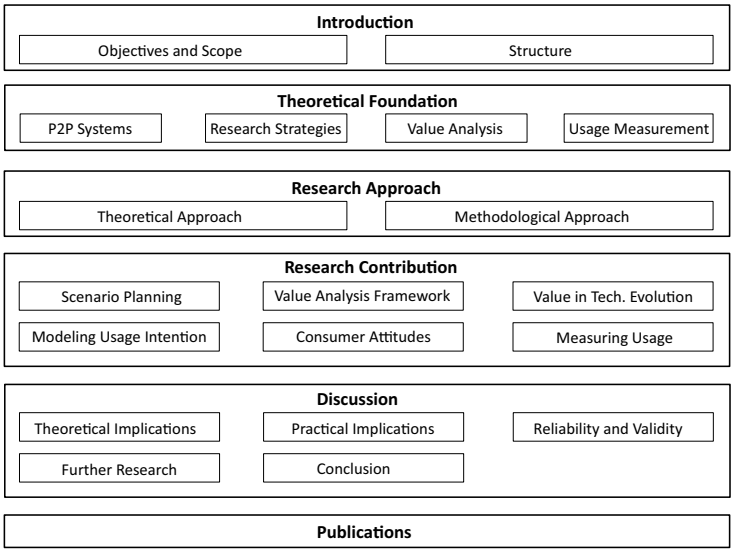


Figure 1.1. Structure of this thesis

1.2 Structure

This thesis consists of this overview and six publications. Figure 1.1 outlines the structure of this thesis.

2. Theoretical Foundation

This chapter presents the theoretical foundation for the publications included in this thesis. First, peer-to-peer systems (Section 2.1) are discussed. Next, two general research strategies, the case study (Section 2.2.1) and the scenario planning (Section 2.2.2) are presented. Then, several research methods for value analysis (Section 2.3) and for usage measurement (Section 2.4) are introduced.

2.1 Peer-to-Peer Systems

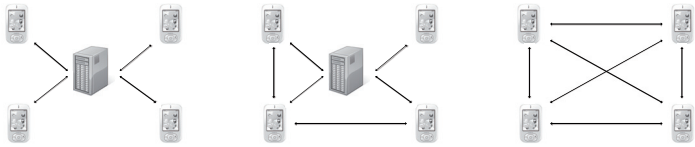
Peer-to-peer systems can be considered to be overlay networks "on top" of the Internet network infrastructure [CLB+06]. Steinmetz and Wehrle [SW05, p. 10] defined a peer-to-peer (P2P) system as

> "a system with completely decentralized self-organization and resource usage."

Decentralized resource usage consists of distributing resources[1] to peers located at the edges of the network,[2] sharing resources among peers, interconnecting peers, and accessing data based on content instead of location; decentralized self-organization consists of cooperative peer interaction without centralized control or coordination, direct access to and exchange of shared resources by peers, combining both client and server functionality into peers, equality and symmetric functionality of peers, and decentralized resource location [SW05].

Androutsellis-Theotokis and Spinellis [TS04] noted the lack of a common definition for P2P systems. They assumed its absence is due to the ambiguous classification of systems based on their external characteris-

[1] *e.g.*, data transfer, storage and processing capacity
[2] thus following the end-to-end argument for network design [SRC84]



(a) Client-server (b) Hybrid (c) Peer-to-peer

Figure 2.1. Application and service architectures

tics instead of their internal architecture. They proposed the following definition for peer-to-peer systems [TS04, p. 337]:

> "Peer-to-peer systems are distributed systems consisting of interconnected nodes able to self-organize into network topologies with the purpose of sharing resources such as content, CPU cycles, storage and bandwidth, capable of adapting to failures and accommodating transient populations of nodes while maintaining acceptable connectivity and performance, without requiring the intermediation or support of a global centralized server or authority."

In practice, many systems, which can be considered to be P2P systems, exhibit only partial decentralization, self-organization, and resource usage. They are often called hybrid or semi-centralized P2P systems, where some centralized components handle tasks related to, for example, maintaining the security and performance of the system.

To summarize the differences between the basic application and service architectures: **Client-server systems** (Figure 2.1(a)) consist of several clients running an application accessing a server or a group of servers to gain access to resources and services. **Hybrid (or semi-centralized) peer-to-peer systems** (Figure 2.1(b)) consist of nodes running an application relying on a peer-to-peer architecture for some functions (*e.g.*, resource sharing) but maintaining a client-server architecture for other functions (*e.g.*, authentication, accounting, and authorization). **Peer-to-peer systems** (Figure 2.1(c)) consist of peers each running an application realizing services to each other and sharing resources among each other.

Peer-to-peer systems can be further classified into structured and unstructured P2P systems [SW05]: **Unstructured P2P systems** rely on centralized elements or flooding[3] to locate a certain resource. Neither approach scales well: a centralized element acts as a single point of failure,

[3] *i.e.*, a peer seeking a resource sends queries to all peers it is aware of

whereas flooding wastes network resources. **Structured P2P systems** rely on algorithms to access resources based on their content or properties, not their location. Several distributed hash table (DHT) structures have been developed to realize those algorithms.[4]

Structured P2P networks are related to content distribution networks (CDNs) [KWZ01, PB07] and information-centric networking (ICN) [ADI+11]. Both CDNs and ICN use DHT structures in their internal organization. A CDN can be considered to be an internally partially P2P-based content distribution service.[5] ICN integrates both CDN and P2P principles into a new resource addressing and locating paradigm. Occasionally P2P networks are confused with "cloud" systems, which are actually a variation of the client-server paradigm and have their roots in grid systems.[6]

2.1.1 Mobile Peer-to-Peer Systems

Deploying P2P systems in mobile networks is challenging. Mobile networks are usually more constrained in terms of resources than fixed networks: mobile networks often have lower data rates and are less reliable than fixed networks. Mobile devices (*e.g.*, handsets and tablets) have less processing power and storage capacity than desktop and laptop computers. Mobile devices often rely on limited battery power, necessitating the optimization of energy consumption of applications and services running on them. Also, mobile P2P systems are commonly characterized by high churn, *i.e.*, nodes joining and leaving the system frequently, due to the transient nature of mobile usage. The high churn rate inflates the free-rider problem, *i.e.*, it increases the number of nodes which do not contribute sufficient resources to the P2P system they are using. Thus, incen-

[4] See for example [TS04, LCP+05, RM06] for reviews of both structured and unstructured P2P overlay networks.

[5] CDNs can also be integrated with P2P networks to form a hybrid CDN-P2P system [XKRC06].

[6] Both the cloud and the grid are utility computing models consisting of dynamic populations of servers, which share the computing workload among each other, and which authorized clients can access. However, the cloud usually serves a higher number of clients and computes smaller tasks than the grid. Also, the grid is commonly only deployed to take care of intensive computing tasks, such as weather forecast modeling, whereas the cloud can act on several levels of abstraction: infrastructure-as-a-service (IaaS), platform-as-a-service (PaaS), and software-as-a-service (SaaS). [http://arstechnica.com/business/news/2009/11/the-cloud-a-short-introduction.ars] and [YBDS08]

tive mechanisms leading to fair resource allocation are often required.[7] In conclusion, mobile P2P systems need to be optimized for the resource constraints of the mobile environments. [KSW05, FXR09]

Mobile P2P (MP2P) systems can be divided into global interconnected systems and local *ad-hoc* systems. Often mobile nodes accessing a global MP2P system are using a cellular link (*e.g.*, GSM[8], UMTS[9], WiMAX[10], or LTE[11]). Such nodes have a fairly stable link to the MP2P system, but both the node and the link are constrained in resources. Therefore, mobile nodes are sometimes assigned a less demanding role than fixed nodes: mobile nodes act more like clients than peers in the system; *i.e.*, mobile nodes access more resources than they share. Local mobile *ad-hoc* networks (MANETs) consist only of mobile nodes, thus distributing the most resource-demanding tasks to fixed nodes is not possible. MANETs can act as the link layer for MP2P systems: the proximity-based optimizations minimizing signaling in MANETs can be relayed to an overlaying P2P system, which can be formed either as a structured or as an unstructured P2P overlay. [SGF02, KSW05, OSM+09]

Most current P2P applications for mobile devices are clients to P2P systems relying on fixed peers, although some applications realizing full peer capabilities do exist. Most of the applications can be roughly divided into communications and content distribution domains. The following Subsections present some applications and services from both domains.[12]

2.1.2 Communications

The Session Initiation Protocol (SIP) [RSC+02] is the *de-facto* signaling protocol for session management in Next Generation Networks (NGNs), or in "all-IP" networks, *i.e.*, in networks where IP[13]-based packet switching is deployed ubiquitously. SIP and its extensions realize services such as voice and video calling, instant messaging, and presence information

[7] See for example Rahman *et al.* [RVH+11] for recent work on modeling incentives in P2P systems.
[8] Global System for Mobile Communications [http://www.3gpp.org/]
[9] Universal Mobile Telecommunications System [http://www.3gpp.org/]
[10] Worldwide Interoperability for Microwave Access [II06]
[11] Long Term Evolution [http://www.3gpp.org/]
[12] The distributed computation domain and other possible domains are omitted, as at the time of writing, in March 2011, they had very few applications for mobile devices.
[13] Internet Protocol [Pos81a]

exchange. The IETF[14] is developing a P2P version of SIP called P2PSIP. The aim of P2PSIP is to provide a decentralized, managed, scalable, and secure distributed version of SIP for heterogeneous network environments, including cellular networks and wireless local area networks (WLANs). P2PSIP is based on a structured P2P system, which removes the need for centralized SIP servers. [HHBY09]

Bryan *et al.* [BMS+11] described the status of P2PSIP overlay reference architecture in October 2011.[15] P2PSIP uses the RELOAD[16] protocol [JLR+11] to form a structured P2P overlay. The nodes in the overlay provide mapping of resources to locations,[17] and the transport of SIP messages. The overlay consists of peers, which are collectively responsible for the functions of the overlay. The peers run a distributed database algorithm which handles the distribution of resources among peers. Also, the peers offer storage and transport services to the overlay. Some peers may offer additional services, such as NAT[18] traversal, and interconnection to other networks (*e.g.*, client-server SIP networks and the PSTN[19]). Another type of participant in a P2PSIP system is the client, which connects to the overlay through peers. Clients do not contribute to the overlay; peers handle the overlay operations for their clients. The client role is especially suitable for mobile nodes. Figure 2.2 illustrates the P2PSIP overlay reference architecture.

Although P2PSIP could be used for other functions than communications, those functions are not considered in this thesis. The Jingle extension to the Extensible Messaging and Presence Protocol (XMPP) [LBSA+09] partially serves a similar purpose as P2PSIP, but it is also not considered in this thesis.

The IP Multimedia Subsystem (IMS) has been proposed as a basis for service distribution in NGNs [CGM06, Thi11]. IMS emphasizes a network operator's control over its customers and over the services distributed in its network. Despite the centralized control structure of IMS, various approaches have been suggested to deploy distributed P2P-based services in centralized IMS-based networks: Liotta and Lin [LL07] proposed complementing the application and service layers of IMS with respective

[14] Internet Engineering Task Force [`http://www.ietf.org/`]
[15] As P2PSIP is under development, the following details are subject to change.
[16] REsource LOcation And Discovery
[17] *e.g.*, mapping of an Address of Record (AoR) to a Contact URI
[18] Network Address Translation
[19] Public Switched Telephone Network

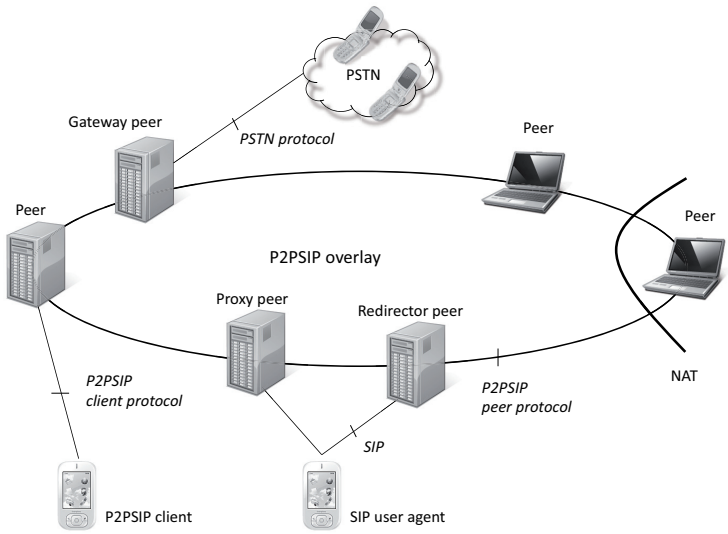


Figure 2.2. P2PSIP overlay reference architecture

P2P-based layers in a system they referred to as P2P-IMS. Marocco *et al.* [MMSC07] suggested registering a P2PSIP user as a visiting subscriber on an IMS network. Hautakorpi *et al.* [HSHY08] proposed deploying a gateway between the two systems.[20]

Skype[21] is perhaps the most well-known proprietary distributed communications system. Baset and Schulzrinne [BS04] analyzed the structure and functionality of Skype. According to them, Skype is based on an P2P overlay which consists of "ordinary hosts" and "super nodes". Most users of the Skype application are ordinary hosts, but some of them with sufficient resources are promoted to super nodes, which handle message routing, NAT and firewall traversal, among other functions. All hosts joining the Skype system must register with a login server, which is the only centralized server in the system. Since its inception, applications to access Skype have been introduced to several mobile platforms.

