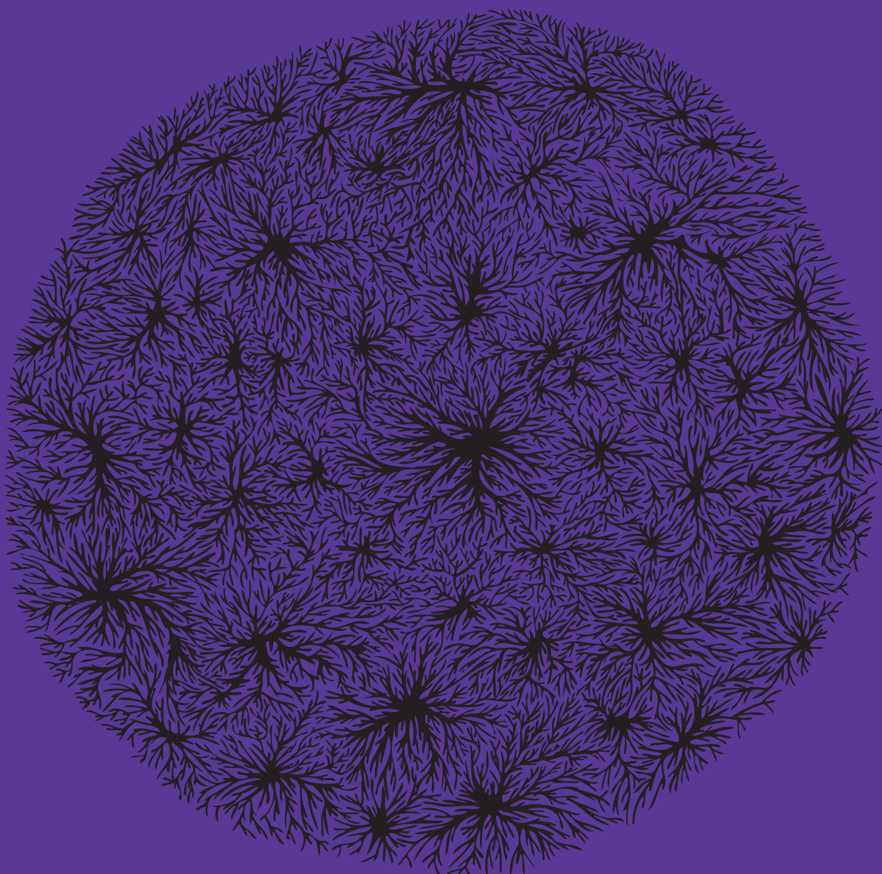
Department of Communications and Networking

Diffusion of Mobile Internet Services

Antero Kivi



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Diffusion of Mobile Internet Services

Antero Kivi

Doctoral dissertation for the degree of Doctor of Science in Technology to be presented with due permission of the School of Electrical Engineering for public examination and debate in Auditorium S1 at the Aalto University School of Electrical Engineering (Espoo, Finland) on the 4th of November 2011 at 12 noon.

Aalto University
School of Electrical Engineering
Department of Communications and Networking

Supervisor
Professor Heikki Hämmäinen

Instructor
Professor Heikki Hämmäinen

Preliminary examiners
Professor Harry Bouwman, Delft University of Technology, The Netherlands
Professor Dimitris Varoutas, University of Athens, Greece

Opponent
Professor Doctor Burkhard Stiller, University of Zürich, Switzerland

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Abstract

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Abstract
Mobile Internet is an outcome of the merging of two significant domains of technological innovation over recent years: mobile/wireless and the Internet. This merging will lead to new forms of end-user behaviour and also provide business opportunities for companies from the converging telecommunications, IT/Internet, and media industries. The diffusion of technological innovations is widely discussed in the literature. However, applications of the diffusion theory to mobile services have mostly concentrated on mobile telephony, and considered this diffusion to result from end-user adoption decisions that are made independently of other innovations. In contrast, the thesis of this dissertation is that the diffusion of mobile Internet services as systemic technological innovations depends on a cluster of separate but interrelated technology components that diffuse interdependently due to both demand-driven adoption and supply-driven dissemination.

This research was conducted using quantitative research data on mobile handsets and services collected from Finland during the years 2005-2009. The diffusion of mobile Internet services was found to depend on the generic technology components of mobile services: devices, applications, networks, and content. These components form an interrelated cluster of technologies. Consequently, direct market actor influence over a specific technology component has indirect effects on the other generic components, and, thereby, also influences the diffusion of mobile Internet services.

This dissertation contributes to the fields of innovation diffusion and mobile services research. Firstly, a general approach for planning and forecasting technology product evolution and new product feature diffusion was developed by isolating the previously unexplored phenomenon of product feature dissemination and linking it to the known phenomena of product category diffusion and product unit replacement. Secondly, observations on the diffusion of systemic technological innovations were made in the context of mobile Internet services related to component technology interdependence, market actor dissemination efforts, and end-user assimilation gaps. Thirdly, the fundamental differences of alternative methods to measure mobile service usage as well as the data provided by them were identified, and a holistic framework for analysing the usage of mobile services was developed. Fourthly, novel research methods and data were utilised.

Keywords Diffusion, mobile, Internet, dissemination, technology cluster, systemic innovation.

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Tiivistelmä

Mobiili Internet on seurausta liikkuvuuden/langattomuuden ja Internetin, kahden merkittävän viimeaikaisen teknologisen innovaation alueen yhdistymisestä. Tämä yhdistyminen johtaa uusiin kuluttajakäyttäytymisen muotoihin ja tarjoaa liiketoiminta-mahdollisuuksia yrityksille lähentyviltä tietoliikenteen, tietotekniikan, ja median toimialoilta. Teknologisten innovaatioiden leviämistä yhteisöissä, eli niin kutsuttua diffuusion ilmiötä on tutkittu laajalti. Diffuusioteorioiden sovellukset mobiilipalveluihin ovat kuitenkin pääasiassa keskittyneet puhepalveluihin ja käsitelleet tällaisten palveluiden diffuusiota erillisenä ilmiönä, joka on riippumaton loppukäyttäjien muista omaksumispäätöksistä. Tämän työn väite sitä vastoin on, että mobiilin Internetin palveluiden diffuusio systeemisinä teknologisina innovaatioina riippuu ryppäästä erillisiä mutta toisiinsa liittyneitä teknologisia komponenteja, jotka leviävät toisistaan riippuvasti sekä kysyntäpohjaisen loppukäyttäjien omaksumisen että tarjontapohjaisen komponenttien levittämisen seurauksena.

Tässä tutkimuksessa käytettiin matkapuhelimista ja matkapuhelinpalveluista Suomessa vuosina 2005-2009 kerättyä kvantitatiivista tutkimusaineistoa. Mobiilin Internetin palveluiden diffuusion havaittiin riippuvan mobiilipalveluiden yleisistä teknologisista komponenteista, jotka ovat: päätelaitteet, sovellukset, verkot, ja sisällöt. Nämä komponentit muodostavat toisiinsa liittyneiden teknologioiden ryppään. Siten markkinatoimijoiden suora vaikutus yhteen teknologiseen komponenttiin vaikuttaa epäsuorasti myös muihin komponentteihin, ja myös mobiilin Internetin palveluiden diffuusioon.

Tämä väitöskirja kontribuoi innovaatioiden diffuusion ja mobiilipalveluiden tutkimus-aloihin. Ensiksi, työssä kehitettiin yleinen menettelytapa teknologiatuotteiden evoluution ja uusien tuoteominaisuuksien diffuusion ennustamiseen eristämällä aiemmin tutkimaton tuoteominaisuuksien levittämisen ilmiö ja yhdistämällä se tunnettuihin tuotekategorioiden diffuusion ja tuoteyksilöiden korvaamisen ilmiöihin. Toiseksi, työssä tehtiin havaintoja systeemisten teknologisten innovaatioiden diffuusiosta mobiilipalveluiden tapauksessa liittyen komponenttiteknologioiden keskinäisiin riippuvuuksiin, markkinatoimijoiden levittämispyrkimyksiin, ja loppukäyttäjien omaksumiskuiluihin. Kolmanneksi, työssä tunnistettiin vaihtoehtoisten aineistonkeruumenetelmien ja niiden tuottaman aineiston perustavanlaatuiset eroavaisuudet, ja kehitettiin holistinen viitekehys mobiilipalveluiden käytön analysointiin. Neljänneksi, työssä käytettiin uusia tutkimusmenetelmiä ja -aineistoja.

Avainsanat Diffuusio, mobiili, Internet, levittäminen, teknologiarypäs, systeeminen innovaatio.

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Preface

"*The reputation I may have acquired on this account by which I shall receive promotion calls to my mind the very great assistance I received therein from you, which will ever be remembered with the most gratefull Acknowledgements*".

Captain James Cook

First and foremost, I want to thank Professor Heikki Hämmäinen for supervising my doctoral dissertation and for providing the context for my research. I am thankful to Professor Burkhard Stiller from the University of Zürich for acting as the opponent of my dissertation, and Professor Harry Bouwman from Delft University of Technology and Professor Dimitris Varoutas from University of Athens for acting as the external examiners of my dissertation. I also want to thank Professor Juuso Töyli for his example on striving for higher academic standards, Timo Smura for the countless discussions on mobile technology and business and for his constant feedback on my ideas, Antti Riikonen for carrying on my work in many areas, and Markus Peuhkuri for his technical council on all matters Internet. In addition, I much enjoyed the working environment within our research team as well as the company of the many colleagues at the department.

I am also grateful to the numerous people at TeliaSonera, Elisa, DNA, Nokia, GfK, and our other research partners for providing funding and invaluable research data for my dissertation. Moreover, I appreciate the financial support provided by the HPY Research Foundation, and the Research and Training Foundation of TeliaSonera Finland Oyj.

Finally, I want to thank my family for their support during my studies.

Nürnberg, September 26th 2011

Antero Kivi

Contents

List of Publications

This dissertation consists of a summary and of the following original articles which are referred to in the text by their Roman numerals.

I Kivi A. (2009). Measuring mobile service usage: methods and measurements points. *International Journal of Mobile Communications*, 7(4), pp. 415-435.

II Smura T., Kivi A., and Töyli J. (2009). A Framework for Analysing the Usage of Mobile Services. *INFO - The journal of policy, regulation and strategy for telecommunications, information and media*, 11(4), pp. 53-67.

III Kivi A., Smura T., and Töyli J. (2009). Diffusion of Mobile Handset Features in Finland. *Eighth International Conference on Mobile Business (ICMB 2009)*, Dalian, China, June 27-28.

IV Kivi A., Smura T., and Töyli J. (2010). Technology Product Evolution and the Diffusion of Product Features, accepted for publication at the *Technological Forecasting and Social Change*.

V Kivi A. (20011). Diffusion of Mobile Data in Finland. *NETNOMICS: Economic Research and Electronic Networking*, 11(3), pp. 243-254.

VI Smura T., Kivi A., and Töyli J. (2011). Mobile Data Services in Finland: Usage of Networks, Devices, Applications, and Content. *International Journal of Electronic Business*, 9(1/2), pp. 138-157.

Author's Contribution

The author contributed to Articles I to VI as follows:

I The author is the sole contributor to this article.

II The idea for this article was formed jointly with Smura, and the framework was also developed jointly with Smura. Smura assembled the manuscript, while the author was responsible for writing Chapters 2 and 4. The manuscript was edited iteratively together with Smura and Töyli.

III The idea for this article was formed jointly with Smura. The author was responsible for collecting and analysing the research data. The author wrote the manuscript, while Smura and Töyli provided comments.