Some argue that client-server based communications systems where no intermediaries are necessarily needed for media transport, for example SIP [RSC+02], push to talk over cellular [Ope09], and XMPP [SA04], should be in fact classified as P2P communications systems. In this thesis, they are not considered as P2P systems, because they rely on centralized

[20]The gateway would be seen as a peer in P2PSIP and as an application server (AS) in IMS.
[21]`http://www.skype.com/`

servers for session establishment and control.

2.1.3 Content Distribution

Several P2P-based systems have emerged in the content distribution domain.[22] Napster [Hon02] was perhaps the first well-known file-sharing system, albeit it relied on a hybrid architecture where only media distribution was done in a P2P manner [SGG03]. Napster was discontinued due to copyright infringement litigation [Hon02]. To address the dependence on central servers on content discovery, file-sharing systems with overlays handling node discovery and content queries, for example Gnutella, were introduced [SGG03]. However, hybrid P2P architectures using "seed" files with references to servers indexing the peers distributing certain content, for example BitTorrent [Coh03, IUKB+04, PGES05, GCX+07], are more commonly used in practice. Albeit BitTorrent is increasingly used for legitimate purposes, most of its usage is assumed to be content distribution unauthorized by copyright holders [Env11].

Streaming of content is more challenging than just sharing it. Some P2P-based methods have been introduced to live streaming, to video on demand streaming, or to both.[23] P2P-based video on demand streaming was shown to reduce the cost of distributing content for content providers, but not necessarily for ISPs[24] [HLR07]. Some see streaming as legitimizing P2P-based content distribution. Licensed commercial content distribution services based on a hybrid P2P streaming system, *e.g.*, Spotify[25] and Voddler[26], are available in certain geographical regions.[27]

Caching of P2P-based content distribution has gained interest among some ISPs. The presumption of many caching advocates is that a significant portion of P2P-based content distribution traffic is directed unnecessarily out of a network domain [SGD+02].[28] A possibly better alternative to caching is biasing the peer selection process so that it favors neighboring intra-network peers, which is often referred to as location- or locality-

[22] See for example [TS04] for a review

[23] See for example [HBM+08, PGW+08, BDVP+09] and [Publication II, Table 2]

[24] Internet Service Providers

[25] `http://www.spotify.com/` and [KN10]

[26] `http://www.voddler.com/`

[27] Copyright holders commonly base their licensing on geographical regions [Hie08, p. 76].

[28] For example, the customers of ISP A fetch unnecessarily P2P-based content from the network of ISP B, while that content would be available within the network of ISP A.

aware P2P-based content distribution [LLX+04, KRP05, BCC+06, CB08, XYK+08, HLH+11, LLD11, RLY+11].[29]

Integrating P2P-based content distribution technologies into the mobile domain is challenging due to their resource demands. P2P-based file-sharing applications consume a significant portion of the capacity of fixed networks [Cis11, San11] and some mobile networks [San11]. Identification and management systems for P2P-based file-sharing traffic have been developed.[30] Controversially, some network operators are restricting the use of P2P-based protocols,[31] or prohibiting their use in contract terms.[32] Besides the traffic volume issues, the energy consumption of P2P-based file-sharing applications is a challenge [NN08, KLN10]. Even though file-sharing application prototypes implementing peer functionalities in mobile handsets exist [KCFC07, ENK08], most applications operating in mobile handsets only act as clients to P2P content distribution systems.[33]

2.1.4 Summary

Table 2.1 summarizes the various systems presented in the previous Subsections, mainly from the viewpoint of content distribution. The systems are sorted primarily according to the level of distribution and secondarily according to the suitability for mobile devices and networks on a scale of low, medium or high. Also locality[34] is depicted using the same scale.[35]

[29] Caching may be used to complement biased peer selection. The critics of both biased peer selection and caching associate them with unsolicited manipulation of user traffic and claim that in some cases the performance of P2P-based content distribution may suffer if it is altered by favoring intra-network peers, see for example `http://arstechnica.com/old/content/2008/03/comcast-bittorrent-pact-not-a-substitute-for-net-neutrality.ars`. Additionally, Piatek *et al.* criticized the general efficiency and feasibility of biased peer selection [PMJ+09]. Finally, as the cost of transferring data is decreasing, the cost of deploying caching and biased peer selection infrastructure may exceed the cost savings achieved in data transfer charges.

[30] See for example [DKSL03, KPF05, XYK+08]

[31] See for example [Fed08, Can09]

[32] See for example [AT&11, §6.2] and [TM10, §17]

[33] For example, mobile Spotify [`http://www.spotify.com/int/mobile/overview/`] and mobile Voddler [`http://www.voddler.com/blog/view/278818994144187217 3/voddler-launches-iphone-app/`] applications act as clients.

[34] *i.e.*, the ability of the system to place resources to certain locations according to certain criteria, usually geographic closeness

[35] The scale is illustrative, not definitive. It is assumed that mobile devices act as clients to CDN-P2P, to utility servers (*i.e.*, to a “cloud” or a grid), to CDN, to ICN,

The stakeholders responsible for the operation of a system (the user or the operator of the system) and for the costs of using a system (the user, the operator, and/or the ISP) are also listed.[36]

2.2 Research Strategies

This section introduces two generic research strategies used in this thesis: the case study (Section 2.2.1) and the scenario planning (Section 2.2.2).

2.2.1 Case Study

Yin [Yin03, p. 13] defined a case study as

> "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident."

A case study is more a research strategy than a method: a case study may contain several methods of data collection and analysis. Case studies can involve single or multiple cases, and single or multiple levels of analysis. The methods and results of a case study can be qualitative or quantitative. The results may be descriptive, exploratory, or confirmatory.

Case study research designs commonly consist of five components [Yin03, p. 21]:

1. Questions of the study
2. Propositions of the study
3. Units of analysis in the study
4. The logic of linking the data to the propositions of the study
5. The interpretation criteria for the findings of the study

to hybrid P2P, and to servers, and as peers in *ad-hoc* P2P, in P2P, in cached P2P, and in locality-aware P2P systems. Also, it is assumed that the systems where the mobile device acts as a client and the *ad-hoc* P2P system are optimized for mobile access.

[36] For many ISPs, P2P traffic, as any other type of traffic, increases their operating costs, but some ISPs benefit financially from relaying P2P traffic [OSC+11]. Ultimately, users always pay for the operating costs, but the secondary payments a user makes to the ISP or the operator in terms of subscription fees *et cetera* are not considered. However, the direct contribution of data transfer or storage resources by users is considered a cost in Table 2.1.

Table 2.1. Summary of client-server, peer-to-peer, and hybrid system properties

System	Distribution level	Suitability for mobile	Locality	Operation responsibility	Cost responsibility
Ad-hoc P2P	High	High	High	User	User
CDN-P2P	High	Medium	Medium	Operator	Operator, User, ISP
P2P	High	Low	Low	User	User, ISP
"Cloud" or Grid	Medium	High	Medium	Operator	Operator, ISP
CDN or ICN	Medium	High	High	Operator	Operator, ISP
Hybrid P2P	Medium	Medium	Medium	Operator	Operator, User, ISP
Cached or Locality P2P	Medium	Low	High	User	User, ISP
Client-server	Low	High	Low	Operator	Operator, ISP

All the publications in this thesis are case studies, although their design components vary. The design components of each publication are discussed throughout this thesis.

2.2.2 Scenario Planning

Herman Kahn was supposedly the first systematic practitioner of scenario planning in military war game simulations during the 1950s [BWB+05]. The Shell Corporation was perhaps the first commercial practitioner in the late 1960s, when it used scenarios to predict the 1973 oil crisis [Wac85a, Wac85b]. Simultaneously, to assess the uncertain future, a group of French academics established the concept *la prospective* [God82], which they subsequently developed into a scenario planning process [GR96]. Porter used a variant of scenario planning to analyze competition within an industry [Por85]. Schoemaker developed scenario planning into a more generic and systematic process [Sch91, Sch93], which this thesis uses. Instead of forecasting the future, scenario planning sets a range of plausible futures based on relevant uncertainties, trends and stakeholders, while avoiding the bias of over-emphasizing the majority opinion [WG99].

Schoemaker described scenario planning as

> "a generic method for scenario construction, in which the focus is on learning and exploring interrelationships among trends and key uncertainties." [Sch93, p. 194]

He defined scenarios as

> "focused descriptions of fundamentally different futures presented in coherent script-like or narrative fashion." [Sch93, p. 195]

Scenarios should be used for

> "bounding and better understanding future uncertainties." [Sch93, p. 196]

Schoemaker's scenario planning method consists of ten steps (from [Publication I, p. 29] based on [Sch93, Table 2]):

1. Defining time frame, scope and decision variables

2. Identifying major stakeholders
3. Listing current trends affecting the decision variables
4. Identifying key uncertainties affecting the decision variables
5. Constructing two forced scenarios
6. Assessing the internal consistency and plausibility of the forced scenarios
7. Creating learning scenarios with internal consistency and a wide range of outcomes
8. Assessing stakeholder behavior in the scenarios
9. Formalising scenarios with a quantitative model, if applicable
10. Formulating decision scenarios

Publication I uses Schoemaker's scenario planning method extensively. Publications II and III use a less formal variation of scenario analysis as a part of formulation of their respective analysis frameworks: Publication II proposes four generic scenarios for service classification; and Publication III assesses three evolution paths, which can be considered to be scenario variants.

2.3 Value Analysis

This section presents the concepts related to value analysis in this thesis: the business model (Section 2.3.1), the revenue model (Section 2.3.2), and different value configurations (mainly the value chain, the value network and their interrelations, Section 2.3.3). Finally, the value analysis concepts are applied to technology evolution (Section 2.3.4).

2.3.1 Business Model

The business model is a concept describing how a company acts and develops in the market to deliver value to its customers and to other stakeholders. The definition and contents of the business model concept vary in literature.

Timmers [Tim98] listed several generic business models for electronic markets and defined a business model as

> "[an] architecture for the product, service and information flows, including a description of the various business actors and their roles; and [a] description of the potential benefits for the various business actors; and [a] description of the

sources of revenues." [Tim98, p. 4]

Amit and Zott found "complementarities," "efficiency," "novelty," and "lock-in" as the basic "sources of value creation" in electronic business [AZ01, Figure 1]. According to them [AZ01, p. 511]:

> "A business model depicts the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities."

Chesbrough and Rosenbloom [CR02, pp. 533–534] attributed the following functions to a business model: articulating a "value proposition," identifying a "market segment," defining "the value chain within the firm," estimating "the cost structure and profit potential," positioning the firm within a "value network," and formulating a "competitive strategy". They reviewed the precursors of the business model concept [CR02, Section 2]. According to them, the business model concept bridges the technical and economic domains by transferring technical inputs into economic outputs [CR02, Figure 1].

Pateli and Giaglis [PG04] reviewed 29 studies on business models and classified their contribution into various domains. They identified a need for integrative research on the business model concept and suggested several directions for future research.

Osterwalder *et al.* selected nine "business model building blocks" from the literature [OPT05, Table 3], and advised how to utilize the business model concept in the information systems domain. Accordingly, they [OPT05, p. 3] understood a business model as

> "a conceptual tool containing a set of objects, concepts and their relationships with the objective to express the business logic of a specific firm."

Ballon [Bal07] listed 12 business model design parameters to analyze control of and value in ICT[37] services. In his later work [Bal09], he elaborated on control typologies of ICT platforms.

Bouwman *et al.* [BFH+08] designed mobile service business models by evaluating parameters in service, technology, organization, and finance domains of a firm developing the service, and by addressing critical design

[37] Information and Communications Technology

issues and critical success factors for the service.

Hughes *et al.* [HLV08] identified seven constraints affecting the business models of peer-to-peer file-sharing services at each of their evolutionary step.

The main limitation of the business model literature is its concentration on individual companies instead of industries consisting of several entities competing against and collaborating with each other. Literature on value configurations (see Section 2.3.3) and value evolution (see Section 2.3.4) address this limitation.

2.3.2 Revenue Model

Revenue model is often perceived as part of the business model of a company, describing how the company profits from its value-generating activities; *i.e.*, a revenue model is a method, or a collection of methods, for generating revenue. Amit and Zott [AZ01, p.515] recognized the following "basic revenue generation modes" of electronic business firms:

> "subscription fees, advertising fees, and transactional income (including fixed transaction fees, referral fees, fixed or variable sales commissions, and markups on direct sales of goods)."

Revenue generation requires consumer demand. Leibenstein [Lei50] separated consumer demand into functional and nonfunctional demand. Functional demand is related to the attributes of a product or a service, whereas nonfunctional demand depends mainly on external effects on utility, such as consumers' tendency to conform, to be individualistic, or to evaluate a product or a service based on its price.

Network effects[38] and bundling of unrelated information goods [BB99] can increase revenue substantially. Also, increasing revenue by establishing two-sided network effects [39] is popular among ICT service providers.[40]

[38] *i.e.*, increase in the number of people consuming a good having a positive effect on the utility of the good for an individual consumer [KS85]

[39] *i.e.*, subsidizing one side of a market to increase the value of the other side of the market [PVA05]

[40] For example, Google [`http://www.google.com/`] provides most of its services free for consumers by selling customized advertising bundled with the services to third parties.

2.3.3 Value Configurations

Allee [All00b, p. 28] defined **value** as

> "a tangible or intangible good or service, knowledge, or benefit that is desirable or useful to its recipients so that they are willing to return a fair price or exchange."

Bouwman *et al.* [BFH+08] distinguished between intended, delivered, expected, and perceived value. A producer intends to deliver a certain amount of value a consumer expects, but the consumer can perceive the delivered amount to be different from the expected amount.

Porter [Por85] established the **value chain** concept where value-creating stakeholders are interlinked sequentially from the perspective of a single firm. A **value system** is a combination of several value chains, encompassing several companies within an industry, where the proximity to the customer defines the amount of captured value and the size of profit margins of a stakeholder. Barnes [Bar02], Maitland *et al.* [MBW02], and Sabat [Sab02] applied the value chain concept to the telecommunications industry. Both value chain and value system concepts emphasize traditional manufacturing processes and lack a dynamic network structure, although Porter [Por01] later justified their applicability to a dynamic networked market.

A variety of **value network** concepts confronted the lack of a dynamic network structure in the value chain and value system concepts. Christensen and Rosenbloom [CR95, p. 240] characterized a dynamic "nested commercial system" as a value network. Normann and Ramírez [NR93, p. 65–66] used the term "value-creating system" to depict an arrangement where stakeholders "co-produce value" by reconfiguring their roles. Later, Ramírez [Ram99] refined the differences between the "industrial view" and the "co-productive view" of value production. Parolini [Par99] analyzed value nets, *i.e.* value in business networks of interrelated nodes. Allee [All00a] depicted value network analysis diagrams. Fransman [Fra01], along with Li and Whalley [LW02], characterized the change from interconnected value chains to more complex value networks in the telecommunications industry. Peppard and Rylander [PR06] analyzed value networks in the provision of mobile services and content.

Stabell and Fjeldstad [SF98] defined three generic value configuration models based on Thompson's [Tho67] typology of long-linked, intensive and mediating technologies: value chain, value shop, and value network (respectively). The value chain is based on Porter's [Por85] "sequential" "transformation of inputs into products" in "interlinked chains"; the value shop consists of "cyclical" "(re)solving customer problems" in "referred shops"; and the value network maintains "parallel" "linking [of] customers" in "layered and interconnected networks" [SF98, Table 1]. Andersen and Fjeldstad [AF03] applied the framework of Stabell and Fjeldstad to the telecommunications industry.

Publication II develops further the concept of value configurations by suggesting four generic service configuration scenarios and by developing a value analysis framework based on them.

2.3.4 Technology Evolution

Tellis and Crawford [TC81, p. 131] suggested "an evolutionary approach to product growth," where

> "products are in a state of constant evolution motivated by market dynamics, managerial creativity, and government intervention, and that the evolution proceeds in a direction of greater efficiency, greater complexity, and greater diversity. The evolutionary process consists of five well-defined patterns: product divergence, development, standardization, differentiation, and demise."

Tushman and Anderson [TA86] used the term "dominant design" to characterize an established product design which has proven to be successful over competing alternative designs. A dominant design develops through a series of incremental improvements. At some point in time, the dominant design is challenged by a major technological innovation superior in the sense it cannot be challenged merely by incremental improvements. This technological discontinuity can be either "competence-enhancing" or "competence-destroying" to existing companies in an industry. A competence-enhancing discontinuity can substitute older technologies but builds on related skills, because the new technology is still based on the old. A competence-destroying discontinuity either creates completely new technology or replaces an older technology, and makes the skills related to the old technology obsolete.

In their subsequent work, Anderson and Tushman [AT90, Figure 1] demonstrated "the technology cycle": a dominant design succeeds a technological discontinuity after an "era of ferment" characterized by competing designs and substitutions, which is followed by an "era of incremental change" characterized by elaboration of the dominant design, to be replaced by another technological discontinuity at a later point in time. Dominant designs are commonly *de facto* standards recognized by customers, or results of market power of a dominant producer, user, committee, alliance, or regulator. A technological discontinuity does not become a dominant design, because a dominant design is the result of the cumulative improvement during the era of ferment, not the result of the disruption caused by a technological discontinuity.

Henderson and Clark [HC90] distinguished between different types of innovation. They demonstrated how architectural innovation, *i.e.*, innovation which alters the architecture of a product but does not change its components, disrupts the competences of established companies. Modular innovation changes the components of a product, but leaves its architecture intact. Incremental innovation, *i.e.*, innovation which refines the architecture of a product by improving its components, benefits established companies because it is based on their competences, or enhances their competences. In contrast, radical innovation, *i.e.*, innovation which alters both the architecture and components of a product, destroys the competences of established companies.

According to Shapiro and Varian [SV99], standardization of technologies results in openness, an increase in market size, and a decrease in market uncertainty. Existing market leverage stems from a large installed base and locked-in customers. A controlled migration strategy with backward compatibility to legacy systems is possible for an incumbent having existing market leverage and standardization control.[41] However, a competing technology can develop to a point where customers are willing to pay the switching costs to gain the benefits of revolutionary performance over evolutionary compatibility.[42] Complementary technologies influence either positively or negatively the value of competing technologies with a

[41]For example, many incumbent software producers release new incrementally improved versions of their products periodically, but maintain compatibility to their previous releases.

[42]For example, some competing software producers have gained market share from incumbents by releasing competing products with superior features.

common platform.[43]

Jacobides *et al.* [JKA06] evaluated value formation within an industry. They confirmed Teece's [Tee86] proposition of relationships between the innovator and vertically related asset-holders determining who benefits from an innovation, and extended Teece's proposition to include industry-wide architectures. They argued that firms can create "architectural advantages" without owning complementary assets in parts of the vertical value chain where they are not active.[44] Consequently, a firm may control its industry by encouraging complementarity through open standards and by limiting mobility within the industry. Furthermore, while imitation by competitors may reduce profitability of an innovator, it increases the value of the underlying assets of the innovator.[45]

Publication III synthesizes the literature on value evolution by developing a value evolution analysis framework for emerging ICT services.

2.4 Usage Measurement

Usage of mobile services can be analyzed in a variety of ways. Surveying end-users, monitoring handset usage, and collecting usage data from network nodes and from servers are the main methods for analyzing the usage of mobile services [Kiv09, SKT09]. This thesis uses the following methods to analyze the usage of mobile P2P systems and services: surveys (Section 2.4.1), analysis of the responses to surveys with conceptual modeling (Section 2.4.2), collecting traffic traces (Section 2.4.3), and handset monitoring (Section 2.4.4).

[43] A platform provider benefits from competing complementary products, but for a single product the effect of competition can be either positive or negative. For example, an operating system provider benefits from having competing applications on its system, but an application provider can both benefit from the overall increase in the number of users of the system and lose customers to competing application providers.

[44] An example of such an architectural advantage is the alliance of Intel and Microsoft in the personal computer market. They encourage competition of personal computer manufacturers by maintaining open interfaces, but they secure their core assets, *e.g.*, processor design and the source code of Windows.

[45] For example, emergence of other restaurants to an area increases competition in the area, but it also increases the value of the original restaurant in the area by enhancing the overall attractiveness of the area.

2.4.1 Survey

Survey provides straightforward access to behavioral information of almost any human population with the possibility of obtaining standardized data. Self-administered surveys are an effective method of collecting anonymous data. Characteristics of the respondents (*e.g.*, experience, motivation, and personality) and self-response bias (*e.g.*, misunderstandings and dishonesty) affect the data collected with surveys. [Rob02]

The surveys included in this thesis used "stratified purposeful sampling", *i.e.*, they sampled "particular subgroups of interest" [Pat02, pp. 243–244]: subject experts in Publications I and III, and Finnish users of advanced handsets in Publications IV, V and VI.

The reliability of a survey depends on internal and external validity [Rob02]. In this thesis, internal validity was increased by customizing the questions in each survey to the corresponding respondent group.[46] External validity of the consumer studies was increased by discussing their generalization only to Finnish users of advanced handsets, not for example to all Finnish handset users.

Besides the surveys in this thesis, for example Hietanen *et al.* [HHK08] and Matuszewski *et al.* [MBLH07] did surveys on related topics.

2.4.2 Conceptual Modeling

Results from surveys are used to either develop or verify conceptual models. Conceptual modeling of usage intention and actual usage of products and services has been studied extensively. Conceptual models are commonly operationalized using structural equation modeling.[47]

The **Theory of Reasoned Action** (TRA, see Figure 2.3) developed by Ajzen and Fishbein [FA75, AF80] was one of the first conceptual models to examine how subjective norms, attitudes and intention towards a behavior manifest actual behavior under volitional control. TRA asserts that a person's attitude and occurring social pressure dictate the person's behavioral intention, leading to actual behavior.

The **Theory of Planned Behavior** (TPB, see Figure 2.3) developed by Ajzen [Ajz85, Ajz88] extended TRA to include also behavior under non-volitional control. Perceived behavioral control was added as a determi-

[46] For example, experts have better knowledge of the subject area than consumers, thus proxies are used for technical concepts in consumer surveys.

[47] See for example [Sha96] for an introduction to structural equation modeling.

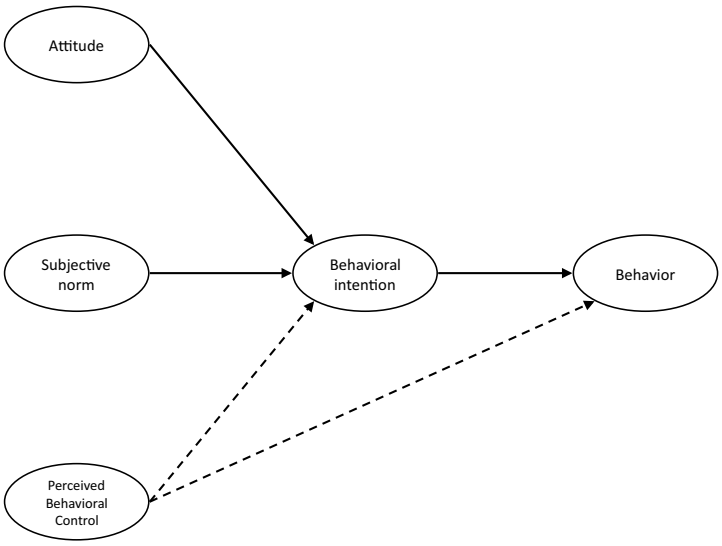


Figure 2.3. Conceptual models: Theory of Reasoned Action (solid lines) and Theory of Planned Behavior (solid and dashed lines)

nant for both behavioral intention and actual behavior. TPB asserts that a person's behavior is dictated by the person's degree of control over the behavior in addition to behavioral intention.

The **Technology Acceptance Model** (TAM) was developed by Davis [Dav89] based on TRA to predict information technology (IT) acceptance and usage in occupational contexts. TAM consists of two constructs: the perceived usefulness measures a person's view on the effect of an IT system on occupational performance, and the perceived ease of use measures a person's view on the effort of using an IT system. Venkatesh and Davis [VD00] added social influence processes and cognitive instrumental processes to TAM. Venkatesh *et al.* [VMDD03] reviewed conceptual models published after TAM to predict user acceptance of IT.

TRA, TPB and TAM have been applied to a variety of contexts.[48] Several studies used conceptual models in a variety of ICT related contexts,[49] including mobile ICT service contexts.[50] Publication IV adds to this body of research by applying TPB in the context of emerging MP2P communications and content distribution services.[51]

[48]See [SHW88, Ajz91, Ven99], respectively, for reviews.
[49]See, for example, [HJS04, HMR97, LL05, LIC03, MV00, SELW01, VMA00]
[50]See, for example, [BCWMC08, NPT05a, NPT05b, Ped05, TSB07, Ver08, VLNMCB10, WL02, YGT06]
[51]TPB was chosen due to its increased accuracy over TRA and its applicability

2.4.3 Network Measurement

Traffic can be measured from various network nodes to depict the usage of mobile services. Kivi [Kiv09] and Peuhkuri [Peu02] compared different traffic measurement methods and analyzed related challenges.

Measuring peer-to-peer traffic in mobile networks is particularly challenging: mobility of nodes makes their identification more difficult compared to fixed nodes. Additionally, peer-to-peer applications commonly try to conceal their traffic. Thus, it is challenging to differentiate P2P traffic from client-server traffic generated by client-server based data transfer and streaming protocols such as HTTP[52], FTP[53] and RTP[54].

The most straightforward method of identifying P2P traffic is to classify it based on port numbers of TCP[55] and UDP[56] packet headers [PCB05, SW04]. However, in response to the traffic management efforts by some ISPs, most modern P2P applications try to conceal their traffic using random port numbers which are either randomized automatically or set by the user. In response to port number randomizing, several statistical methods[57] and deep packet inspection methods[58] have been developed. Some P2P-based networks[59] encrypt traffic to further hinder its identification. Section 2 of Publication VI describes the variation of measurement points and reported metrics in previous P2P traffic measurement studies.