IV The idea for this article was formed jointly with Smura. The planning and forecasting approach was developed jointly with Smura. The author was responsible for conducting the literature research and for collecting the research data, whereas data analysis was conducted jointly with Smura and Töyli. The author assembled the manuscript and was responsible for writing Chapters 1, 3, and 5. The manuscript was edited iteratively together with Smura and Töyli.

V The author is the sole contributor to this article.

VI The idea for this article was formed jointly with Smura. The author was responsible for collecting the research data, whereas data analysis was conducted jointly with Smura. Smura assembled the manuscript, while the author was responsible for writing Chapters 3 and 4. Smura and the author edited the manuscript iteratively together, while Töyli provided comments.

List of Abbreviations

AAA	Authentication, Authorisation, Accounting
CDR	Charging Data Record, formerly Call Detail Record
DNS	Domain Name System
DPI	Deep Packet Inspection
EDGE	Enhanced Data rates for Global Evolution
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
HSDPA	High-Speed Downlink Packet Access
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IMEI	International Mobile station Equipment Identity
IP	Internet Protocol
LAN	Local Area Network
MAN	Metropolitan Area Network
MMS	Multimedia Messaging Service
P2P	Peer-to-Peer
PAN	Personal Area Network
PDA	Personal Digital Assistant
SMS	Short message service
SPI	Shallow Packet Inspection, or Stateful Packet Inspection
TCP	Transmission Control Protocol
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VoIP	Voice over Internet Protocol
WAP	Wireless Application Protocol
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

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1 Introduction

Mobile Internet is an outcome of the merging of two significant domains of technological innovation over recent years: mobile/wireless and the Internet. The mobile telephone is one of the most widely diffused high-technology products, with the global annual unit sales of 1.2 billion mobile handsets far exceeding, for instance, the 302 million personal computers and 73 million automobiles sold in 2008[1]. Similarly, the Internet is among the largest media worldwide, with the almost 1.7 billion users being comparable to the 1.9 billion daily newspaper readers in 2008[2]. Moving the Internet to mobile devices presents plenty of potential for consumers and businesses alike, as the current Internet applications and services will likely be accompanied by brand-new and yet unimaginable applications specifically developed for the mobile environment. This development will lead to new forms of end-user behaviour and also provide business opportunities for companies from the converging telecommunications, IT/Internet, and media industries.

The diffusion of technological innovations is widely discussed in the literature (see Chapter 2 for a review), and the diffusion theory has also been applied to the diffusion of mobile services (see Section 2.4 for a review). However, these applications mostly concentrate on the diffusion of mobile telephony, and consider diffusion as a result of end-user adoption decisions that are made independently of other technologies or innovations. In contrast, the thesis of this dissertation is that the diffusion of mobile Internet services as systemic technological innovations depends on a cluster of separate but interrelated technology components that diffuse interdependently both due to demand-driven adoption as well as supply-driven dissemination. Accordingly, the research question of the dissertation reads:

> *Q How is the diffusion of mobile Internet services affected by the demand-driven adoption and supply-driven dissemination of the individual technology components of these services?*

---

[1] Information on mobile handset, personal computer, and automobile unit sales volumes was obtained from International Data Corporation (IDC) press releases and General Motors Corporation annual report.

[2] Information on Internet and newspaper consumption was obtained from Internet Usage Statistics (http://www.internetworldstats.com/stats.htm), and World Association of Newspapers (http://www.wan-press.org).

This research question is approached with research objectives that are related to three complementary topic areas: measuring and analysing mobile service usage, diffusion of mobile handsets, and diffusion of mobile data services.

First, research data on the usage of mobile services can be collected from numerous sources using many alternative methods. In fact, the concept of "mobile service" is quite ambiguous. The usage of a particularly mobile technology component such as a portable device (e.g. mobile handset or laptop computer), a wireless network (e.g. 2G/3G cellular network, WLAN, or WiMAX), or handset-adapted content (e.g. WAP pages) is often considered as usage of mobile services. In addition, the amount and complexity of digital information available on the usage of various technology components of mobile services is increasing rapidly (Gantz et al. 2008), making large-scale data collection and analysis an increasingly relevant research topic. This broad topic area is narrowed down with the following research objective:

> O_1 *Identify the alternative methods to measure the usage of mobile devices and services, and determine the fundamental similarities and differences of these methods and the data provided by them.*

Second, the mobile handset is a central technology component for the adoption and usage of mobile Internet services. The handset and new handset features are prerequisites for the adoption of many other service components, and need to undergo the time-consuming diffusion process to spread through the population of adopters. Moreover, the handset is often bundled with other technology components such as mobile networks (e.g. bundling of subscriptions and handsets), handset applications (e.g. platform-specific and factory-installed third party software applications), and content (e.g. operator portals). Mobile handsets also include many features (e.g. digital camera, GPS receiver, Java software platform) that enable new services to complement and substitute the traditional mobile communications services. The diffusion of handsets and handset features is a topic area that is approached by setting the following research objective:

> O_2 *Determine the evolution process of mobile handset populations and the diffusion process of mobile handset features.*

Third, the diffusion of mobile Internet services depends on both end-user adoption decisions and on the strategic decisions of companies providing the technologies underlying these services, as well as on the related regulation. Therefore, a holistic research approach is needed in order to understand the nature of mobile Internet service diffusion. Accordingly, the third research objective reads:

> O_3 *Identify the generic technology components of mobile services, and determine the factual diffusion and usage patterns of these components in an example market.*

The scope of this dissertation is defined by its title: diffusion of mobile Internet services. The concept of "diffusion" refers to the process in which an innovation spreads in a human society over time. The focus of this dissertation is on the aggregate level phenomenon (i.e. diffusion), not on the level of individual end-users and their decision-making (i.e. adoption). Mobile Internet services are seen as "systemic innovations" in that their benefits are attained only in conjunction with related complementary technologies. The concept of "mobile" is understood broadly in this dissertation, and encompasses all types of mobile/wireless devices, applications, networks, content, and services. Nevertheless, the primary interest of the research is on mobile handsets and their role as platforms for consuming mobile services. Furthermore, the concept of "mobile handset" is used instead of "mobile telephone" throughout the dissertation in order to distinguish between the simple mobile telephones of the 1990s and the more advanced "smart phones" and "mobile computers" of the 2000s. Finally, the dissertation concentrates on the innovative use of mobile handsets, especially concerning services and content provided in the Internet. There is no particular focus towards mobile operators as service providers, except as providers of the mobile data access (a.k.a. "bit-pipe") service. Therefore, traditional mobile telecommunications services such as voice calling and short message services (SMS) are not in the scope of this dissertation.

The diffusion of mobile Internet services as an innovation is the phenomenon of interest in this dissertation. Consequently, the theory on the Diffusion of Innovations provides the overall context for this research. Nevertheless, no single overarching research gap is identified from the field of diffusion research in this dissertation. Instead, separate but related research gaps are identified within the three topic areas and combined in the thesis of this dissertation.

The dissertation contributes to the fields of innovation diffusion and mobile services research (see Section 6.1 for details). Firstly, a general approach for planning and forecasting technology product evolution and new product feature diffusion is developed by isolating the previously unexplored phenomenon of product feature dissemination and linking it to the known phenomena of product category diffusion and product unit replacement. Secondly, observations on the diffusion of systemic technological innovations are made in the context of mobile Internet services related to component technology interdependence, market actor dissemination efforts, and end-user assimilation gaps. Thirdly, the fundamental differences of alternative methods to measure mobile service usage as well as the data provided by them are identified, and a holistic framework for analysing the usage of mobile services is developed. Fourthly, novel research methods and data are utilised.

The research in this dissertation is conducted using quantitative research data on mobile handsets and services collected from Finland during the years 2005-2009. The research data were collected from multiple sources in close collaboration with mobile operators, handset manufacturers, market research companies, and other third parties.

The dissertation consists of a summary and six original articles. The summary provides a general introduction to the studied phenomenon, gives an overview of the research conducted in the individual articles, and discusses the obtained research results. The six articles document in more detail the actual research conducted in this dissertation. The scientific and practical contributions are made in the individual articles, whereas the summary itself does not make a notable contribution. The summary is structured so that after the introduction, a selective overview on the diffusion of innovations theory is given in Chapter 2 ranging from the more general diffusion theories and concepts to the more specific and recent applications within the topic area of mobile services. The research data and methods are introduced in Chapter 3 and the research results on the diffusion of mobile Internet services are presented in Chapter 4. The results are discussed in Chapter 5, and the summary closes with concluding remarks in Chapter 6. The summary has a dichotomy between mobile handsets and mobile services, manifesting particularly in the internal structure of Chapters 2, 3, and 4. This dichotomy corresponds to two of the major research topic areas of the dissertation. The six original articles are included in the appendix. The structure of the dissertation is illustrated in Figure 1.

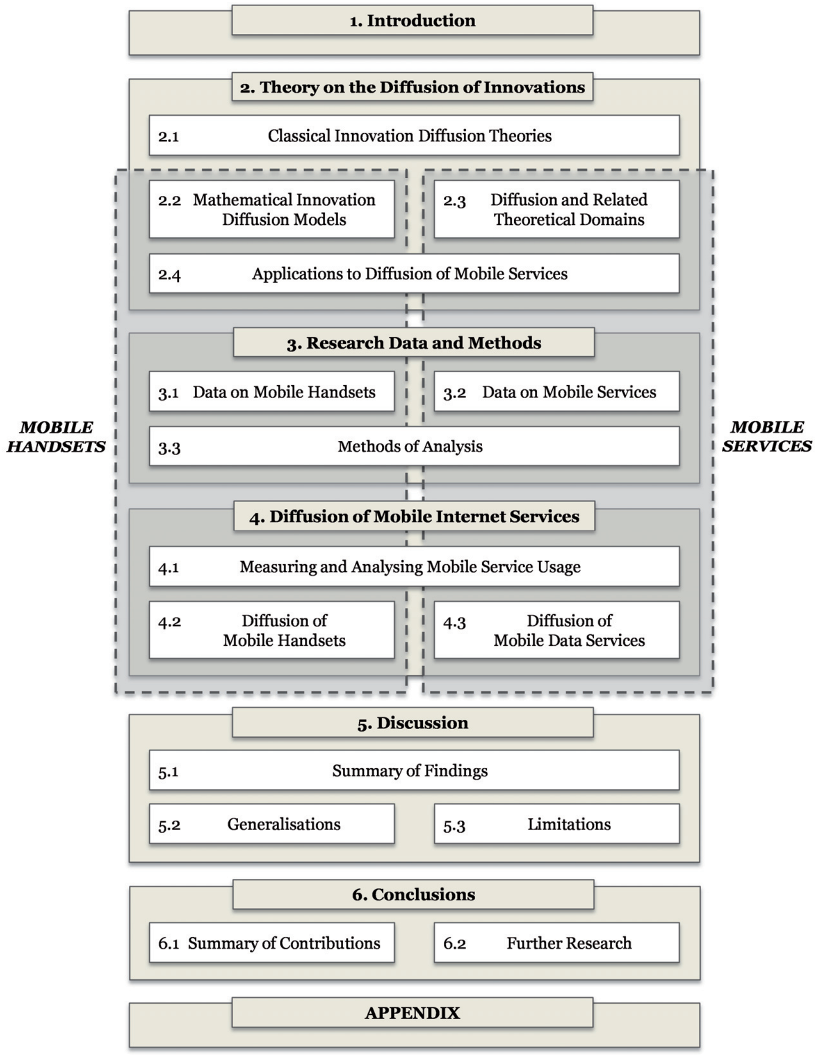

Figure 1 Structure of the dissertation

2 Theory on the Diffusion of Innovations

The phenomenon of innovation diffusion is as old as human history. New ideas, practices, and objects have spread through human societies since pre-historic times. These include the domestication of plants and animals, literacy, as well as various technological innovations related to, for instance, vehicles and weaponry (Diamond 1997). In modern times, innovation diffusion has become a popular research topic in social sciences. The most significant findings and theories on diffusion have been synthesised by Everett M. Rogers (2003) in his book Diffusion of Innovations, first published in 1962. Diffusion of innovations is not a well-defined, unified, and comprehensive theory. Instead, it defines a broad theoretical domain (Stinchcombe 1973) consisting of units of analysis, environments within which the theory is supposed to hold, and a substantive focus described by a set of concepts and relations between these concepts. Diffusion of innovations is the topic of a vast body of social science literature. The number of international peer-reviewed innovation diffusion related academic publications is counted in thousands (Rogers 2003), while new extensions and applications of the theory are published continuously.