2.4.4 Handset Monitoring

Handset monitoring is a method of collecting usage data from end-users by deploying software which continuously runs in the background, logs data on usage of applications and features from the mobile handsets of the end-users participating in the study, makes the data anonymous, and submits them for analysis.

Verkasalo [Ver09] and Kivi [Kiv09] described the handset monitoring method in more detail. Handset monitoring is not a very common method:

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to services under development [Ajz91].

[52] Hypertext Transfer Protocol [FGM+99]

[53] File Transfer Protocol [PR85]

[54] Real-time Transport Protocol [SCFJ03]

[55] Transmission Control Protocol [Pos81b]

[56] User Datagram Protocol [Pos80]

[57] *e.g.*, [GDJ06, KBFC04, OHTK05, WLZ07]

[58] *i.e.*, identifying application-specific signatures in packet payload, see, for example, [BR05, GDS+03, HKA08]

[59] *e.g.*, Tor [DMS04]

Kivi [Kiv09] noted five research projects [DLSZ06, EP06, Kiv06, ROPT05, VH07] employing the method. However, its popularity is increasing: Karikoski [Kar] discussed several contemporary research projects based on handset monitoring. Additionally, handset monitoring was used in analyzing user attitudes towards the energy consumption of mobile devices [BRC+07, HNSH, RZ09].

Panel composition is a significant source of bias in handset monitoring. Another source of bias is the classification of applications into categories. Also, one has to consider whether to distribute pre-configured handsets to panelists, or to encourage them to install the monitoring software themselves. Distributing handsets may lead to bias by experimental usage. Requiring a software installation discourages some potential panelists from participating in the panel, *i.e.*, leads to self-selection bias. Finally, guaranteeing privacy of the panelists encourages participation.

3. Research Approach

This thesis consists of six publications, each of them with distinctive methods and contributions:

Publication I studies the applicability of the scenario planning method to decision making related to emerging mobile services, using a case study of a novel P2P communications protocol.

Publication II develops a framework to analyze the value distribution of ICT services by integrating existing aspects, concepts and constructs from the literature and by using case studies of centralized and distributed communications and video streaming.

Publication III describes and explains value in the technology evolution of mobile P2P communications, which potentially disrupts the positions of incumbents by introducing alternative evolution paths.

Publication IV operationalizes the Theory of Planned Behavior conceptual model to predict the intention to use novel mobile P2P communications and content sharing services.

Publication V surveys consumer attitudes towards different aspects of mobile P2P services, such as usage intention, usage satisfaction, revenue models, battery consumption, and social sharing.

Publication VI measures mobile P2P usage in Finland during 2005–2007 by analyzing traffic traces from the networks of three major Finnish mobile operators and by investigating the usage log files from a panel of Finnish advanced handset users.

The following Sections discuss the theoretical (Section 3.1) and methodological (Section 3.2) research approaches leading to the distinctive research approaches of each publication.

3.1 Theoretical Approach

Hevner *et al.* [HMPR04] argued that acquiring information system (IS) related knowledge requires the application of two distinct but complementary research paradigms: behavioral science [Kap64] and design science [Sim96]. Behavioral science uses some research methods from natural sciences.[1] It develops and justifies theories explaining or predicting organizational and human behavior regarding information systems. The design science paradigm is based on engineering and "the sciences of the artificial" [Sim96]. It solves problems based on existing theories, and creates innovations to facilitate the use of information systems.

March and Smith [MS95] proposed the use of a framework to classify information technology (IT) research based on research activities (build, evaluate, theorize, and justify) and research outputs (construct, model, method, and instantiation).[2] Building and evaluating outputs is related to design science, whereas theorizing and justifying outputs is related to natural science.

Järvinen [Jär04] extended and simplified the framework of March and Smith [MS95] by proposing a taxonomy of six research approaches: mathematical, conceptual-analytical, theory-testing, theory-creating, innovation-building, and innovation-evaluating approaches. Mathematical approaches are mainly interested in concepts not connected with reality. Approaches studying reality can be divided into natural and social science approaches (conceptual-analytical, theory-testing, and theory-creating), and design science approaches (innovation-building and innovation-evaluating). Within natural and social science approaches, conceptual-analytical approaches do not require empirical data, whereas theory-testing and theory-creating approaches use data to test or create a theory. Within design science approaches, an innovation[3] is built and evaluated.

Based on Hevner *et al.* [HMPR04], Järvinen [Jär04], and March and Smith [MS95], the publications of this thesis can be classified as follows (summarized in Table 3.1).[4]

[1] *e.g.*, statistical analysis

[2] The terms IS and IT are sometimes used interchangeably in the literature. However, often IS includes the holistic aspects related to IT, *e.g.*, adoption and management of IT.

[3] *e.g.*, an artifact, a framework, or a process

[4] Smura [Smu12] originally presented the idea of classifying techno-economic research based on Hevner *et al.* [HMPR04], Järvinen [Jär04], and March and Smith [MS95].

Table 3.1. Research paradigms, approaches, activities, and outputs of the publications

	Research paradigm [HMPR04]	Research approach [Jär04]	Research activities and outputs [MS95]
I	Design science	Innovation-building and -evaluating	Building models and evaluating a method
II	Design science	Innovation-building and -evaluating	Building and evaluating a model
III	Design science	Innovation-building and -evaluating	Building and evaluating a model
IV	Behavioral science	Theory-testing and -creating	Justifying a model and theorizing constructs
V	Behavioral science	Theory-testing and -creating	Justifying and theorizing instantiations
VI	Behavioral science	Theory-testing and -creating	Justifying methods and theorizing instantiations

Publications I, II, and III follow the design science paradigm: they are mainly concerned with building or evaluating innovations, *i.e.*, analysis frameworks for mobile P2P systems and services. Publications IV, V, and VI follow the behavioral science paradigm: they focus on the behavior of users of mobile P2P systems and services.

Publications I, II, and III follow both innovation-building and innovation-evaluating approaches: Publication I builds scenarios (models) for deployment of a novel protocol, and evaluates the applicability of scenario planning (a method) for decision making in the context of emerging mobile services. Publication II builds a value analysis framework (a model) and evaluates it in the context of centralized and distributed communications and video streaming services. Publication III builds a value evolution framework (a model) and evaluates it in the context of mobile P2P communications services.

Publications IV, V, and VI follow both theory-testing (*i.e.*, justifying) and theory-creating (*i.e.*, theorizing) approaches: Publication IV justifies the established Theory of Planned Behavior (a model) in the context of distributed communications and content distribution services and theorizes constructs to evaluate intention to adopt novel mobile services. Publication V theorizes survey results related to mobile P2P services (instan-

tiations) and justifies the results of previous studies on relevant topics. Publication VI theorizes usage measurements of mobile P2P services (instantiations) while justifying methods from previous studies.

3.2 Methodological Approach

A multimethod research design is used in this thesis.[5] The multimethod approach is a fairly established approach in social and behavioral research [TT03], and is emerging in information systems research [Min01, Min03].

Mingers [Min03] classified elementary research methods according to several characteristics:

Positivism *versus* Interpretivism: Positivism asserts that rational claims can be scientifically verified;[6] Interpretivism allows subjective interpretation and understanding of the phenomenon under study.

Quantitative *versus* Qualitative: Quantitative methods[7] are associated with positivism; Qualitative methods[8] are associated with interpretivism.

Nomothetic *versus* Idiographic: Nomothetic methods are associated with positivism and aim at the discovery of general laws and representativeness over a large population concerning objective phenomena; Idiographic methods are associated with interpretivism and aim at understanding and specifying subjective phenomena.

Extensive *versus* Intensive: Extensive methods collect data over a large number of subjects and aim to generalize about a few variables; Intensive methods study in depth a small number of subjects and aim towards understanding causal structures and meanings.

Data-driven *versus* Theory-driven: Data-driven methods approach

[5] The multimethod research design is also referred to as mixed, multiple or pluralistic methods research design in the literature. However, Tashakkori and Teddlie [TT03, p. 190] distinguished between the terms mixed method design and multimethod design by major or core methods: in a mixed method design one method is a core method which other methods complement, whereas in a multimethod design all the methods are equal. Thus, for clarity, the methodological research design of this thesis is referred to as a multimethod research design. However, Publications I and III of this thesis use a mixed method design as they both contain a confirmatory quantitative survey to complement the main qualitative analysis.

[6] *e.g.*, using logical or mathematical proofs

[7] *i.e.*, methods which use quantities to study a phenomenon

[8] *i.e.*, methods which use qualities to study a phenomenon

data without specific theories or hypotheses; Theory-driven methods approach data based on a theory or a hypothesis.

Table 3.2 summarizes the elementary methods used in the publications of this thesis according to Mingers' [Min03] classification.[9] All publications of this thesis use the case study method to isolate and to define a problem domain for study. Surveying is done to gather primary data in Publications IV and V and to collect secondary confirmatory data in Publications I and III. Interviewing is the source of primary data in Publication I; observation in Publication VI.

Different types of multimethod research designs exist [Min01]. In this thesis, the sequential and parallel multimethod designs are used: methods are employed in sequence or parallel, and results give input to subsequent or parallel studies. Figure 3.1 illustrates the methodological research design of this thesis. Elementary methods act as basis to integrated methods: interviews and survey for scenario planning; survey for the value evolution framework, for the Theory of Planned Behavior, and for the usage survey; observation for usage observation; and case studies for all the integrated methods.[10] The integrated methods were applied either in sequence or parallel (denoted by their horizontal placement).[11] Each integrated method acts as a basis for a publication of this thesis. In addition, some integrated methods contribute implicitly to others: scenario planning to both the value analysis and the value evolution frameworks; usage observation to both the Theory of Planned Behavior and usage survey. The dashed arrows mark the implicit connections between the methods and between the publications.[12] The interrelations between the publications correspond with the interrelations between the methods.

[9] One should note that the characteristics of an elementary method may vary depending on context, and that the confirmatory surveys are not taken into account when classifying the methodology of Publications I and III in Table 3.2.

[10] The different color of the arrows from the case study method is for clarity.

[11] Scenario planning and usage observation were done before the other studies, whereas the value frameworks and the two other usage studies were done in parallel.

[12] Despite the publications make no explicit linkages to each other, they influenced each other implicitly: The value analysis and the value evolution frameworks, and the survey based on the Theory of Planned Behavior and the usage survey, respectively, were co-iterated.

Table 3.2. Classification of elementary methods in this thesis based on [Min03]

Publication	Elementary methods	Positivism / Interpretivism	Qualitative / Quantitative	Nomothetic / Idiographic	Intensive / Extensive	Theory-driven / Data-driven
I	Case study, Interviews, Survey (confirmatory)	Interpretivism	Qualitative	Idiographic	Intensive	Data-driven
II	Case study	Interpretivism	Qualitative	Idiographic	Intensive	Theory-driven
III	Case study, Survey (confirmatory)	Interpretivism	Qualitative	Idiographic	Intensive	Theory-driven
IV	Survey, Case study	Positivism	Quantitative	Nomothetic	Extensive	Theory-driven
V	Survey, Case study	Positivism	Quantitative	Nomothetic	Extensive	Data-driven
VI	Observation, Case study	Positivism	Quantitative	Nomothetic	Extensive	Data-driven

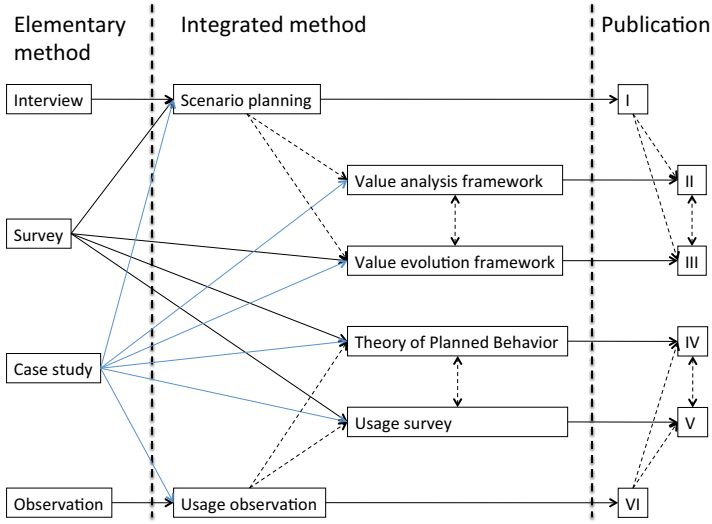

Figure 3.1. The methodological research design of this thesis

4. Research Contribution

This chapter presents the research contribution of each publication included in this thesis. It contributes to scenario planning (Section 4.1), value analysis (Sections 4.2 and 4.3), modeling usage intention (Section 4.4), analyzing consumer attitudes (Section 4.5) and measuring usage (Section 4.6) in the context of novel mobile services. In addition, it answers the research questions Q1–Q6 of this thesis (see Section 1.1) by confirming related hypotheses. Section 4.7 summarizes the methods, datasets, research questions and confirmed hypotheses of the publications.

4.1 Scenario Planning

Publication I applied Schomaker's scenario planning method on mobile P2PSIP communications usage in a hypothetical Western European country during 2008–2012.[1] The analysis is based on three "brainstorming" sessions[2] with ten subject experts, and a verification questionnaire completed by ten subject experts.