A selective review of diffusion theories related to the topic of this dissertation is presented in this chapter. First, the relevant classical innovation diffusion theories and related concepts are introduced. Second, the most common mathematical innovation diffusion models are presented. Third, the relation between diffusion and other related theoretical domains is discussed. Fourth, applications to the diffusion of mobile services are reviewed.

2.1 Classical Innovation Diffusion Theories

According to Rogers (2003), diffusion is *"the process in which an innovation is communicated through certain channels over time among the members of a social system"*. This process is discussed next.

2.1.1 Adoption and Diffusion

The decision to adopt an innovation by an individual or other decision-making unit is not an instantaneous act. Instead, it is a process, which occurs over time. This process, also known as the innovation-decision process, can be seen as having five distinct stages; knowledge, persuasion, decision, implementation, and confirmation (Rogers 2003). In other words, the individual goes through a process from having first knowledge of an innovation, to the formation of an attitude toward the innovation, to a decision to adopt or reject the innovation, to the implementation and use of the innovation, and, finally, to the confirmation of this decision. Adoption (or rejection) takes place in the decision-stage of this process, and refers to a decision “to make full use of an innovation by a single decision-making social unit” (Rogers 2003). The actual use of the innovation takes place after this process. At a later stage, an adopter can also discontinue the use of the innovation.

In contrast to adoption, diffusion is a system-level phenomenon in which members of the social system adopt the innovation over time. The rate of adoption (or diffusion rate) is the relative speed with which members of a social system adopt an innovation (Rogers 2003). Adoptions of an innovation in a social system are typically normally distributed, i.e. adoptions follow a bell-shaped curve when plotted over time on a frequency basis, whereas cumulative adoptions form the classical S-shaped diffusion curve. Accordingly, the diffusion of an innovation in a social system goes through a period of slow (but accelerating) growth before experiencing a period of relatively rapid growth, which again slows down (decelerates) near saturation. Eventually, successful innovations are often followed by another, superior innovation that leads to discontinuance and decline in the number of adopters of the prior innovation. This discontinuance is not shown by the basic diffusion curve. The adoption and diffusion curves are illustrated in Figure 2.

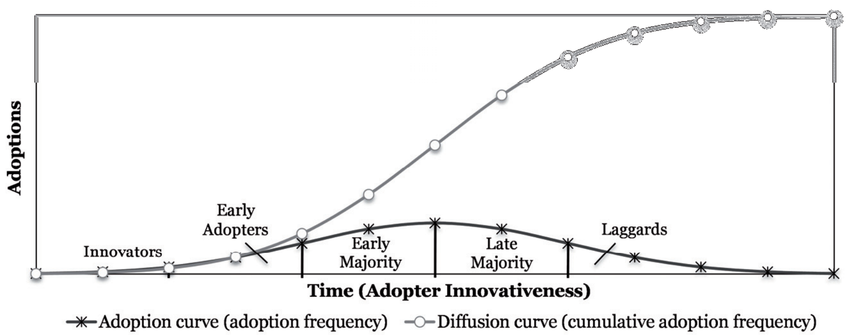

Figure 2 Adoption and diffusion curves, and adopter categorisations

The concept of adoption (i.e. decision to make full use of an innovation) is actually quite ambiguous, and depends on the nature of the innovation in question. The classical definition of diffusion as the communication of an innovation over social links implies that adoption essentially refers to the transfer of information. Epidemic diffusion models (see Section 2.2.1) are built on the same premise of information diffusion (e.g. Geroski 2000). In new product diffusion research, adoption is typically defined as the purchase or physical acquisition of the innovation (e.g. Bass 1969 and Meade & Islam 2006). Such definition of adoption does not apply well to products that have high knowledge barriers (e.g. information systems) or have multiple purposes of use (e.g. personal computers). This difference between innovation acquisition (purchase) and deployment (adoption) is sometimes called the "assimilation gap" (Fichman & Kemerer 1999).

The concept of diffusion is also sometimes used ambiguously. Some authors use the term "diffusion" to refer to the spontaneous unplanned spread of an innovation, whereas "dissemination" refers to a process directed and managed by change agencies. (Rogers 2003). Similarly, the relative importance of supply-push (a.k.a. technology push) and demand-pull (a.k.a. market or business pull) on technology diffusion has also been studied (e.g. Zmud 1984).

The diffusion of innovations can also be seen to result from different ideal types of innovation-decisions (i.e. decisions to adopt or reject the innovation). Optional innovation-decisions are made by individuals independently of the decisions of other members of the social system. Despite this independence, the individual decisions are still affected by general system norms and communication with other members of the system. Collective innovation-decisions are made by the consensus among the members of the system. Once the collective decision has been made, all units of the system must conform to it. Authority innovation-decisions are made by a relatively few individuals who possess power, status, or technical expertise in the system. In such decisions individual members have little or no influence on the outcome of the decisions. Finally, contingent (i.e. conditional) innovation-decisions are decisions that can be made only after a prior innovation-decision has been made. (Rogers 2003)

2.1.2 Innovativeness and Adopter Categories

Innovativeness is one of the concepts of behavioural sciences with the most immediate relevance to consumer behaviour (Hirschman 1980). Rogers (2003) defines innovativeness as the degree to which an individual is relatively earlier in adopting new ideas than other members in the social system. Innovativeness is a continuous variable that is often partitioned into discrete categories as a conceptual simplification. Consequently, members in a social system are traditionally categorised into five adopter categories based on their innovativeness; innovators, early adopters, early majority, late majority, and laggards (Rogers 1958). Adopter categories are typically characterised by differences in socio-economic status, personality values, and communication behaviour of their members. Moore (2002) argues there is a discontinuity (or "chasm") between early adopters and the early majority that explains the delays or failures in the diffusion of some innovations. Similarly, De Marez and Verleye (2004) suggest that the adoption curve of ICT innovations is double-peaked rather than bell-shaped. However, past research does not show conclusive support for these claims more generally (Rogers 2003).

A simple method to implement the adopter categorisation proposed by Rogers (1958) is to assume that individual innovativeness (i.e. adoptions over time) is normally distributed, and then use two basic statistical parameters, the mean time of adoption and its standard deviation, to divide adopters into the categories as depicted in Figure 2. More complex extensions allow for a flexible number of adopter categories as well as the use of other diffusion models besides the normal distribution (e.g. Peterson 1973, and Mahajan et al. 1990).

Rogers' simple definition of innovativeness has been strongly criticised for both theoretical and methodological reasons (e.g. Midgley & Dowling 1978, Hurt et al. 1977). Consumer innovativeness is generally seen as a personality trait possessed by all members of the society (e.g. Midgley & Dowling 1978, Roehrich 2004), whereas time of adoption is observable behaviour that is supposed to operationalise the latent construct of innovativeness. Furthermore, relying on the time of adoption method introduces problems related to the reliability and validity, comparability, and generalisability of the results (Hurt et al. 1977). The cross-sectional method is an alternative for measuring consumer innovativeness. In this method, innovativeness is measured by determining how many of a pre-specified list of new products a particular individual has purchased at the time of the survey (Midgley & Dowling 1978). However, the cross-sectional method suffers from many of the methodological limitations of the time of adoption method. Moreover, this method measures innovativeness as a global personality trait, and, therefore, is not of much use while studying innovativeness within a specific domain. (Goldsmith & Hofacker 1991)

The theoretical and methodological issues of time of adoption and cross-sectional methods can be avoided by using standardised multi-item self-report scales (e.g. Goldsmith & Hofacker 1991, Goldsmith et al. 1995) that measure consumer innovativeness by taking into account various theoretical perspectives such as novelty seeking, independence of others' experiences, and need for uniqueness (Roehrich 2004). Such scales have been developed at different levels of generality in order to measure both general (or innate) innovativeness as well as domain-specific innovativeness. In general, a broadly defined construct (e.g. general innovativeness) has lower predictive validity over specific behaviour but is able to predict diverse behaviours. In contrast, a narrowly defined construct (e.g. domain-specific innovativeness) predicts with high accuracy within a limited range of behaviours. (Moskowitz 1982, Goldsmith et al. 1995)

A further distinction can be made between adoptive innovativeness and use innovativeness, as the former refers to exploratory purchase behaviour and the latter to variety seeking in product usage (e.g. Price & Ridgway 1983).

2.1.3 Diffusion and Social Structure

The structure of the social system has a profound impact on flow of communication and the resulting innovation diffusion within the system. The nature of communication flow through social networks can be understood by the concepts of homophily and heterophily. Homophily is the degree to which two individuals who communicate are similar (in e.g. socio-economic status and education), whereas heterophily is the opposite of homophily. Innovations diffuse rapidly within homophilous networks, as communication is more effective when source and receiver are homophilous. (Rogers 2003) However, completely new innovations are more likely to be introduced by a heterophilous contact. This is consistent with Granovetter's (1973) theory on the strength of weak ties that postulates that weak social links (i.e. ties) enable reaching populations and audiences that are not accessible via strong links.

The actions of certain kinds of individuals can accelerate adoption. An "opinion leader" is an individual who is able to influence other people's attitudes or behaviour. Once opinion leaders adopt, they start influencing other people's opinions, and the diffusion accelerates. Opinion leadership is found to be highest among early adopters of innovations. A "lead user" is a similar concept referring to a user whose present needs will become general in the market in the future (von Hippel 1986). Therefore, understanding lead users' needs is beneficial in product development. Finally, a "change agent" is an individual who attempts to influence other individuals' innovation decisions in a direction desired by a change agency (Rogers 2003).

Models of communication flows can also be used to analyse the flow of information from mass media to opinion leaders, and onwards. The hypodermic needle model is a model of communications claiming that the mass media has a direct and immediate effect on mass audiences. This model was popular until the 1940s, after which it was superseded by the two-step flow model. (Lazarsfeld et al. 1944) Unlike the hypodermic needle model, the two-step flow model emphasises human agency. Accordingly, mass media information is channelled to the mass market through opinion leaders.

The critical mass (or tipping point) in the diffusion of an innovation occurs at the point at which enough individuals in a system have adopted an innovation so that the innovation's further rate of adoption becomes self-sustaining (Rogers 2003). The critical mass is particularly important in the case of interactive innovations, such as email, where each additional adopter increases the utility of adopting the innovation for all adopters. Such benefits are often called network externalities (or network effects), because the utility of the innovation is external to the individual adopter (Shapiro & Varian 1998).

2.1.4 The Innovation

The concept of technological innovation can be defined generally as *"an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention"* (Freeman 1991). This definition highlights the importance of technological development, the market introduction of the invention to end-users, and the subsequent adoption and diffusion (Garcia & Calantone 2002). However, in the diffusion of innovations theory an innovation refers more restrictively to an idea, practice, or object that is perceived as new by an individual or other decision-making social unit (Rogers 2003).

The concept of "innovation" is often replaced with that of "new product" in the diffusion of innovations context. Typically, a new product refers to a new product category such as the mobile handset or the television receiver. However, the concept of "really new product" is also sometimes used (e.g. Urban et al. 1996, Garcia & Calantone 2002) to make the distinction between completely new product categories or revolutionarily new product models, and more incremental innovation manifesting in new product models and variants. New units are typically not referred to as new products in the diffusion literature, although the sale of new units within a product category is the topic of interest in replacement sales modelling (see Section 2.2.2 for details).