The following stakeholders are relevant to the analysis: user, network operator, service operator, service infrastructure operator, device provider, application provider, and regulator.[3]

Nine trends and six uncertainties are relevant to the analysis.[4] The

[1] At the time of writing, in March 2011, the author is not aware of any P2PSIP systems being deployed for public use, although P2PSIP standardization work is ongoing. On the other hand, Skype had 25 million concurrent users in November 2010 [http://blogs.skype.com/en/2010/11/25_million.html]. In retrospect, Publication I overestimated the deployment of P2PSIP.

[2] *i.e.*, semi-structured group interviews

[3] See Section 4.4 of Publication I for a description of them.

[4] See Tables 2 and 3 of Publication I for a listing of the trends and the uncertainties, respectively, and for a description of their estimated impact on mobile P2PSIP communications usage.

trends are grouped into business and technology domains, and their interrelations are described.[5] The correlations of the uncertainties are depicted.[6]

Altogether eight scenarios are built.[7] The scenarios are divided into global, *ad hoc*, and private groups. In the global group, P2PSIP is used as a global communications system. The global group consists of the following scenarios: pure public global, semi-centralized public global, pure open global, and semi-centralized open global. In the pure scenarios mobile devices act as peers in a P2PSIP network; whereas in the semi-centralized scenarios mobile devices act as clients to a P2PSIP network, and fixed nodes[8] handle peer functionalities. In the public scenarios the P2PSIP network is not interconnected to other similar networks, but it may be interconnected to client-server SIP networks and the PSTN (*i.e.*, the public scenarios mimic current proprietary P2P-based communication services such as Skype); whereas in the open scenarios the P2PSIP networks are interconnected to each other and to other communications networks (*i.e.*, the open scenarios resemble the PSTN). Additionally, two *ad hoc* P2PSIP network scenarios are characterized according to the network size. Finally, global and local private P2PSIP network scenarios are depicted.

Stakeholders' behavior is described in each of the scenarios. In the public global scenarios, incumbent service and network operators would regard a new P2PSIP communications service as a threat to their established business models. They could limit adoption by restrictive firewall and NAT policies. However, some non-incumbent operators could make collaborative agreements with the new service operator if the service reached a certain adoption threshold. The service operator could use both cost advantage and feature differentiation strategies to enter the market. Its revenue models could be transactional income from value-added transactions (such as interconnection to other networks), or advertising.

In the open global scenarios, regulators could apply the current PSTN regulation to the service, and thus require emergency dialing and lawful interception capabilities. There could be competing service operators and

[5] See Figure 2 of Publication I

[6] See Table 4 of Publication I

[7] See Table 5 of Publication I for a description of the outcomes of the uncertainties in each scenario.

[8] *e.g.*, desktop computers or dedicated servers

application providers if the service was completely based on open standards. The application could be offered as part of a mobile operating system platform to add value to its users. Subscription fees, transactional income and advertising were possible revenue models if incumbent network operators allowed the service in their networks.

In the *ad hoc* scenarios, the service would most probably be realized using a feature in a mobile operating system platform, independently of a service operator. The possible revenue from the service would come from the increased sales of devices incentivized by the feature, *i.e.*, by transactional income. The *ad hoc* scenarios could be realized, for example, during events or emergencies when other mobile networks are unavailable.

In the private scenarios, the service would be used by a limited community. The service operator or application provider could collect subscription or transaction based revenue from set-up and support. The private scenarios are most applicable to closed communications within an organization, or across a limited number of collaborating organizations.

Summary: Publication I applied Schoemaker's scenario planning method to a case study on mobile Peer-to-Peer Session Initiation Protocol (P2PSIP) based communications services. The method was found suitable for decision making in the context of emerging mobile services. According to the analysis, a potential P2PSIP service operator or application provider should seek *ad hoc* and private environments where network and legal settings are the most favorable; a potential P2PSIP service operator considering global service provisioning should assess the semi-centralized public global scenario.

Publication I answers the research question Q1 by confirming the hypotheses H1a and H1b:

Q1: What are the most relevant scenarios related to mobile Peer-to-Peer Session Initiation Protocol communications usage in a hypothetical Western European country during 2008–2012?

H1a: Scenario planning is applicable in the context of emerging mobile services.

H1b: Ad hoc, private, and semi-centralized public global scenarios are the most relevant scenarios for Peer-to-Peer Session Initiation Protocol deployment in a hypothetical Western European country during 2008–2012.

4.2 Value Analysis Framework

Publication II developed a value analysis framework consisting of value architecture, value production, and value network domains, based mainly on business model, revenue model, value chain, and value network concepts (see Section 2.3). The framework was applied to centralized and distributed communications and video streaming case studies.

While studying value distribution in the mobile ICT industry, two common characteristics in the established value analysis theories were noticed: depicting service provisioning as a long-linked value chain, and focus on single firms instead of industries.

To alleviate these shortcomings, a value analysis framework was developed. It consists of three distinct domains: value architecture, value production and value network (see Figure 4.1). The domains are described as follows [Publication II, pp. 45–46]:

> "First, we analyze the value architecture of a service or a technology. The value architecture consists of technical components, and roles responsible for operating and maintaining the components. We define technical component as a collection and realization of technical functionalities; and role as a set of activities and technical components, the responsibility of which cannot be divided between separate actors." [...]
>
> "Second, we examine the value production of a service or a technology. Value production explains how roles are configured to enable the production of value. [...R]oles may be either collaborating in a fairly equal manner, or one role may be supporting another role in a submissive manner." [...]
>
> "Third, we review the value network of a service or a technology. [...T]he value network illustrates which roles each actor may have, the contractual relationships between the actors, and the level of competition between the actors. The actors can be companies, organizations, individuals, or groups of individuals."

The value analysis framework was verified by classifying services using four generic service configuration scenarios.[9] Industry structure type (horizontal *vs.* vertical) and technical functionality distribution (centralized *vs.* decentralized) are the variables of the scenarios. The variables

[9] See Figure 2 of Publication II

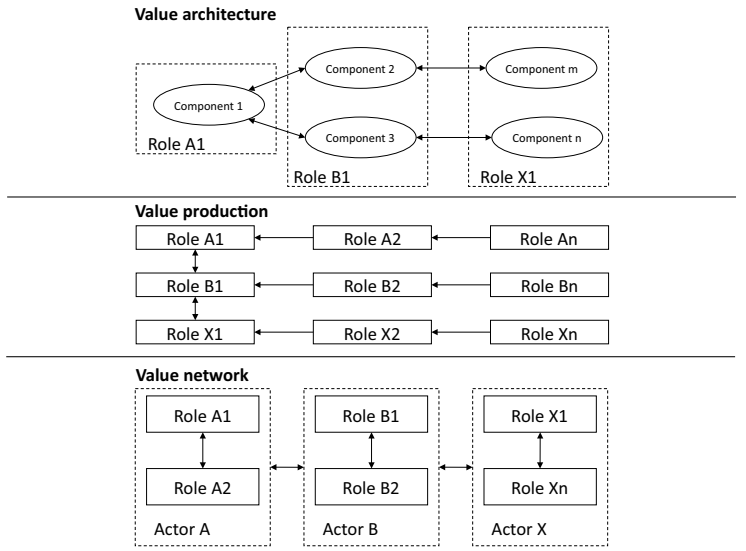

Figure 4.1. Value analysis framework domains. Published in Publication II, p. 46. Copyright 2010 Emerald Group Publishing Limited. Reprinted with permission.

are distinguished as follows [Publication II, p. 46]:

> "In a vertical industry structure, roles which are involved in different but related activities or processes are joined in the actor domain, creating commonly a lock-in situation for the user, where the user has to use a specific service or technology, or face relatively high switching costs. In a horizontal industry structure, roles which are involved in different but related activities or processes remain independent in the actor domain, allowing the user to choose or use simultaneously with relative ease different services and technologies." [. . .]
>
> "Centralized services deploy a client-server (C-S) infrastructure where clients access a server (or a group of servers) to get the service they need. Distributed services deploy a peer-to-peer (P2P) infrastructure where peers exhibit both client and server functionalities, thus realizing the service among each other. Thus, very few or even no centralized components are needed."

The first case study was the value analysis of centralized and distributed communications.[10] Multiple services fitting each of the scenarios in the service classification framework were identified.[11] Horizontal centralized

[10] See Section 4 of Publication II
[11] See Table 1 of Publication II

services are implemented with open protocols such as the Session Initiation Protocol (SIP) or the Extensible Messaging and Presence Protocol (XMPP). Vertical centralized services are deployed using a platform under the control of a single operator, such as the IP Multimedia Subsystem (IMS). Horizontal distributed services can be realized with standards under development, *e.g.*, P2PSIP and the Jingle extension to the XMPP. Vertical distributed services (*e.g.*, Skype) consist of a distributed service architecture controlled by a single operator.

The value architecture domain divides service, control, transport and signaling components among devices and servers.[12] Servers are present in centralized scenarios, but they are absent in distributed scenarios. Control components affect the whole system in vertical scenarios, whereas they affect only specific components in horizontal scenarios.

The value production domain depicts role constellations and value flow interactions (*i.e.*, collaboration and support) between roles.[13] For centralized services, moving from horizontal to vertical industry structure increases role co-location. For distributed services, the effect is opposite due to differences in the technical structures of the services, which influence role configuration.

The value network domain shows constellation of roles into actors, contractual relationships between actors, and competition level between actors.[14] Moving from horizontal to vertical industry structure increases actor co-location and decreases competition for both centralized and distributed services.

The value analysis framework was verified with a second case study on another class of ICT services, video streaming. Some differences compared to the communications case were noticed, but essential findings remained the same.[15] The value analysis framework simplifies the two distinct domains into similar structured classifications.

Summary: Publication II developed a value analysis framework taking into account existing value analysis concepts from the literature. The framework describes value exchanges between different actors related to an ICT service, and their role constellations based on technological components. The practical applicability of the framework was verified by doing case studies on centralized and distributed communications and video

[12]See Figure 3 of Publication II
[13]See Figure 4 of Publication II
[14]See Figure 5 of Publication II
[15]See Section 5 and Table 2 of Publication II for details

streaming. The case studies are technically different from each other but exhibit similar characteristics in value flows and role constellations.

Publication II answers the research question Q2 by confirming the hypotheses H2a and H2b:

Q2: How can value distribution be analyzed in service configuration scenarios?

H2a: Architecture, production and network domains are relevant when analyzing value distribution in service configuration scenarios.

H2b: Services can be classified to four generic configuration scenarios based on industry structure (horizontal vs. vertical) and distribution of functionality (centralized vs. decentralized).

4.3 Value in Technology Evolution

Publication III developed an analysis framework for assessing value in technology evolution. The framework is based on an extensive literature review.[16] The framework consists of five main components: technology, initiation, finance, market, and value. Each component contains variables for analysis. Figure 4.2 illustrates the framework, and Section 3.1 of Publication III describes each component and its variables.

The analysis framework was evaluated by assessing responses to a questionnaire study from 49 subject experts. Descriptive statistics and factor analysis were used in the assessment.[17] Market development, incumbent control, and complementary technologies were found as the most important factors for evaluating value in technology evolution.

The analysis framework was applied to a case study on mobile peer-to-peer communications. Three potential evolution paths for mobile P2P communications were identified: Internet-driven, telecom-driven, and proprietary. The Peer-to-Peer Session Initiation Protocol (P2PSIP), P2P over IP Multimedia Subsystem (P2P-IMS), and Skype represented each evolution path, respectively. Each evolution path was assessed first based on literature and expert opinions, then by doing a factor analysis on the questionnaire responses. The following subsections describe each evolution path using the domains of the framework. They also summarize the results of the factor analysis for each evolution path.

[16] See Section 2 of Publication III

[17] See Section 3.2 of Publication III for a detailed description of the respondents and the study

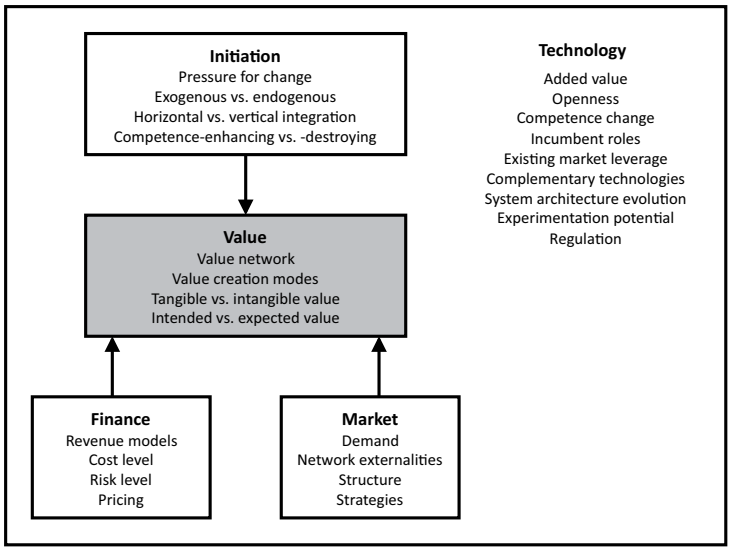

Figure 4.2. Value in technology evolution: analysis framework. Published in Publication III, p. 64. Copyright 2010 Emerald Group Publishing Limited. Reprinted with permission.

4.3.1 Internet-Driven Evolution

P2PSIP represents the Internet-driven evolution path characterized by openness similar to most current Internet technologies. P2PSIP is an open standard available to all stakeholders, like other IETF standards. Developers, mobile network operators, and mobile device vendors would need to co-operate to deploy P2PSIP extensively.

Technology: P2PSIP enhances the competences of both mobile device and network vendors through increased demand for advanced devices and networks. Most incumbent network operators do not benefit from P2PSIP because it reduces revenue from circuit-switched communications by decreasing the number of circuit-switched calls, and increases the cost of providing flat-rate data subscriptions by increasing traffic volume. Client-server SIP users and proprietary mobile P2P communications service users provide market leverage for P2PSIP. Cost efficiency is the main added value of P2PSIP for the end user. P2PSIP is architectural evolution from client-server SIP. Mobile networks optimized for IP traffic, such as LTE and WiMAX, are complementary technologies for P2PSIP. Regulators may require the integration of emergency dialing and legal interception into P2PSIP, and facilitate its adoption if it becomes a viable replacement to established communications services.

Initiation: General adoption of Internet-based technologies is the exogenous pressure for change in the initiation phase of P2PSIP services, potentially leading to horizontal integration of mobile network operators due to competence-destruction.

Finance: Flat-rate mobile data subscription is the basic revenue model of P2PSIP; advertising, interconnection fees and bundling agreements are additional sources of revenue. P2PSIP has mid-level cost, risk, and pricing when compared to P2P-IMS which has them the highest, and to Skype which has them the lowest.

Market: The demand for P2PSIP services is similar to the demand fluctuation of other Internet-driven services. Current and future SIP users, along with users of proprietary communications services, form the network externalities. P2PSIP is expected to spread from *niche* customer segments into general consumer segments as its integration into mobile devices progresses.

Value: The value network of P2PSIP is balanced among different stakeholders.[18] Cost efficiency is the primary value creation mode of P2PSIP, technological efficiency is the secondary. P2PSIP has high intended value, but moderate expected value.

Three factors were formulated for Internet-driven evolution: high value proposition, profitability, and subscription fees as an important revenue model.[19]

4.3.2 Telecom-Driven Evolution

P2P-IMS represents the telecom-driven evolution path characterized by the control of incumbent operators over mobile P2P communication services. Incumbent network operators and vendors would control the development and deployment of P2P-IMS services. P2P-IMS would be a "walled garden" system which is aimed at maximizing operator's control over its customers.

Technology: P2P-IMS is competence-enhancing for mobile device and network vendors because it could stimulate the sales of advanced devices and networks. P2P-IMS is also competence-enhancing for incumbent mobile network operators because they could use it for service provision control and charging. The existing customer base of incumbent operators is a significant market lever for P2P-IMS. P2P-IMS could bring users in-

[18] See Figure 5 of Publication III
[19] See Table 4 of Publication III

creased stability and reliability, and lower experimentation barriers compared to P2PSIP and Skype through tighter integration to operator's infrastructure. Advanced IP-based networks are complementary technologies to P2P-IMS. P2P-IMS is architectural evolution from IMS. Regulators would probably pose similar requirements to P2P-IMS services as they pose to other IMS services.

Initiation: Endogenous pressure of incumbent network operators to avoid being commodity "bit-pipe" providers forms the initiation phase of P2P-IMS. New capability requirements may impose vertical integration of fixed and mobile network operators, along with service operators.

Finance: Monthly subscription fees and unit-based transaction fees are the most probable revenue models for P2P-IMS services as they are the established revenue models of incumbent mobile network operators.

Market: The demand for P2P-IMS services depends on the demand for other IMS-based services. The large existing customer base of incumbent operators creates high network externalities. A mixed marketing strategy would be needed due to the large market consisting of several heterogeneous customer segments of incumbent mobile network operators.

Value: The value network of P2P-IMS is operator-centric.[20] The primary value creation mode is complementation to existing service designs, and the secondary value creation mode is lock-in of customers. Both intended and expected values are high.

Five factors were formulated for telecom-driven evolution: value creation, market leverage, competence leverage, regulatory intervention, and universal customer benefits.[21]

4.3.3 Proprietary Evolution

Skype represents the proprietary evolution path characterized by proprietary solutions promoting themselves as de-facto standards. Skype is a closed system where its operator has complete control over its users.

Technology: Skype is competence-enhancing to mobile device vendors because it creates incentives for the adoption of advanced mobile devices. Skype is also competence-enhancing to mobile network vendors because it causes more IP traffic, leading to network updates and possibly to deployment of traffic management solutions. Skype is competence-destroying to incumbent mobile network operators as it decreases demand for estab-

[20] See Figure 6 of Publication III
[21] See Table 6 of Publication III

lished communications services. Skype can use its significant customer base in fixed networks as leverage in mobile networks. Skype maintains a lock-in situation by not offering interconnectivity to other proprietary service providers. Cost-efficiency is the main added value of Skype for the end-user. Skype has a certain experimentation barrier but also means to control the user experience. Skype benefits from the adoption of advanced IP-based mobile networks and advanced mobile devices more than P2PSIP and P2P-IMS, because Skype relies more on network and device capabilities than P2PSIP and P2P-IMS. Skype becomes more susceptible to regulation as its influence increases.

Initiation: During the initiation phase, a new entrant with a novel technology enters the market, *i.e.*, exogenous pressure for change appears. The entrant remains independent, thus probability for horizontal or vertical integration is low, at least initially.[22]

Finance: Subscription and transaction fees from value-added services, mainly interconnection to other networks, are the primary revenue models of proprietary technologies; advertising and bundling with devices are secondary revenue models.

Market: The demand for proprietary solutions depends on the market situation: if a dominant proprietary provider has saturated the market, barriers to entry are high for other proprietary providers, unless they can provide a significant advantage exceeding the switching costs of the consumers. Network externalities depend on the existing customer base of the provider. Proprietary services are usually targeted on a distinct customer segment, commonly cost-aware customers, for which a targeted strategy is appropriate.

Value: The value network of a proprietary service is service provider centric.[23] Cost efficiency is the primary value creation mode, customer lock-in is the secondary. Intended value is moderate and expected value is low.

[22]However, at later stages, when the entrant matures, the probability of integration increases. For example, Skype, founded in 2003, was acquired by eBay, an Internet auction company, in September 2005. eBay failed to integrate Skype with its auction site. In November 2009, Skype was acquired by an investment group, which concentrated on developing Skype's core business, value-added communications services. In May 2011, Skype was acquired by Microsoft, presumably with plans to integrate Skype with its own proprietary communications services and systems. [http://about.skype.com/press/2011/05/microsoft_to_acquire_skype.html]

[23]See Figure 7 of Publication III

Three factors were formulated for proprietary evolution: successful value proposition, creation of alliances of competitors, and competence enhancements to mobile device vendors.[24]

4.3.4 Summary

Publication III developed an analysis framework for value in technology evolution and validated it with a case study considering three possible evolution paths for mobile peer-to-peer communications. As an additional verification, factor analysis was done on responses of domain experts to a survey concerning the framework and the case study. Internet-driven evolution enables new business opportunities for independent service operators and equipment vendors; telecom-driven evolution benefits mostly incumbent network operators; and proprietary evolution enables independent service operators to compete against incumbent actors.

Publication III answers the research question Q3 by confirming the hypotheses H3a and H3b:

Q3: How can value distribution be analyzed in technology evolution scenarios?

H3a: Technology, initiation, finance, market and value related variables are relevant when analyzing value distribution in technology evolution scenarios.

H3b: Internet-driven, telecom-driven, and proprietary evolution are the three distinct evolution paths of mobile peer-to-peer communications.

4.4 Modeling Usage Intention

Publication IV modeled the intention to use novel mobile peer-to-peer services by applying the Theory of Planned Behavior (TPB) conceptual model in the context of mobile peer-to-peer communications and content distribution services based on a questionnaire study among 155 Finnish users of advanced handsets done in 2008.[25]

A confirmatory factor analysis assessed the overall reliability of the model, and several methods controlled common method bias.[26] A high construct reliability was achieved, very probably due to the fact that the

[24] See Table 8 of Publication III

[25] See Section “Model” of Publication IV for details of the TPB model and Section “Data” of Publication IV for details of the sample

[26] See Section “Results” of Publication IV for details

items and their distribution into factors has been evaluated and validated extensively in previous research. They were adapted to be suitable in the context of novel mobile services.

Respondents had high behavioral intention to use novel mobile services. That was probably due to the characteristics of the respondents: the users of modern handsets are keen and capable of experimenting with novel mobile services, explaining high attitude and even higher perceived behavioral control scores; also, possibly most of the respondents' friends have similar characteristics, explaining relatively high subjective norm scores.

Most fit indices indicated an acceptable fit for both communications and content sharing models.[27] Content sharing models had a worse fit than communications models, partly because the data deviated more from the normal distribution.

For the communications service, attitude was the most important variable defining behavioral intention; subjective norm and perceived behavioral control had a much smaller, but almost identical, effect on behavioral intention. The value of a communications service for an individual is dependent on adoption of it among one's social network, leading to the significance of subjective norm. Positive experiences from using established novel communications services, *e.g.*, Skype, could explain the significance of perceived behavioral control.

For the content distribution service, attitude was again the most important variable defining behavioral intention; subjective norm and perceived behavioral control had a statistically non-significant effect on behavioral intention. Possibly respondents did not value the content distribution service *per* their social network, thus the statistically non-significant subjective norm. Also, potentially respondents did not associate existing usage experiences of content distribution services to the proposed service, thus the statistically non-significant perceived behavioral control.

Summary: Publication IV tested the validity of an established conceptual model (Theory of Planned Behavior, *i.e.*, TPB) in a context it had not been applied to previously (*i.e.*, the adoption of novel mobile services under development). The suitability of TPB was confirmed in the context, the most important variables affecting the intention to adopt novel mobile services were identified, and the relevance of the results, along with some of the challenges, pitfalls and limitations in obtaining the results, were discussed. Mobile peer-to-peer communications and content sharing

[27] See Section "Results" of Publication IV for details

services had high adoption potential among respondents with advanced handsets. User attitude was the main driver for intention to use novel mobile services.

Publication IV answers the research question Q4 by confirming the hypotheses H4a and H4b:

Q4: What is the adoption potential of mobile peer-to-peer communications and content sharing services among Finnish users of advanced handsets?

H4a: The Theory of Planned Behavior is a valid conceptual model for analyzing the adoption potential of mobile peer-to-peer communications and content sharing services.

H4b: Mobile peer-to-peer communications and content sharing services have high adoption potential among Finnish users of advanced handsets.

4.5 Consumer Attitudes

Publication V studied consumer attitudes towards different aspects related to mobile peer-to-peer services by surveying 196 Finnish users of advanced handsets in 2008.[28]

First, the respondents were inquired about familiarity with the P2P concept and different P2P service classes. 90% of the respondents had heard about the P2P concept. Almost 70% had tried or used P2P communications or file-sharing services with computers, less than 30% with mobile handsets.[29]

Second, mobile service usage was studied. Over half of the respondents used only web browsing and email besides calling and SMS[30] messaging with their mobile handsets during the study period (Oct–Dec 2008). The respondents who had tried other services were mostly satisfied with them, but their usage intention materialized only partially into actual usage.[31]

Third, revenue model options for mobile services and digital content distribution were examined. Depending on the mobile service, 5%–25% of the respondents were willing to pay for a mobile service, and 10%–40% of the respondents accepted advertising as a revenue model for a mobile service.[32] Software and music downloading attracted most payment will-

[28]See Section 2 of Publication V for details of the sample
[29]See Figure 1 of Publication V
[30]Short Message Service [Thi10]
[31]See Figures 4 and 2 of Publication V, respectively
[32]See Figure 5 of Publication V

ingness and tolerance for advertisements. Out of the potential revenue models for digital content distribution, downloads free of Digital Rights Management (DRM) and legal file-sharing received most support.[33]

Fourth, attitudes related to energy consumption and battery recharging were studied, because energy efficiency is an important design aspect for mobile P2P services. 62% of the respondents were satisfied with their battery life. The respondents did not recharge their handset batteries very often: 2% several times a day, 17% once a day, 16% 5–6 times a week, 36% 3–4 times a week, and 30% less often. Using email reception delay as a proxy measure, the respondents were found to be more sensitive to increasing energy consumption than worse service quality in the form of increased delay. Also, the respondents were not keen to adjust their recharging behavior to enable new functionality: 42% of the respondents were not willing to recharge their handset battery more often to be able to download applications directly from the Internet instead of using a cable to connect the handset to a computer; 45% could recharge their handset battery 1–2 times more a week to be able to do so. The respondents estimated rather well the energy consumption of several mobile services, although they overestimated the energy consumption of then novel services, particularly video playback.[34]

Fifth, sharing of content, location and presence data was examined, as it is also relevant to some novel mobile P2P services. The respondents were willing to share them with 30%–50% of their active contacts, content mostly with closest friends and family.[35]

Summary: Publication V reported the results of a survey designed for understanding consumer attitudes towards mobile P2P services. Respondents to the survey were familiar with P2P services, many had tried or used them, and many were open to new revenue models enabled by them. Respondents estimated energy consumption of mobile services well, but neglected new service designs consuming more energy.