The characteristics of innovations, as perceived by individuals, can also help to explain their different rates of adoption. Rogers (2003) identifies five such attributes. “Relative advantage” is the degree to which an innovation is perceived superior to the innovation it supersedes. “Compatibility” is the degree to which an innovation is perceived consistent with the existing values, habits, past experiences, and needs of a potential adopter. “Complexity” is the degree to which an innovation is perceived difficult to understand and use. “Trialability” is the perceived degree to which an innovation may be experimented with on a limited basis. “Observability” is the perceived degree to which the results of an innovation are visible to others. Innovations that are perceived as having greater relative advantage, compatibility, trialability, and observability, along with less complexity are more likely to be adopted more rapidly.

Diffusion of innovations research typically assumes that the diffusion of each innovation is independent of other innovations. However, individuals rarely perceive innovations as independent. Instead, innovations are often perceived as bundles, and the adoption of one innovation might lead to the adoption of others. A technology cluster (or innovation package) consists of *“one or more distinguishable elements of technology that are perceived as being closely interrelated”* (Rogers 2003). The diffusion of technologies belonging to a technology cluster is interdependent. In fact, it has been argued that the ownership of related technology products predicts the adoption of a new product better than Rogers’ (2003) classic perceived innovation characteristics (e.g. Reagan 1987, Vishwanath & Chen 2006). While the technologies forming a cluster tend to be compatible with each other and possess other similar characteristics, it has also been suggested that technology clusters are not formed by their perceived attributes but rather due to their shared infrastructure (Atkin & LaRose 1992). Change agencies often bundle technologies in order to facilitate adoption.

Many technological innovations are fundamentally systemic, so that their benefits can be attained only in conjunction with related, complementary technologies (Chesbrough & Teece 1996). Similarly, “complex goods” or products can be defined as systems with components that have multiple interrelations and constitute a non-decomposable whole. The overall performance of such goods depends on the performance of individual components that also require close configuration. (Mitchell & Singh 1996) Increased product complexity is also recognised as an emerging topic of diffusion research (Renana et al. 2010). A further distinction of systemic technology innovation can be made between the components of a product and the ways they are integrated into the system. In “modular innovation”, only the technology components of a system are changed, whereas in “architectural innovation” the relationships between the components of a system are reconfigured. (Henderson & Clark 1990) The service science takes a broader view on the topic, and defines “service systems” as value-co-creation configurations of people, technology, other internal and external service systems, and shared information (Maglio & Spohrer 2007, Spohrer et al. 2007). Finally, Adomavicius et al. (2007, 2008) propose a conceptual model of “technology ecosystems”, consisting of populations of technologies organised as overlapping hierarchies and having multiple interrelationships.

The nature of technological innovation has been widely discussed in the literature. Accordingly, innovations and technologies have been characterised as incremental/radical, continuous/discontinuous, evolutionary/revolutionary (e.g. Abernathy & Utterback 1978, Tushman & Anderson 1986, and Porter 1985), and sustaining/disruptive (Bower & Christensen 1995, Christensen 2000). These partly overlapping concepts are typically related to performance improvement provided by the new technological innovations. Similarly, diffusion research has been conducted on successive generations of technologies. In such research, a new generation is defined by a significant performance improvement of the diffusing technology (e.g. Islam & Meade 1997).

2.2 Mathematical Innovation Diffusion Models

Mathematical models have been developed to quantify the process of innovation diffusion. These models provide functions that simplify and formalise the diffusion process, and help in analysing, characterising, and comparing different diffusion processes. Diffusion models are also used for forecasting the unit sales and rates of adoption of new product categories in future time periods.

2.2.1 Types of Technology Diffusion Models

Empirical studies have shown that typically the temporal diffusion pattern of a technology forms a sigmoid (i.e. S-shaped) curve. Alternative theoretical models have been proposed to explain this form, and much of diffusion research concentrates on the mathematical modelling of the diffusion process. The epidemic model and the probit model are among the most popular types of diffusion models, although less well-known alternatives such as plant growth models are also sometimes applied (Marinakis 2011).

The epidemic model of diffusion, named after its analogy with the spread of contagious diseases, is the most popular explanation of the S-curve

(Geroski 2000). In epidemic models, technology diffusion results from the diffusion of information. A superior new technology is not adopted immediately by all people because they are not immediately aware of the existence or performance of the technology, not because of delays in individual adoptions. Therefore, new technology diffusion is determined by the spread of information about it. The process of information diffusion can be modelled from different perspectives; as transmission of information from a central source directly to all adopters, or as word-of-mouth information transmission where previous adopters are the main source of information for new adopters. These two processes are often combined in so called mixed information source models (e.g. Bass 1969). In such models, users are divided into two types, those more susceptible to central source information (sometimes called "innovators") and those who insist on receiving word-of-mouth information before adoption (sometimes called "imitators"). The epidemic model is predominant within marketing and sociology, among other disciplines.

The probit model of diffusion (David 1969) is the prime alternative to the epidemic model. In probit models, the differences between adopters (e.g. individuals, households, companies) explain patterns of diffusion. In such models, the potential adopters differ in some characteristic (e.g. company size) that affects the benefit from adopting the new technology. This characteristic is distributed across the population according to some function (e.g. normal distribution). Adoption will take place when the characteristic exceeds a threshold level (e.g. cost of adoption). Diffusion progresses when the threshold or the benefit from adoption change, i.e. when the cost decreases and/or the benefit increases. The probit model focuses on the potential determinants of diffusion, and, therefore, enables the analysis of the actions of specific adopters (e.g. companies) unlike epidemic models that concern themselves with the market on aggregate. (Geroski 2000) The probit model is particularly popular among economists (Stoneman 2002).

All in all, the choice between epidemic models and probit models is not decisive. Epidemic models can be extended with decision variables (e.g. marketing mix) to allow for heterogeneous populations, whereas all drivers of diffusion featuring in epidemic models can also be expressed in probit form. (Geroski 2000)

2.2.2 Diffusion, Substitution, and Replacement Models

Diffusion models have been extended to forecast the unit sales of new products beyond first purchases. Such models have incorporated product replacements and substitutions, as well as multiple generations and categories of the products.

Basic diffusion models, such as the classical Bass model (Bass 1969), depict the growth of the number of innovation adopters, and serve the purpose of forecasting the first purchase sales of new products. (Mahajan et al. 1990) However, as diffusion progresses and the product matures, first purchase units are replaced by newer units, and total unit sales eventually become dominated by replacement purchases. Replacement purchase models (e.g. Olson & Choi 1985, and Kamakura & Balasubramanian 1987) decompose total unit sales into first purchases and replacement purchases. Emphasis is placed on modelling the process that drives current owners of the product to discard the worn-out or obsolete units and replace them with new units, which is typically achieved by making assumptions about the lifetime of sold products (Islam & Meade 2000). Models of technological substitution (e.g. Fisher & Pry 1971) assume that a new technology or product completely substitutes its predecessor, and enable the estimation of the market shares of the alternative technologies at a given time.

Technology diffusion and substitution have been combined in categorical and generational models. Diffusion models incorporating product sub-categories have been used to analyse the effect of, for instance, competing standards and brands on product diffusion rates and market potential (e.g. Mahajan et al. 1993, Krishnan et al. 2000). Multigenerational models have been developed for modelling the diffusion of successive generations of technology products. In such models, the diffusion of a new product generation results not only from first purchases but also from substitutions of previous generations' units. Eventually, the new product generation diffuses to a wider population of users, and the sales of the previous generations' units end. The work by Norton & Bass (1987, 1992) on multigenerational models has been later extended and applied by, for instance, Mahajan & Muller (1996) and Islam & Meade (1997). Kim et al. (2000) and Chu & Pan (2008) combine generational models with categorical models to analyse the diffusion of multiple products that compete to fulfil the same function (e.g. analogue and digital mobile telephones, and pagers).

2.3 Diffusion and Related Theoretical Domains

Traditional diffusion research measures adoption as a simple binary decision of adoption or rejection. Even so, the post-adoption use of the technology is important in describing the success and failure of formally adopted technologies and the true extent of diffusion (e.g. Robertson & Gatignon 1986). Parts of the overall process covering both adoption and post-adoption phases are in the focus of several theoretical interdisciplinary domains, including diffusion, adoption, domestication, uses and gratification, and consumer behaviour. These domains vary based on their primary focus on the adoption or the post-adoption phase, and on the aggregate or individual view taken on adopters and users. The different domains can be positioned roughly based on these two dimensions, as illustrated in Figure 3.

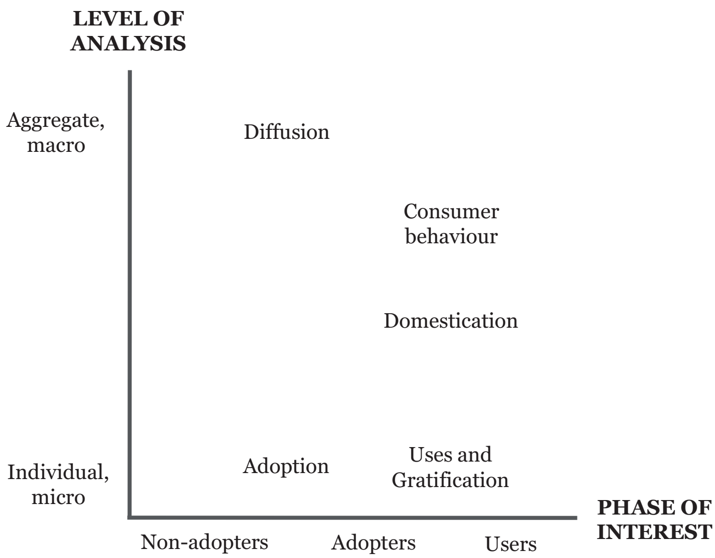

Figure 3 Relative positions of diffusion and related theoretical domains

Diffusion research itself is conducted in a range of academic disciplines including sociology, marketing, and communication. Diffusion studies concentrate on the aggregate diffusion of a technology within, for instance, an organisation, a community, or the society in general. (Rogers 2003) The "use-diffusion model" (Shih & Venkatesh 2004) attempts to complement this classical adoption-diffusion perspective by inspecting post-adoption use of an innovation. The focus of the use-diffusion model is on rate and variety of use instead of timing and rate of adoption. Consequently, the user population is divided into intense, specialised, non-specialised and limited users following these dimensions, instead of Rogers' (1958) classical segments (innovators, early adopters, etc.).

Adoption research belongs to the domain of information systems science. Typically, it focuses on the information and communication technology adoption decisions of individuals in the organisational context by applying theories and models of decision making. The most popular such models are the theory of reasoned action or TRA (Fishbein & Ajzen 1975), the theory of planned behaviour or TPB (Ajzen 1985), the technology acceptance model or TAM (Davis 1989), and the unified theory of acceptance and use of technology or UTAUT (Venkatesh et al. 2003). Several hundred studies extending and applying these theories have been published.

Domestication research is a topic of social sciences studying the societal consequences of the domestication (i.e. taming) of technology, the process in which the use of a certain technology becomes integrated into everyday life. Throughout this process, the technologies are adapted to users' everyday practices, the users and their environment adapt to the technology, and these adaptations ultimately shape the next generation of the technology. (Silverstone & Hirsch 1992) Domestication studies have been conducted on both individuals and aggregates, and covered technologies such as fixed telephony, television and home computers (Pedersen & Ling 2003).