Publication V answers the research question Q5 by confirming the hypotheses H5a and H5b:

Q5: What are the attitudes towards different aspects of mobile peer-to-peer services among Finnish users of advanced handsets?

H5a: Finnish users of advanced handsets are familiar with peer-to-peer

[33]See Figure 6 of Publication V

[34]See Table 1 and Section 3C of Publication V for details

[35]See Tables 2 and 3 of Publication V

services.

H5b: Finnish users of advanced handsets are open to new revenue models enabled by mobile peer-to-peer services.

4.6 Measuring Usage

Publication VI studied the development of mobile peer-to-peer traffic and application usage in Finland during 2005–2007. The dataset consisted of IP traffic traces measured from three Finnish GSM/UMTS networks which covered 80%–90% of the Internet-bound mobile data traffic by Finnish mobile subscribers, and of usage log files collected from 579 panelists by a Symbian handset monitoring application.[36]

The overall traffic volume in 2006 was four times larger than in 2005. The traffic generated by computers using for example USB[37] modems to access the mobile data network was fourteen times larger in 2007 than in 2006, whereas traffic generated by mobile handsets was only three times larger. The overall share of computer-generated traffic in mobile networks grew from 70%–75% in 2005–2006 to over 90% in 2007, whereas the overall share of traffic generated by Symbian handsets dropped from 15% to 4%.

The proportion of web traffic increased from 57% in 2005 to 79% in 2007 of all handset-generated traffic, whereas the proportion of email traffic shrank from 24% in 2005 to 10% in 2007. The proportion of handset-generated identified P2P traffic remained marginal during 2005–2007.[38]

The computer-generated traffic profile developed very differently during 2005–2007. The proportion of web traffic decreased from 69% to 35%, and the proportion of email traffic went down from 7% to 1%. The proportion of identified P2P traffic increased from 1% to 4%. Most notable is the substantial rise of unidentified traffic: from 10% to 58% of total computer-generated traffic volume during 2005–2007.[39]

Based on the diurnal distribution of computer-generated traffic,[40] and uplink traffic profiles,[41] most of the unidentified computer-generated traffic was assumed to be in fact P2P traffic.

[36] See Section 3 of Publication VI
[37] Universal Serial Bus [http://www.usb.org/]
[38] See Figure 1 of Publication VI
[39] See Figure 2 of Publication VI
[40] See Figure 3 of Publication VI
[41] See Section 4.1 of Publication VI

The proportion of BitTorrent traffic rose to be 51% of the computer-generated identified P2P traffic.[42] However, as most P2P traffic was unidentified, the actual relative share of BitTorrent traffic may have been higher.

In the handset monitoring portion of the study, three major categories of P2P applications were found: Voice over IP (VoIP), instant messaging and file sharing clients accessing P2P networks. Most of the identified applications received very little usage: typically they had only a few users who rarely used them on a regular basis.[43] Fring, then a client to Skype and other communications networks,[44] was the most popular P2P client application: 5% of the panelists tried it, 1% used it regularly, and it generated 4% of its users' data volume.[45]

Summary: Publication VI used both IP traffic traces and handset measurements to get a comprehensive view of mobile P2P usage in Finland during 2005–2007. The proportion of computer-generated P2P traffic increased substantially in Finnish mobile networks. BitTorrent was the most popular P2P protocol. Handset-based P2P usage, however, was negligible.

Publication VI answers the research question Q6 by confirming the hypotheses H6a and H6b:

Q6: What was the level of usage of peer-to-peer applications in Finnish mobile networks during 2005–2007?

H6a: The share of computer-generated peer-to-peer traffic increased substantially in Finnish mobile networks during 2005–2007.

H6b: Handset-based peer-to-peer usage was negligible in Finnish mobile networks during 2005–2007.

4.7 Summary

The research contribution of this thesis consists of applying multiple research methods to case studies on mobile services and systems, developing frameworks for the analysis of them, extending existing theories and methods for their analysis, and reporting results from surveys and usage measurements on them. Table 4.1 summarizes the methods, datasets, research questions and confirmed hypotheses of the publications.

[42] See Figure 4 of Publication VI
[43] See Table 2 of Publication VI
[44] Fring discontinued Skype interconnectivity on 12 July 2010 [http://www.fring.com/newsroom/skypeblocksfring.asp].
[45] See Tables 2 and 3 of Publication VI

Table 4.1. Methods, datasets, research questions and confirmed hypotheses of the publications

Publication	Method	Datasets	Research question	Hypotheses confirmed
I	Scenario planning	Case study, interviews (N=10), survey (N=10)	Q1	H1a, H1b
II	Value analysis framework	Case study	Q2	H2a, H2b
III	Value evolution framework	Case study, survey (N=49)	Q3	H3a, H3b
IV	Theory of Planned Behavior	Survey (N=155)	Q4	H4a, H4b
V	Usage survey	Survey (N=196)	Q5	H5a, H5b
VI	Usage observation	Traffic traces (80%-90% coverage of the Finnish market), handset monitoring panel (N=579)	Q6	H6a, H6b

5. Discussion

This chapter discusses the theoretical and practical implications of each publication included in the thesis (Sections 5.1 and 5.2). Next, it assesses reliability and validity of the thesis and the publications (Section 5.3). Then, it introduces possible directions for further research (Section 5.4). Finally, the main conclusions of this thesis are drawn (Section 5.5).

5.1 Theoretical Implications

The theoretical implications of this thesis are as follows:

Co-existing scenarios should be accepted as a methodological variant of the scenario planning method, where scenarios normally depict completely different futures. The variant could be suitable to other scenario planning case studies. [Publication I]

Studying technical architecture, value flows between producers, and contractual relationships between value-producing entities and their customers are collectively required to understand the value configurations of mobile services. Relying solely on established concepts such as business model, revenue model, value chain, and value network is not sufficient to understand comprehensively the value configuration of a mobile service, but combining them into a synthesizing framework produces a better view of the value configuration. Both value configuration and value evolution viewpoints are necessary for understanding the value of a technology and the services enabled by it. The main difference of the value evolution framework of Publication III compared to the value analysis framework of Publication II is that the value evolution framework puts more emphasis on the evolution of value in conjunction with the evolution of technologies, whereas the value analysis framework focuses on evaluating value in static configurations.

Publication IV verified the feasibility to generalize the Theory of Planned Behavior in the context of modeling the intention to adopt novel mobile services. The service descriptions and survey items should be customized according to the respondent group, resulting in the use of proxies for technical concepts in the survey targeting users of advanced handsets among the Finnish general population.

5.2 Practical Implications

The practical implications of this thesis are as follows:

Schoemaker's scenario planning a suitable method for decision making regarding novel mobile services, including mobile P2P-based services. The method is most suitable as a structure for "brainstorming" sessions with subject experts. The scenarios can serve as a basis for more detailed qualitative or quantitative analysis. [Publication I]

Initially very complex mobile service configurations, including mobile P2P configurations, can be classified into four generic scenarios[1] based on their architecture, value flows, and role constellations [Publication II]. The classification is valuable in typifying services and understanding the underlying industry structure.

Publication III developed a value evolution framework, where an initiation phase, finance variables, market conditions, and technological background define the value of services enabled by distinct technologies. Together with the value analysis framework of Publication II, the value evolution framework leads towards a comprehensive understanding of the value of novel mobile services.

User attitude is the defining variable for the intention to use novel mobile P2P services [Publication IV]. This result could potentially be generalized to other novel mobile services. Consequently, mobile service developers and marketers should focus on affecting user attitudes to generate success for their services.[2]

Users of non-established mobile services (such as mobile P2P-based services) are generally satisfied with them [Publication V]. However, most of the usage intention towards non-established services does not convert into

[1] *i.e.*, horizontal centralized, vertical centralized, horizontal distributed, and vertical distributed

[2] For example, developers and marketers should demonstrate the usefulness of their service and make it appealing for the target customers.

actual usage. Marketers of those services face a challenge how to make the conversion. Established payment trajectories determine willingness to pay, but new business models attract some interest. This suggests marketers of non-established mobile services should preserve the value of their service offering, but be open to new ways to generate value for their consumers. Novel mobile services have a reputation for consuming more energy than established services. This reputation could potentially limit the adoption of novel services. Social sharing services should be optimized for small sharing networks as people are mostly willing to share only with closest friends and family.[3]

The Finnish P2P traffic was dependent on global trends in 2005–2007: the proportion of BitTorrent traffic and masqueraded P2P traffic grew, as was evident in other studies on the topic. However, some particular characteristics of the Finnish market, such as the heavy marketing efforts of flat rate mobile data subscriptions complemented with subsidized USB data modems for computers, and the decision of operators not to evidently manage P2P traffic in mobile networks, probably mostly explain the exponential rise of total mobile data traffic and the increase in proportion of potential P2P traffic, respectively. [Publication VI]

5.3 Reliability and Validity

Yin [Yin03, p. 98–99] discussed the use of several different sources of information based on Patton's [Pat87] four types of triangulation in evaluation: the triangulation of data, investigators, theory, and methods. In this thesis, all four types of triangulation, *i.e.*, several data sources, collaborators, theories, and methods, are used to study mobile P2P systems and services.

Mingers [Min01] argued that research combining multiple methods, preferably from distinct paradigms, is in general more reliable than research just relying on a single method. Tashakkori and Teddlie [TT03, p. 205] positioned that interdependent studies on a phenomenon together with a multimethod research design provide a more comprehensive view on the phenomenon than they would do independently. Thus, the multimethod

[3]The privacy controversy related to Facebook implicitly enabling wider sharing of private information seems to follow this notion, see for example http://www.theatlantic.com/technology/archive/2010/05/the-facebook-privacy-wars-heat-up/56344/

research design of this thesis increases the overall reliability of this thesis.

Johnson [Joh97] discussed descriptive, interpretive, theoretical, internal, and external validity in qualitative research (*i.e.*, Publications I–III of this thesis). In this thesis, coherent to Johnson [Joh97], investigator triangulation increases descriptive validity, participant feedback increases interpretive validity, theory triangulation increases theoretical validity, method and data triangulation increases internal validity, and explicit sampling increases external validity (*i.e.*, generalizability). Internal and external validity are relevant also to quantitative research (*i.e.*, Publications IV–VI of this thesis).

Considering the reliability and validity of the publications:

Regarding Publication I, subjective bias is an intrinsic characteristic of the scenario planning method, because building the scenarios cannot be a completely objective process. However, the structured, systematic, and iterative steps in the process increased the objectivity of the scenarios. Gathering a varied pool of domain experts to the scenario building sessions increased the quality of the scenarios.

Regarding Publication II, one can argue that subjective bias was present while constructing the analysis framework and the classification scenarios, and while classifying the services under study. The bias was minimized by using a structured, systematic and iterative process when surveying the literature, constructing the framework and the scenarios, and classifying the services. Also, analyzing a large number of services increased the validity of the framework.

Regarding Publication III, one can again argue that subjective bias was present in constructing the analysis framework and doing the analysis. Again, the bias was minimized by using a structured, systematic and iterative process in the analysis. Additionally, a confirmatory survey was done, and factor analysis was used to classify its results. Choosing domain experts as respondents to the survey increased its validity but restricted the sample size. Results from factor analysis are always susceptible to multiple interpretations.

Sample bias and representativeness are concerns regarding the questionnaire samples of Publications IV and V, and the panel sample of Publication VI. The sampling process may have lead to self-selection bias. Also, it could not be proven that the samples represent the Finnish users of advanced handsets, as was the goal of sampling. However, sampling was

done from a large potential pool of participants by sending invitations to ca. 10,000 customers of the major Finnish mobile service operators, which constitutes a broad and valid sampling process.

Publication IV used several methods to avoid bias. The respondents were inquired about complicated technical concepts using proxies.[4] Non-response bias was tested for by comparing demographics of the respondents to the demographics of the non-responding panelists. Common method bias was reduced by respondent anonymity, a counterbalanced order of questions, careful construction of the scale items, and controlling common methods variance.[5]

Regarding Publication V, combining two sampling groups increased sample size, but may have resulted in over-representation of young students in the sample.[6] The more technical questions about battery consumption and social sharing were more challenging to answer than the general questions about service usage in the survey, potentially leading to decreased reliability of the corresponding results. Interpreting the results is more susceptible to bias in descriptive surveys than in surveys employing a conceptual model, because confidence limits and fit indices cannot be calculated.[7]

Publication VI was not able to identify reliably a significant portion of the traffic, but the analysis strongly suggested that most of the unidentified traffic is P2P traffic. In the panel section of the study, the small number of data points related to P2P application usage is the main concern. Usage monitoring is more reliable than surveying usage due to self-reporting bias.[8]

[4]For example, increased battery consumption was used as a proxy for P2P system design.

[5]See Section "Results" of Publication IV for details

[6]On the other hand, the publication was focused on active users of advanced handsets. According to Pagani [Pag04], 18–24-year-old students are more actively experimenting with new mobile services than other age and occupation groups. Therefore, the increased number of young students is justified in the sample considering the focus of the publication, although students are over-represented compared to the general population.

[7]In other words, Publication V is more susceptible to bias than Publication IV.

[8]Thus, the application usage monitoring results in Publication VI are more reliable than the self-reported application usage results in Publication V.

5.4 Further Research

This thesis does not extensively consider the policy and regulatory issues related to mobile peer-to-peer systems and services. Vaishnav [Vai10] argued that the current US regulatory structure is not fit to address modular Internet services, including P2P-based VoIP services. The regulatory framework of the EU is different from the US structure, and seems to handle, for instance, Skype at its current form [GR05]. However, as P2P-based communications services develop and may become partial substitutes for the PSTN, regulatory concerns such as facilitating emergency dialing, lawful interception,[9] interconnection, and assessing significant market power become more relevant.

P2P-based content distribution services have also introduced policy issues. The main concern is "piracy"[10] in P2P file-sharing networks. The media industry claims it causes significant losses and lobbies strict copyright law enforcement, whereas some parties necessitate the development of new business models for P2P-based content distribution instead of excessive litigation.[11]

A broader policy issue is the discrimination of third-party services threatening the profits of network operators, such as P2P-based services enabling free voice calls or video streaming, which are competing against corresponding premium services of network operators.[12] The discrimination is commonly based on managing traffic with deep packet inspection,

[9] Skype may already provide lawful interception, see `http://www.h-online.com/security/news/item/Speculation-over-back-door-in-Skype-736607.html` and §4 in `http://www.skype.com/intl/en-us/legal/privacy/general/`

[10] Infringement of exclusive rights in creative works, especially for financial gain, is commonly called "piracy".

[11] For example, Hietanen [Hie08] analyzed creative commons licensing as an alternative for copyright; Karaganis [Kar11] came to the conclusion piracy is caused by misdefined consumption of media and "unmet consumer demand" due to inefficient distribution and pricing of media goods, especially in developing markets; and Kokkinen [Kok10] developed a system to legalize copyright-infringing transactions in P2P file-sharing networks.

[12] The issue is part of the network neutrality debate: some believe traffic discrimination endangers innovation on the Internet, whereas others believe traffic management is needed to sustain reasonably priced access to the Internet. See van Schewick [vS10] for an overview on the topic. In particular regarding P2P-based content distribution services, Pouwelse *et al.* [PGES08, p. 711] proposed "new and sustainable Internet-compatible business models" for content distribution. If new business models are not adopted, one possible scenario is that "the telecommunication and content industries will combine to halt 'innovation at the edge' by blocking competing P2P services."

imposing usage-based billing instead of flat-rate billing, or by using both strategies. Further research is warranted on the regulatory and policy issues raised by P2P-based services.

Another interesting point for further research could be the interplay between P2P services and their enabling technology platforms. The topic could be studied from a techno-economic point of view, where the relation between the technology platform provider and service provider is analyzed.[13] The question could be generalized into other technology platform classes and technology patent litigation in general. Finally, studying the diffusion of P2P services to consumers and its possible differences compared to the diffusion of other service classes could be of interest.[14]

Considering further research regarding the publications of this thesis:

Publication I suggested building quantitative models based on scenario analyses using, for example, techno-economic modeling and system dynamics,[15] refining stakeholder interactions with, for instance, value network[16] and incentive analyses, and building decision scenarios,[17] as points of further study.

Publication II proposed extending and verifying the value analysis framework by applying it to different case studies. Also, extending the framework by applying it to dynamic value allocation situations, where service characteristics and industry structure change over time, could be beneficial.[18] Finally, the publication proposed using quantitative data[19] to substantiate the value analysis.

Publication III suggested embedding quantitative analysis into the value evolution framework and applying the framework to other cases as points of further research. Also, studying more extensively the interplay of the

[13] An illustrative example is the now settled dispute between Joltid, the technology platform provider for Skype and its licensor eBay, the parent company of Skype. See p. 15 in `www.sec.gov/Archives/edgar/data/1065088/000119312509157212/d10q.htm` and `http://blogs.skype.com/en/2009/11/joltid_settlement.html`

[14] See Peres *et al.* [PMM10] for a recent review on diffusion processes of new products and services.

[15] See Sterman [Ste00] for an introduction to system dynamics.

[16] Value network modeling in conjunction with scenario analysis was done in Publications II and III, although using more general scenarios than those in Publication I.

[17] Building decision scenarios is bound to the objectives of the decision maker, and is more suitable to actual decision making situations than to academic study.

[18] The value analysis framework is applicable to static situations, where characteristics of the services are fixed according to the situation at the time of study.

[19] *e.g.*, service usage measurements and economic indicators of stakeholders

frameworks suggested in Publications II and III could be of interest.

Publication IV proposed further research to verify the results in the context of other novel mobile services. Studying further the integration of communications and content sharing services could be of interest. Finally, a potential need for the development of a blank slate conceptual model for measuring the intention to adopt and the actual adoption of mobile services was identified.

Publication V suggested comparing distinct user segments, using other methods to measure usage,[20] doing a more detailed comparison of user perceptions of energy consumption to actual energy consumption of mobile services, and developing a theoretical framework of mobile service adoption and usage as points of further research. Also, combining surveys with usage measurements is a promising approach towards understanding user behavior.[21]

Publication VI proposed using more advanced P2P traffic identification metrics, and modifying them to take into account the peculiarities of mobile networks as further work for traffic trace measurements. For handset monitoring, more precise application identification and analyzing possible correlations between demographics and usage were identified as further work.

Perhaps the most important question remaining for further research is what constitutes as the ultimate competitiveness of mobile P2P systems and services. The benefits of P2P systems are clear in non-mobile environments: they are efficient in large-scale content distribution,[22] and in benefiting from computing processes of a large group of users.[23] Using P2P systems often results in cost savings in energy consumption, and in data transfer and processing capacity allocation for the service provider (but not necessarily for the user), and in more efficient functioning of the service due to the distributed architecture. However, ISPs face increasing costs of relaying high volume traffic outside their network domains, which can be dealt with usage quotas or traffic shaping.[24] One can en-

[20]Publication VI uses traffic trace measurements and handset monitoring to measure usage of mobile P2P applications.

[21]Later, the author participated in a study [HNSH] using both surveys and handset monitoring to understand user behavior regarding energy consumption of mobile handsets and services.

[22]*e.g.*, in distributing video and other high volume content, see Section 2.1.3

[23]e.g., connectivity in P2PSIP and in Skype, see Section 2.1.2

[24]See Sections 2.1.3 and 2.4.3. However, the same argument holds for most services generating high-volume traffic, such as streaming video from servers

vision a bright future for P2P in optimized content distribution,[25] and in intranets of large-scale service providers.[26] The main threat for this vision is the restrictive policy environment for P2P systems due to privacy and security concerns. However, the real benefits of *mobile* P2P systems are to be shown in the future. At their current trajectory, mobile P2P systems are beneficial in some *ad-hoc* scenarios, but in the majority of other scenarios mobile devices only act as clients to fixed P2P systems due to resource limitations of mobile devices and networks.[27]

5.5 Conclusion

This section answers to the overall research question Q0 of this thesis with the finding F0:

Q0: How can one analyze and characterize the effect of emerging mobile peer-to-peer systems and services on the technology and business domains of the Internet?

F0: Based on the value distribution and usage analyses of this thesis, one can assert that mobile peer-to-peer systems and services are transforming the technology and business domains of the Internet. To assess the extent of the transformation, one needs to use several methods, as this thesis does. Qualitative methods, such as scenario planning and value analysis, are needed for understanding the overall characteristics of the transformation from the viewpoints of various stakeholders. Quantitative methods, including surveying users and measuring usage, quantify the actual size and scale of the transformation. This thesis demonstrates that a multimethod approach is beneficial in understanding the technological and economic impacts of systems and services enabled by a novel technology.

The other main findings F1–F6 of this thesis are:

outside of an ISP's domain.

[25] For example, it is beneficial for an ISP to use a P2P system as a supplementary content distribution network for video streaming. ISPs would probably refrain from applying usage quotas to this "semi-transparent caching" opposed to file-sharing and streaming from third parties. However, this procedure could violate the possibly upcoming network neutrality legislation.

[26] Although it remains a semantic question whether commonly deployed distributed scalable file systems such as HDFS [`http://hadoop.apache.org/common/docs/stable/hdfs_design.pdf`] can be considered to be privately deployed P2P systems.

[27] See Section 2.1.1

F1: Depicting value creation as a long-linked value chain and focusing on individual firms instead of industries is not sufficient to understand the value formation of a novel technology. Instead, the value of a technology needs to be evaluated at least in architecture, production, network, and evolution domains. [Publications II and III]

F2: The value of mobile peer-to-peer services and systems differs among stakeholders and is dependent on the interrelationships between stakeholders and on the configuration of a service or a system. [Publications I-III]

F3: The commercial potential of mobile peer-to-peer services and systems has not been fully realized due to conflicts of interest between stakeholders (*e.g.*, between emergent service providers and incumbent network operators). [Publications I-III]

F4: The development of mobile devices and networks facilitates certain mobile peer-to peer service and system configurations. Some new entrants endorse them because of their potential to enable new business models, but incumbent stakeholders neglect them due to the risk of them disrupting established business models. [Publications I-III]

F5: Content distribution with peer-to-peer file sharing applications became the most prolific service in Finnish mobile data networks in 2007, depicting the rapid diffusion of peer-to-peer systems into the mobile domain, following the pattern from the fixed Internet. [Publication VI]

F6: A subset of Finnish consumers showed interest in mobile content distribution and communications services based on peer-to-peer systems, and in related revenue models, illustrating the commercial potential of mobile peer-to-peer services. [Publications IV and V]

The main techno-economic challenges in deploying mobile peer-to-peer systems and services are related to the following domains:

Business models: Incumbent network operators, service providers, content providers and platform providers have various reasons to object to mobile P2P systems and services. Network operators fear that P2P services lead to excessive traffic in their capacity-limited mobile networks and increase the expenses related to capacity upgrades and traffic management. Service providers face competition from low-cost or free P2P-based services. Content providers attribute P2P-based content distribution to illicit file-sharing. Platform providers, such as application store operators, dread the legal and policy implications of providing P2P applications and using private consumers' resources to provide P2P-based

services. However, harnessing free idle resources from computers with P2P systems remains a business opportunity.

Resources: Mobile P2P systems commonly require more connectivity and processing than client-server systems. This is due to maintaining the P2P overlay. Increased connectivity and processing consumes energy, which is an issue for mobile devices relying on limited battery power for their operation.[28] This issue can be partially circumvented by having mobile devices acting only as clients to P2P systems, which leads to incentive issues. The proliferation of mobile devices over stationary computers and the increasing cost of energy escalate the lack of resources by reducing the number of fixed peers.

Incentives: Incentive issues are characterized by the "free rider problem" in P2P systems: how to ensure the participants to the system commit enough resources to maintain the operation of the system. System design solves some incentive issues, but not all of them [ACM04]. Incentives have to be especially considered in mobile P2P systems, where some participants may only act as clients to the system.

Usability: Due to their resource demands, mobile P2P-based applications commonly require advanced mobile devices, such as advanced handsets or tablets, as their operating platform. Advanced devices are intrinsically more complex than basic devices, thus advanced devices are more difficult to use for many users than basic devices. P2P-based applications may also require more configuration by the user than client-server-based applications. Maintaining transparency of the resources shared may complicate the user experience more than obfuscating the information.

Security: Due to the complex nature of P2P systems, they have many potential security issues related to, for example, provisioning access to shared resources and maintaining the integrity of the overlay by eliminating malicious nodes and falsified resources [Wal03]. A limited number of control points handle security more feasibly than a system with distributed governance, but a control point can also be a single point of failure.

Policy: Regulatory decisions on network management practices and access pricing models have a significant impact on proliferation of mobile P2P services, as they commonly depend on relatively unconstrained and symmetric data transfer capacity and flat-rate pricing. Legal decisions on

[28] Firewall and NAT configurations of mobile ISPs may escalate energy consumption by necessitating ineffecient connectivity [WQX+11].

illicit P2P-based file-sharing will affect also legitimate P2P-based content distribution, as commonly a P2P system (*e.g.*, BitTorrent) is used for both purposes.

Solving these issues to a reasonable extent requires the collaboration of the whole community developing and deploying mobile peer-to-peer systems and services. Perhaps the main concern is that mobile peer-to-peer systems would be categorized as maladjusted due to these issues, which would not be beneficial for the society as a whole. If these issues are sufficiently solved, mobile peer-to-peer systems have potential for major innovation in realizing mobile services.

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Errata

Publication I

In Table 4, the triangle formed by dashes ("–") should not be interpreted as negative correlations.

Publication III

Tables 2, 4, 6, and 8 lack indication to which factor each variable belongs to. In Table 6, superscript "*" for item "Has subscription fees as an important revenue model" should be superscript "a".

Peer-to-peer (P2P) systems are an integral part of many technology and business domains of the Internet. P2P-based services are disrupting established business models, and they are emerging in the mobile domain. This dissertation analyzes the effects of emerging mobile P2P-based services and systems in the technology and business domains of the Internet by using a multimethod research design.

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