Uses and Gratifications research has its origin in media and communication theory, and studies the gratification (i.e. satisfaction) sought by users of different media. The principle in uses and gratifications research is that individual users seek gratification in technology use based on their individual needs or motivations. (Katz et al. 1973) Originally, uses and gratifications research concentrated on mass communication media but later studies have analysed other technologies such as the Internet and email.

Consumer behaviour is an interdisciplinary domain combining elements from, for instance, economics and psychology. Essentially, it refers to the study of buyer decision-making process, i.e. the process dealing with the acquisition, consumption, and disposition of products and services. Consumer behaviour identifies both the roles of buyers and users, as adoption and use of new products and services are both within its scope, and analyses buyer behaviour at both aggregate and individual levels. (Foxall 2005)

2.4 Applications to Diffusion of Mobile Services

The diffusion of innovations theory has been applied extensively to the diffusion of mobile services. The evolution of mobile services can be divided into two phases: mobile telephony and mobile data services. The previous research on the diffusion of mobile telephones (i.e. handsets) and mobile data services is reviewed selectively in the following sections.

2.4.1 Diffusion of Mobile Handsets as Technology Products

Mobile telephony (i.e. mobile voice calling service) was the primary service enabled by 1G and 2G mobile handsets and networks. Therefore, the diffusion of mobile telephony has been modelled as the diffusion of mobile handsets[3]. This diffusion has been modelled using generic new product diffusion models (see Section 2.2). These models have been applied to study mobile telephony diffusion on both single (e.g. Botelho 2004, Frank 2004, Massini 2004, Singh 2008, Michalakelis et al. 2008, Gamboa & Otero 2009, Hwang et al. 2009, Liu et al. 2009) as well as multiple national markets (e.g. Dekimpe et al. 1998, Jang et al. 2005, Rouvinen 2006). Multigenerational diffusion models have also been applied to the diffusion of successive generations mobile technologies (e.g. Islam & Meade 1997, Kim et al. 2000, Danaher et al. 2001, Liikanen et al. 2004, Chu & Pan 2008, Michalakelis et al. 2010). Moreover, multiple handset-related product categories (Kim et al. 2000, Chu & Pan 2008) as well as handset subcategories (Krishnan 2000) have also been analysed using the diffusion models. Many of these studies have also explained the variance in the diffusion patterns by incorporating external decision variables (e.g. marketing mix variables) to the models.

During recent years, mobile handsets have evolved into multi-purpose devices with a rich variety of hardware and software features in addition to basic telephony functionalities. Handset features such as digital cameras and GPS receivers enable completely new mobile services that complement and substitute the traditional voice calling and text messaging services. Moreover, these features form a cluster of technologies with interdependent diffusion patterns.

The diffusion of new mobile handset features has been previously studied implicitly in order to better explain handset diffusion (e.g. Nair et al. 2004). In multigenerational diffusion models, the introduction of a new feature or a major feature upgrade is seen to result in a significant performance improvement and thereby define a generational change in handset

[3] In fact, such modelling is typically conducted using mobile subscription statistics, assuming that each subscription corresponds to a unique mobile handset (the new product) and a unique user of mobile telephony (the adopter).

evolution (e.g. Bayus 1992).[4] Currently, however, new feature introductions and upgrades are made more often and in higher numbers (e.g. Koski & Kretschmer 2007), and one single feature rarely defines a new generation or a significant performance improvement. For instance, certain mobile telecommunications technologies are commonly referred to as second and third generation technologies (2G and 3G, respectively), however, for end-users 3G is essentially a new handset feature offering performance improvement that could also be obtained, for example, with the WLAN feature. Consequently, the boundaries between different generations of mobile handsets have become increasingly vague and an increased level of detail is needed while modelling the diffusion of new features. Despite the growing importance of mobile handset features, no large scale attempts to quantify and model the diffusion of features has been made.

2.4.2 Diffusion of Mobile Data Services as Systemic Technologies

Mobile data services have been an increasingly important feature of 2G and 3G mobile handsets and networks ever since the introduction of the SMS. The technology components of these services have gradually evolved towards those of the Internet, replacing circuit-switched with packet-switched data transmission in wireless access, enabling mobile web browsing first with WAP and later with full HTML browsers, and shifting from ring tone and wall paper content to multimedia and application downloading. This convergence of mobile data services and the Internet has been accompanied by the convergence of mobile handsets and other end-user devices like personal computers and televisions, as well as that of GSM/UMTS networks and other wireless networks like WLAN and WiMAX.

The systemic nature of mobile services has been previously studied from various perspectives. Jørstad et al. (2005) analysed and compared the technological components and sub-components of mobile services, taking into account the viewpoints of end-users, mobile network operators, handset manufacturers, as well as application service and content providers. Ishii (2004) and Akiyoshi & Ono (2008) studied the diffusion of mobile Internet in Japan and compared the determinants of mobile and computer based Internet use, while taking the differences of the underlying technology components into account. Yoo et al. (2005) studied the role of standards, regulations, and actor strategies in promoting, enabling, and

[4] Substitutive product categories have also been modelled as new generations of technology products, like in the case of pagers and mobile handsets (Kim et al. 2000).

constraining the development of the technology components of mobile network infrastructure, and the resulting diffusion of broadband mobile services in South Korea. Carlsson et al. (2006) studied the adoption of 3G+ services in Finland, and found that the costs of handsets and subscriptions as well as the limitations of current handsets and network technologies were important constraints to the adoption and diffusion of such services.

The diffusion and usage of clusters of technologies has also been studied previously. Vishwanath & Chen (2006) studied the clustering of 30 different technologies between adopters and non-adopters, whereas van Rijnsoever & Castaldi (2009) compared the clustering based on technology ownership and perceptions, and van Rijnsoever et al. (2009) the interdependency of the perceived characteristics of 16 consumer electronics technologies. Lee et al. (2009) analysed the diffusion of convergence products in relation to single-function products. These studies analysed a wide range of technologies, including different types of mobile handsets, computers, portable music players, digital cameras, and broadband Internet access among others.

Alternatively, individual technology products with multiple features that enable multiple purposes of use have also been considered as technology clusters. Ram & Jung conceptualise (1990) the usage of multi-purpose products such as personal computers identifying the two dimensions of usage frequency (how often the product is used) and usage variety (to which purposes the product is used), and analyse (1994) the potential effect of adoption timing on the usage of such products. Moreover, Shih & Venkatesh (2004) replaced usage frequency with rate of use (or amount of use) in their use-diffusion model (see Section 2.3 for details) explaining the post-adoption behaviour of personal computer users. Similarly, Chircu and Mahajan (2009) suggested using both mobile technology depth (i.e. adoptions, penetration) and mobile service breadth (i.e. variety of services used) as metrics in innovation diffusion and digital divide research. Usage rate and variety were also discussed by Lee (1986), who noted that the acquisition (possession) of personal computer hardware and software alone does not guarantee adoption.

The importance of supply-push and demand-pull factors on technology diffusion has also been studied in this context. Prescott & Van Slyke (1997) analysed the diffusion of Internet as a cluster of various hardware and software technologies, and concluded that this diffusion has been affected by both push as well as pull factors. van den Ende & Dolfsma (2005) studied the evolution and diffusion of various computing technologies since the year 1900, and argued that both supply and demand factors have had an effect on evolution and diffusion. Moreover, both of these studies concluded that the relative importance of push and pull factors on technology diffusion has fluctuated in time along the progress of the diffusion. In contrast, Gruber and Koutroumpis (2010) studied the diffusion of different generations of mobile services and proposed that the delayed market performance of 3G technology resulted from excessive supply-push and lack of true demand-pull.

The diffusion of mobile handsets has also been explained with performance improvements in not only handsets but also other technology components (e.g. Nair et al. 2004). Similarly, the effect of such improvements on the usage of systemic technologies has been studied. Hitt & Tambe (2007) found that broadband access drove the quantity and diversity of online content consumption in comparison to narrowband (i.e. dial-up) access. Yun et al. (2011) demonstrated that content and hardware quality, ubiquity, cost, and relational factors were important predictors of actual use of mobile browsing services. In contrast to these studies, Sugai (2007) showed that pre-existing usage habits had a far more important role in post-upgrade usage behaviour than the incremental technical capabilities of the new handset.

In summary, the diffusion and usage of mobile data services have been previously studied from the perspectives of enabling technology components, technology clusters, and push-pull effects, among others. Nevertheless, the diffusion process of mobile Internet services resulting from the supply-push and demand-pull factors on the individual technology components of these services has not been studied comprehensively.

3 Research Data and Methods

Research data on mobile devices, applications, networks, and content were collected from multiple sources. The relations between different data and their links to the technical components of mobile services are illustrated in Figure 4 and discussed in detail in the following sections. The methods of analysis used are also described.

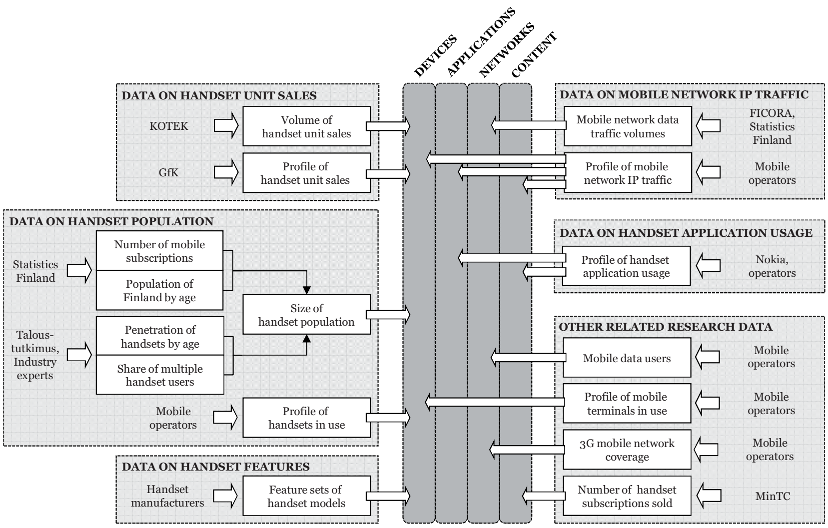

Figure 4 Data sources and their links to the components of mobile services

3.1 Data on Mobile Handsets

Research data on mobile handsets in Finland were collected from multiple perspectives. These data represent well the entire Finnish mobile handset retail sales as well as the Finnish mobile handset population. The different data sets are described in detail in the following sections.

3.1.1 Mobile Handset Unit Sales

Data on the monthly handset retail sales unit volumes were received from the collaboration forum of the Finnish consumer electronics and appliance industry KOTEK (www.kotek.fi). The annual unit volume of mobile handset retail sales has been growing steadily over recent years, approaching 2 million units or roughly 40% of the size of the Finnish handset population in 2008. Mobile handset retail sales vary between seasons with high unit sales occurring especially around the December holiday season and to a lesser extent during the summer.

Model-specific data on monthly handset unit sales were obtained from GfK (Gesellschaft für Konsumforschung), a market research company specialised in collecting sales data on technical consumer goods. Point-of-sale data on mobile handsets were collected from mobile operators and other traditional retailers, as well as online resellers and mail order houses. Such data have been collected in Finland since January 2003, during which the market coverage of the retailer panel has risen from about 70% in 2003 up to 90% in 2008, corresponding to roughly 1.3 to 1.8 million handsets yearly. These data were obtained for the research, and included the model-specific monthly unit sales volume of each individual handset model sold in Finland between January 2003 and December 2008.

The model-specific data were scaled up to full market coverage using the monthly retail data provided by KOTEK.

3.1.2 Mobile Handset Population

Data on the actual size of the mobile handset population in Finland are not readily available at any single source. This size was estimated by collecting related research data on mobile subscriptions and handsets. Statistics Finland, a government agency responsible for gathering various statistics on the Finnish society, has reported the number of analogue and digital mobile subscriptions in Finland yearly since 1980. Statistics Finland also publishes annual statistics on the size of the Finnish population, itemised, for instance, by age group. Taloustutkimus, a Finnish market research company, has reported the yearly penetration of mobile handsets among the 15 to 79-year-olds in 1999-2007 (15 to 74-year-olds before 2004) based on extensive survey studies. These penetrations were scaled up to correspond to the whole of Finland using the population figures collected by Statistics Finland. In addition, estimates for the share of mobile handset users having two or more handsets in active use were obtained from both Taloustutkimus as well as Finnish mobile industry experts.

Model-specific data on the mobile handsets in actual use were measured in cooperation with all three Finnish GSM/UMTS network operators having a combined market share of about 80-99% of mobile subscriptions and devices in Finland. The resulting size of the studied sample varied between 4-6 million handsets, depending on the measurement year. The data were collected each year and included the unique devices observed in each mobile network during September 2005, 2006, 2007, 2008, and 2009. The data collection was based on the charging functionalities of the studied mobile networks. A GSM/UMTS network creates special Charging Data Records (CDR) on all chargeable network events generated by mobile subscribers. Each CDR contains an International Mobile station Equipment Identity (IMEI) code that uniquely identifies each mobile terminal in the network, among other details. Research data were extracted from the CDR data by counting the number of unique terminal devices (i.e. unique IMEI codes) per terminal model that had used voice calling, text messaging (SMS), or packet-switched data transmission services during the research period. Mobile handsets were identified from other types of terminals based on manufacturer and model information.

The model-specific data were scaled up to full market coverage by combining them with the results on the size of the Finnish mobile handset population.

3.1.3 Mobile Handset Features

Data on the features supported by individual handset models were collected from handset manufacturer web pages and online databases. The collected feature data consisted of over 600 different handset models, covering over 99% of both the total monthly unit sales and the yearly mobile handset populations. Furthermore, manufacturer press releases were sought to obtain information on handset model introductions, i.e. the month and year each model was introduced to the public.

Sixteen mobile handset features were selected for analysis. The selected features have been introduced to handsets throughout the 2000s and, therefore, represent different phases of mobile handset evolution and have varying penetrations within the handset population. The selected features were also functionally different, including both integrated hardware features (GPRS, EDGE, WCDMA, WLAN, HSDPA, colour display, camera, FM radio receiver, Bluetooth, infrared, GPS) and pre-installed software features (WAP browser, Java, MMS, Email, HTML browser).

3.2 Data on Mobile Services

Research data on mobile services were collected from multiple perspectives, covering the usage of mobile devices, applications, networks, and content. The different data sets are described in detail in the following sections.

3.2.1 Mobile Network IP Traffic

Data on the volume of IP traffic in Finnish mobile networks were composed from the quarterly market reviews of the Finnish Communications Regulatory Authority (FICORA, www.ficora.fi) as well as the annual statistics on telecommunications by Statistics Finland (www.stat.fi).

IP traffic measurements were conducted simultaneously at the GSM/UMTS networks of the Finnish mobile network operators over two weeks during autumn between the years 2005-2008, corresponding to the market situation at the end of the third quarter. In 2005 and 2008, two of the three operators were in the scope of the measurements, whereas in 2006-2007 the networks of all three operators were measured. The measurements were conducted at a central node of the mobile network, and depending on the year included the packet-switched data traffic to/from the Internet generated by approximately 40-90% of Finnish mobile subscribers. The research data were assumed to represent the entire Finnish mobile market at the time of each measurement.

The underlying operating systems (e.g. Symbian, Windows, Linux) of the end-user devices generating the IP traffic were identified using a method called transmission control protocol (TCP) fingerprinting (Smith & Grundl 2002). In TCP fingerprinting, different operating systems are recognised by identifying idiosyncrasies in the implementation of their respective TCP/IP stacks. Different application protocols were identified from the traffic traces using transport protocol port numbers. These protocols were then grouped into three protocol categories: Web, Email, and Others. Furthermore, domain name system (DNS) lookups were also captured to determine the most popular web servers and content accessed by mobile handset users.

3.2.2 Mobile Handset Application Usage

Data on mobile handset application and feature usage were collected by organising mobile handset monitoring panels. Panels were organised for a period of two months during autumn between the years 2005-2007. A client application installed in each monitored Symbian S60 handset created log files on the usage of handset features and applications, and sent the log files daily to a centralised server. Individual usage events were observed and aggregated to obtain metrics on the usage frequencies, durations, and volumes of different handset applications. Moreover, data on the use of handset radio interfaces (e.g., GSM, WCDMA, WLAN), as well as offline features (e.g. camera, multimedia player, games) were obtained. Furthermore, the cell identity codes of visited mobile network cells were obtained, making it possible to link user location (i.e. home, office, or elsewhere) to usage data.

Potential participants were randomly sampled from the subscriber bases of three Finnish mobile operators. SMS recruitment messages were sent to 20,000 consumer subscribers using Symbian S60 devices, yielding about 500-700 active participants for each panel. Each year, the panellists were mainly young to middle-aged men, although other demographics were also represented. As the penetration of S60 handsets in Finland has been rather low during the panels (5% in 2005 10% in 2006, and 18% in 2007), the data likely represent early adopters of advanced mobile services instead of mainstream end-users. The data collection process used is described in detail in Verkasalo and Hämmäinen (2007) and the details of the panellist recruitment process are provided by Kivi (2006).

3.2.3 Other Related Research Data

Data on the share of active mobile data users and the number of different types of mobile terminals (e.g. handsets, data terminals, others) were collected from mobile operators, as described in Section 3.1.2.

Data on 3G mobile network coverage were collected from the Finnish operators' public press releases. Information from dozens of individual press releases from the three operators was combined to obtain a time-series of 3G network coverage.

Data on the number of mobile subscriptions bundled to a 3G device sold from April 2006 to December 2007 were obtained from a report of the Finnish Ministry of Transport and Communications (2008).

3.3 Methods of Analysis

The research data were analysed using quantitative and qualitative methods, including mathematical diffusion and replacement models, as well as other methods developed in this dissertation.

3.3.1 Diffusion Model and Estimation

A range of first-purchase diffusion models has been proposed in the literature, as discussed in Section 2.2. Meade and Islam (1998) provide an extensive review of the alternative models by identifying and comparing 29 different diffusion models. Moreover, guidelines have been suggested to aid in diffusion model selection (e.g. Meade & Islam 1998, Kumar & Kumar 1992), however, there are no common criteria for selecting an appropriate diffusion model for a particular case (Meade & Islam 1998).

The diffusion models utilised in this dissertation included the simple logistic (Verhulst 1838), the Bass (i.e. extended logistic, Bass 1969), and the Gompertz (1825), as these are among the most commonly used diffusion models. The parameters of the diffusion models were estimated using nonlinear least squares as suggested by Srinivasan & Mason (1986). More details on the conducted estimation of diffusion models are provided in Articles III and IV.

3.3.2 Replacement Model and Estimation

Product replacement modelling concentrates on the process where currently used units are discarded and replaced with new units. This process can be formulated using the number of unit sales s_t and discards d_t of all the individual units during a time period *t*. The number of units in use at the end of time period *t* is given by

$$n_t = \sum_{i=0}^{t} (s_i - d_i), \tag{1}$$

where n_t is the cumulative sum of unit sales s_i and discards d_i during time periods *0 … t*.

Many alternative models for the product replacement process have been proposed in the literature (see e.g. Islam & Meade 2000 for a review). Typically, the unit lifetime (or replacement age) *T* is assumed to be a random variable, and thereby several replacement distributions can be utilised as the probability density function *f(T)* of unit lifetime. These distributions include, for instance, Weibull, Gamma, and Rayleigh, as well as the superposition of two or more random variables when replacement results from multiple different causes. Assuming the cumulative probability *F(T)* as a proportion of the aggregate population of units sold during the same time period *t* (Kamakura & Balasubramanian 1987) and that all discards follow the same probability distribution, the number of discards during time period *t* is given by

$$d_t = \sum_{i=1}^{t-1} s_i \left[F(t-i) - F(t-i-1) \right]. \tag{2}$$

The *f(T)* can estimated using Equation (2), if sufficient data are available about the number of units in use n_t, unit sales s_t, and discards d_t for time periods *0 … t*. Another, more common approach is to rely on average unit lifetime *E(T)* and maximum unit lifetime T_{max} while estimating *f(T)* (e.g. Islam & Meade 2000). The maximum unit lifetime can be defined (Oates & Spencer 1962) as

$$Prob\ (T > T_{max}) = 0.0001. \tag{3}$$

The replacement models were estimated using Equation (2) as follows. First, the number of yearly discards d_t of was calculated based on the data on monthly unit sales s_t and yearly numbers of units in use n_t. Then, following the work of Islam & Meade (2000) a number of distributions (Weibull, Gamma, Rayleigh, and Poisson) were tested. More details on the estimation of replacement models are provided in Article IV.

3.3.3 Other Methods of Analysis

Some of the methods developed in this dissertation were also used while analysing the diffusion of mobile Internet services in Finland. First, the developed planning and forecasting approach (see Section 4.2.2 and Article IV for details) was used to forecast the diffusion of mobile handset features. Second, the framework for analysing mobile service usage (see Section 4.1.2 and Article II for details) was used to analyse the diffusion of mobile data services in Finland.

4 Diffusion of Mobile Internet Services

Research results were obtained in three complementary topic areas: measuring and analysing mobile service usage, diffusion of mobile handsets, and diffusion of mobile data services. The results were originally published in six separate research articles. A summary of these articles is presented in Table 1.

The results obtained in these articles are presented in the following three sections, corresponding to the described three topic areas. In addition, the results in Section 4.1 describing the alternative data collection and analysis methods have been complemented with new results obtained after the publication of Article I.

4.1 Measuring and Analysing Mobile Service Usage

Research data on mobile service usage can be obtained from numerous measurement points and data collection methods, as illustrated in Figure 5.

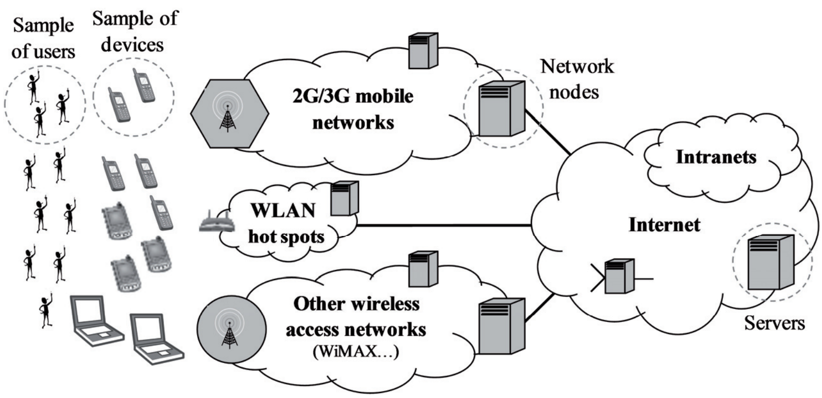

Figure 5 Sources of data on mobile service usage (Article I)

Table 1 Summary of research articles

	Measuring and analysing mobile service usage		Diffusion of mobile handsets		Diffusion of mobile data services	
	Article I	Article II	Article III	Article IV	Article V	Article VI
Article title	"Measuring mobile service usage: methods and measurement points"	"A framework for analyzing the usage of mobile services"	"Diffusion of mobile handset features in Finland"	"Technology product evolution and the diffusion of new features"	"Diffusion of mobile data in Finland"	"Mobile data services in Finland: usage of networks, devices, application, and content"
Research purpose	To identify the fundamental differences in the methods to collect primary research data on mobile service usage	To suggest and apply a holistic framework that helps in designing communicating, positioning, and comparing mobile service usage research	To compare the diffusion patterns of mobile handset features, and to explore characteristics that explain the diffusion rates of different features	To develop an approach for planning and forecasting technology product evolution and the diffusion of new product features	To provide factual information on the penetration and usage of mobile devices and services in Finland, and to identify key factors that have affected the diffusion of mobile data services	To analyse the usage of mobile data services in Finland applying a framework developed by in Article II, and to suggest mobile data market metrics that enable country comparisons
Research methods and data	Literature review No empirical data, practical experiences from multiple data sets, and data collection and analysis methods	Literature review No empirical data, practical experiences from multiple data sets, and data collection and analysis methods	Estimation of multiple diffusion models Data on mobile handset population, unit sales (first sales months of each model), and features	Estimation of multiple diffusion and replacement models Time-series and causal forecasting Data on mobile handset population, unit sales, and features	Descriptive statistics Data on mobile handset population and features Data on mobile network IP traffic Other related research data	Descriptive statistics Analytical framework developed in Article II Data on mobile handset population, unit sales, and features Data on mobile network IP traffic and mobile handset application usage, and other related research data

The most straightforward way available to all researchers is to do a survey or a panel study on a sample of real end-users. User behaviour can also be observed by monitoring a sample of end-users or end-user devices. Service usage can also be measured directly at intermediary network nodes in the wireless network and the core network by conducting traffic measurements, or by logging usage at various servers. In addition, access and service provider usage accounting systems are also good sources of information.

4.1.1 Methods for Measuring Mobile Service Usage

Mobile usage can be adequately covered only with some of the possible measurement points and data collection methods, as discussed in Article I. These include:

1. End-users: surveys and panels

2. Usage monitoring systems:
   user and handset monitoring

3. Wireless network nodes:
   traffic measurements and usage accounting

4. Selected servers: log collection

In contrast to Article I, the analysis concerning traffic measurements is developed further in this section. More specifically, these measurements have been further divided into pure IP traffic measurements, and IP traffic measurements combined with additional support data that enable the separation of individual network users from the traffic. The support data can be collected from the access network AAA (Authentication, Authorisation, Accounting) servers, and in some cases like the GSM/UMTS such information can also be available in lower layer protocol headers. Furthermore, the analysis based on transport layer headers (i.e. “shallow” packet inspection, SPI) is compared to the more complete utilisation of application layer data conducted in deep packet inspection (DPI).

The data collection methods differ regarding the typical researcher, method scope and sample size, as well as the type of services that can be measured. A summary of the research scope by the measurement points and methods is presented in Table 2, and described in detail in Article I. The additional analysis related to traffic measurements is discussed below.

There is no difference between the traffic measurements regarding their availability to researchers, as both pure IP traffic measurements as well as measurements using support data require direct access to the network and, therefore, are available only to wireless access operators. Similarly, the scope and sample of the alternative traffic measurements are identical. The use of SPI and DPI in collecting and analysing IP traffic defines the services covered with traffic measurements. In measurement using SPI, various common IP protocols (e.g. email, web browsing) as well as servers accessed (e.g. web sites) via the measured network can be observed. In DPI measurements, practically all IP protocols can be identified (e.g. streaming, P2P, VoIP). Moreover, DPI enables a more detailed analysis of the transferred content, and can cover a wide range of content types including users' search queries and advertisements on web sites, among others.

The nature of collectable data varies by method, and the method also largely determines which specific dependent usage variables and which measurable and non-measurable independent explanatory variables can be obtained. A summary of the characteristics of data provided by each measurement point and method is presented in Table 3, and discussed in detail in Article I. The additional analysis related to traffic measurements is discussed below.

Regarding the nature of collectable data, the different types of traffic measurements are fairly similar. Both measurements provide objective, quantitative, and highly accurate data. The granularity of data can be improved with the use of DPI instead of SPI.

The use of support data improves the explanatory power of wireless network IP traffic measurements considerably, as individual users can be separated from each other and background information from customer registers (e.g. subscription type, tariff) can potentially be linked to these subscribers. In such measurements in GSM/UMTS networks the used device model can also be identified depending on network configuration, whereas the device operating system can be determined in both types of traffic measurements using either TCP fingerprinting (SPI) or HTTP User Agent information (DPI). The exact time of usage is registered in both types of traffic measurements. Finally, location data at the level of individual cells (cell ID) is also be available in GSM/UMTS networks, either from lower layer protocols (DPI) or with the means of separate data collection from the operator's network (both SPI and DPI).

Table 2 Research scope by measurement point and method (mod. from Article I)

	End-users		Usage monitoring systems		Wireless networks			Servers
Method attributes	Surveys	Panels	User monitoring	Handset monitoring	IP traffic measurements	IP traffic measurements & support data	Usage accounting	Log collection
Access to data sources	Anybody (e.g. academics, analysts, company R&D)	Anybody (e.g. academics, analysts, company R&D)	Those with monitoring equipment (cameras, test devices, etc.)	Those with monitoring client and ability to recruit the panellists	Wireless access operators	Wireless access operators	Wireless access / service operators	Service / content providers, search engines, web content adaptation providers, etc.
Method scope and sample size	Survey respondents / interviewees: $10 – 10^5$	Panel participants: $10 – 10^3$	Study participants: $10 – 10^2$	Panel of users with specific handset OS(s): $10 – 10^3$	Operator's subscriber / terminal base: $10^2 – 10^8$	Operator's subscriber / terminal base: $10^2 – 10^8$	Operator's subscriber / terminal base: $10^2 – 10^8$	Users of the measured service(s): $10^2 – 10^7$
Measurable services	Services known by the user	Services known by the user	Services specifically selected to be studied (e.g. application, user interface, web service)	Handset applications and features, networks and servers used (e.g. camera, WLAN)	SPI: common IP protocols (e.g. email, web browsing) and content / services used (e.g. web sites) via measured network DPI: all IP protocols (e.g. streaming, P2P, VoIP) and content / services (e.g. web sites, search queries, ads.) via measured network	SPI: common IP protocols (e.g. email, web browsing) and content / services used (e.g. web sites) via measured network DPI: all IP protocols (e.g. streaming, P2P, VoIP) and content / services (e.g. web sites, search queries, ads.) via measured network	Services charged by access / service operator (e.g. calls, SMS, data transfer)	Intermediary and actual destination service (e.g. search, web sites)

Table 3 Data characteristics by measurement point and method (mod. from Article I)

Data characteristics	End-users		Usage monitoring systems		Wireless networks			Servers
	Surveys	Panels	User monitoring	Handset monitoring	IP traffic measurements	IP traffic measurements & support data	Usage accounting	Log collection
Subjectivity	Subjective	Subjective	Objective	Objective	Objective	Objective	Objective	Objective
Type of data	Qualitative & quantitative	Qualitative & quantitative	Qualitative & quantitative	Qualitative & quantitative	Quantitative	Quantitative	Quantitative	Quantitative
Granularity	Low	Medium	High	High	SPI: medium DPI: high	SPI: medium: DPI: high	High	High
Accuracy	Low	Low	High	High	High	High	High	High / medium
Measurable explanatory / independent variables								
• User	Any variables on respondents	Any variables on panellists	Any variables on participants	Any variables on panellists	None (individual users / devices not separated)	Possible to link some data on subscriptions (type, tariff) to users, no data on real end-users	Some data on subscriptions (type, tariff), no data on real end-users	Depends on method (identify individuals, variables on registered users, separate mobile usage, time of usage)
• Device	Handset model	Handset model	Test device	Handset model and access network	Device OS	Device model (GSM/UMTS), device OS	Device model (GSM/UMTS)	
• Time	Perceived time and location / context of usage	Higher accuracy on perceived time and location / context of usage with diary method	Time of usage	Time of usage	Time of usage	Time of usage	Time of usage	
• Location			Location limited to test environment (lab/field)	Location (cell ID, WLAN access point name, GPS coordinates)	SPI: no location DPI: location (cell ID in GSM/UMTS)	SPI: no location DPI: location (cell ID in GSM/UMTS)	No location data (on a large scale)	No location data (unless from user or third party)
Nonmeasurable explanatory / independent variables	Any (user intentions, perceptions, motivations, satisfaction, etc.)	Any (user intentions, perceptions, motivations, satisfaction etc.)	Some (based on device / service usage), any (by doing a survey)	Some (based on device UI clickstream), any (by doing a survey)	SPI: none DPI: none (individual users not separated)	SPI: none DPI: some (based on search queries or browsing clickstream),	None	Some (based on search queries or browsing clickstream)
Usage / dependent variables								
• Volume	Sessions, durations, money	Sessions, durations, money	Sessions, durations	Sessions, durations, bytes	SPI: bytes, flows DPI: as SPI, queries, page impressions etc.	SPI: sessions, users, bytes DPI: as SPI, visitors, queries, page impressions etc.	Connections, bytes, money	Sessions, visits, queries, page impressions, etc.
• Frequency	Any freq.	Any freq.	Limited freq.	Any freq.	No freq.	Any freq.	Any freq.	Any freq.
• Diversity	Limited div. (studied services only)	Limited div. (studied services only)	Limited div. (studied services only)	Broad div. (all services)	No div. (individuals not identified)	Broad div. (all IP services)	Limited div. (offering only)	Limited div. (offering only), broad div. (all services)

Considering collecting data on non-measurable independent variables, no such data can be collected with pure IP traffic measurements, as individual users cannot be separated. In measurements using support data and DPI, some such variables can be obtained by observing actual user behaviour (e.g. via browsing clickstream and search queries) that might reveal some of the user's underlying intentions and motivations.

Traffic measurements differ also in the three conceptual dimensions of service usage (usage volume, usage frequency, and usage diversity). Considering usage volume, pure IP traffic measurement using SPI only capture traffic byte volumes and flow counts, whereas the use of DPI enables the counting of search queries and page impressions, among other generic quantities. Measurements using support data and SPI make counting the number of unique users and usage sessions possible, in addition to traffic byte volumes. With DPI, the number of unique visitors to specific web pages, as well as a range of other user-specific metrics such as search queries and page impressions can be computed. Measuring usage frequency is possible only when individual users can be separated from one another. Therefore, no data on usage frequency can be obtained in pure IP traffic measurements, whereas the use of support data enables the computation of any frequency measure. Usage diversity, i.e. how diverse set of applications or services is used, is defined by the services measurable by each method. Pure IP traffic measurements are not able to measure usage diversity, as individual users cannot be identified. In contrast, measurements using support data enable a broad analysis of usage diversity, including all types of IP services covered by the employed SPI or DPI methods.

4.1.2 Framework for Analysing Mobile Service Usage

Comprehensive understanding of mobile service usage is increasingly difficult as the usage diverges between different types of devices and networks. Therefore, a holistic framework for analysing the usage of mobile services was developed based on the experiences obtained in the series of longitudinal and cross-sectional mobile service usage measurements conducted for this dissertation (see Chapter 3). This framework is presented in Figure 6.

The framework consists of two layers: measurement points, and technical components of mobile services. These technical components comprise of devices, applications, networks, and content. In addition, the framework presents example classifications for each component. Ideally, such classification should be based on consistent use of relevant criteria, and produce categories that are mutually exclusive and jointly exhaustive (e.g. Rogers 2003).

The device component consists of a continuum of devices from mobile phones to laptop computers that offer a varying degree of mobility to the users. The classification of mobile devices is based on three classification criteria; the physical size of the device, the capability to make 2G/3G circuit-switched voice calls with the device, and the type of operating system running on the device. Based on these criteria, the following mobile device classes were recognised: 1) mobile phones, 2) smart phones and PDAs, 3) ultra-mobile PCs, 4) laptops and tablet PCs, and 5) other devices.

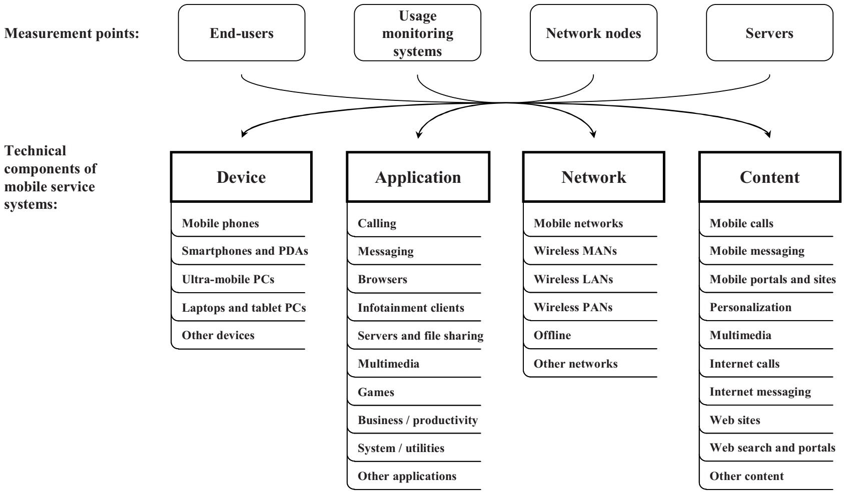

Figure 6 A framework for analysing the usage of mobile services (Article II)

The application component includes the various software applications required for delivering specific services to the devices. Some applications are typically deeply integrated into the software platform of mobile handsets, whereas others are developed by third parties and installed to the devices by the users, much in the same way as with personal computers. Moreover, these applications can run independently in the device, or be distributed between multiple computers communicating over a network. Consequently, a classification of mobile device applications is effectively a classification of computer software. The example classification criteria used in the framework are the nature of interactivity that the application provides, as well as the type of content handled by the application. The resulting classification is similar to those used by major PC software libraries, and includes ten mobile device application classes: 1) calling, 2) messaging, 3) browsers, 4) infotainment clients, 5) servers and file sharing, 6) multimedia, 7) games, 8) business / productivity, 9) system / utilities, and 10) other applications.

The network component contains the alternative technologies that provide wireless connectivity to mobile devices. The used classification of wireless networks is based on their geographical range. In addition, the framework includes the “offline” class to account for cases where solely the local device features are used and no network connections are required (e.g. taking photos with a camera phone), and “other networks” to account for, for instance, fixed connections or mesh technologies. In sum, the example network classes are: 1) mobile networks, 2) wireless MANs, 3) wireless LANs, 4) wireless PANs, 5) offline, and 6) other networks.

The content component refers to the content transmitted via the wireless networks and/or consumed with the mobile devices and applications. The example classification is strongly linked both to the applications as well as to the utilised networks. The first criterion is whether the content is mobile-specific or generic Internet content (e.g. WAP vs. Web pages). Second, the classification is based on the application accessing and transferring the content. The classification covers the most relevant and widely accessed types of content, and includes the following ten content classes: 1) mobile calls, 2) mobile messaging, 3) mobile portals and sites, 4) personalization and applications, 5) multimedia, 6) Internet calls, 7) Internet messaging, 8) Web sites, 9) Web search and portals, and 10) other content.

4.2 Diffusion of Mobile Handsets

The diffusion of mobile handset features was studied by applying existing new product diffusion models to the collected research data, as well as by developing a new approach for planning and forecasting product evolution process and the resulting diffusion of product features.

4.2.1 Diffusion of Mobile Handset Features

Several commonly used diffusion models were fitted to the research data on handset feature penetrations (see Section 3.3.1 for details), assuming that the ultimate saturation level is full 100% penetration. The penetrations of selected mobile handset features in Finland over the years 2005-2008, and their historical diffusion curves are presented in Figure 7. The features have been grouped into cellular radio, hardware, and software –related features for clarity.

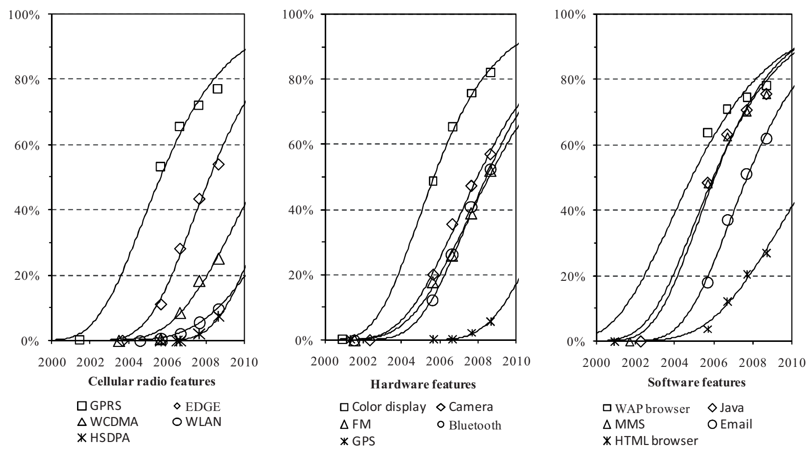

Figure 7 **Historical diffusion of mobile handset features in Finland (Article III)**

The typical phases of a diffusion process are visible from the data presented in Figure 7. The slow early adoption phase can be observed in the penetrations of the emerging features (e.g. WLAN, GPS), whereas the phase of rapid adoption has been driving the diffusion of, for instance, FM receiver and Bluetooth during the observation period. Market saturation is also visible in the slower growth of the penetrations of, for example, colour display and WAP browser.

Accordingly, the diffusion curves were found to fit reasonably well to the research data. However, for some features (e.g. GPRS and WAP browser) a lower saturation level than the assumed 100 % would seem to provide a better fit to the data. This is likely to result from an existing (albeit diminishing) population of low-end handsets that acts as an upper limit to feature diffusion (see Kivi 2009).

A comparison of the diffusion curves depicted in Figure 7 is complicated because the diffusion of different features has started at different times. In order to better compare the diffusion rates, the curves were reorganised by coinciding the first month when a handset equipped with the feature in question was sold in Finland. In other words, the month in which the penetration of each feature departed from zero was set as zero on the X-axis in Figure 8.

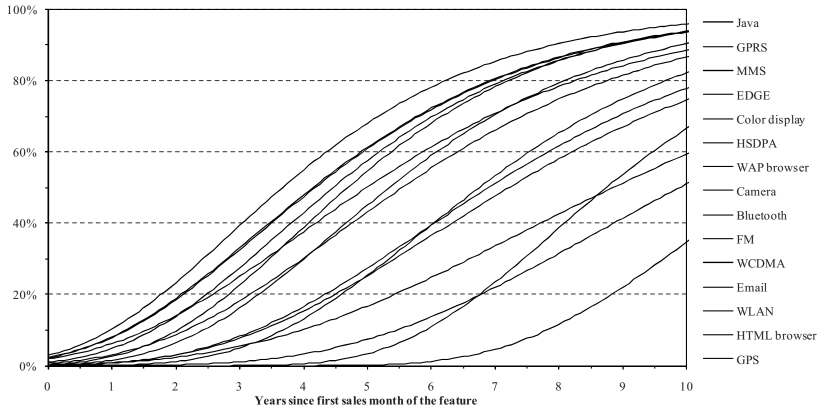

Figure 8 **Normalised diffusion of mobile handset features in Finland (Article III)**

The curves in Figure 8 indicate clearly observable differences in the early diffusion of different features. In particular, the diffusion of GPS, Email, and HTML browser features has been delayed significantly. These features were introduced to the market in pioneering handset models. The first GPS-equipped handset (Benefon Esc!) was sold in Finland in June 2001, whereas the subsequent GPS-capable model from other handsets manufacturers entered the market in July 2005. Similarly, the first Email-capable handset (Nokia 9110 Communicator) was first sold in December 1998, and was followed by other (non-Communicator) models in July 2002. Finally, the first handset with an HTML browser (Nokia 9210 Communicator) was sold in January 2001, notably earlier than the following HTML-capable models in December 2003.

The introductions of new features in these models can be seen as strategic moves by companies pursuing first-mover advantage in new markets. However, the relative immaturity of the cluster of technologies related to these features made the introduction of competing models initially unattractive for other manufacturers. For example, in the early 2000s, other features of handsets did not support the use of GPS for positioning and navigation. Display sizes and resolutions, battery lives, handset memories, and data transmission speeds were all inadequate for displaying, storing and transferring high-quality map content to the devices. GPS chips were also relatively large and costly, making GPS integration less appealing. Similarly for HTML browser and Email, neither the overall handset performance nor the implementation of the Email and browser applications was sufficient to provide satisfactory user experience. Furthermore, handset manufacturers were also investing in WAP technology at that time, drawing focus away from HTML browser development.

A further normalisation of the initial delay in the diffusion of handset features revealed further differences in the diffusion patterns of different handset features (see Article III for details). The rapid diffusion of colour display and Java has been sustained by the fact that these features are relatively independent of other technologies in the handset and the network. On the contrary, similarly independent features such as camera and FM receiver have diffused more slowly, because these features have been used to differentiate handset models targeted to different end-user segments. The diffusion of specific handset features also depends on other strategic decisions of handset manufacturers with sufficient market power. Such manufacturers benefit from economies of scale and scope by integrating hardware features into a number of high production volume models and building product platforms with similar feature sets instead of individual handset models. Moreover, new technologies are also often bundled to facilitate end-user adoption (Rogers 2003). Therefore, a number of new features are often introduced into a range of handset models, which is later observed in the similar diffusion patterns of the features.

4.2.2 Product Evolution Process

Technology products can be analysed at multiple levels, including product categories, product features, product models, and individual units (cf. Bayus 1998). Product categories, like mobile handsets, tend to go through continuous evolution, i.e., *"a process of gradual change occurring in a system, . . . product, etc. . . . from a simpler to a more complex or advanced state"* (Oxford English Dictionary). In contrast, individual product models, like the Apple iPhone 3GS, follow life cycles consisting of introduction, growth, and decline. Therefore, product evolution *"is determined by the cumulative changes in the attributes [i.e. features] of individual new product models that are introduced within a given [product] category"* (Christensen 1997). Consequently, product evolution is manifested in the diffusion of new features within the product population.

The life cycles of product models and individual units differ. An individual unit enters the product population (i.e. all units of a product category in use) when it is purchased and taken into use by its first owner (e.g. individual or household). During the lifetime *T* of the unit, its ownership may change and it may sometimes be temporarily out of use during and between ownerships. Finally, the life cycle of the unit ends when it is discarded by its last owner. Analysis of the unit life cycle is simplified by the use of such aggregate discards (or aggregate replacements), as changes in the ownership of individual units (e.g. in the second-hand market) do not need to be explicitly modelled.

The life cycle of a product model begins with model introduction, which often takes place at an industry exhibition or trade show, and might also be announced in a press release by the manufacturer. After the model introduction, some time may pass before the start of sales, after which unit sales start to increase. This time delay may vary considerably, depending on the product model and market. Similarly, the length of the sales period, time to peak sales, and the distribution of unit sales vary between different models and markets (Bayus 1998). Eventually, for every model, the end of sales takes place, after which new units of the particular model can no longer be purchased. After some time has passed since the start of sales, the sold units start to disappear from the product population, as they are discarded by their last users. The life cycle of a product model ends when the last unit is discarded and disappears from the product population.

The evolution process of a product population can be examined by looking at the changes that take place in the population during a certain time period *t*. Previous research decomposes total unit sales into first purchases, replacement purchases, and additional unit purchases (e.g. Olson & Choi 1985, Kamakura & Balasubramanian 1987, Bayus et al. 1989, and Steffens 2003). Accordingly, the evolution process of a product population is illustrated in Figure 9.

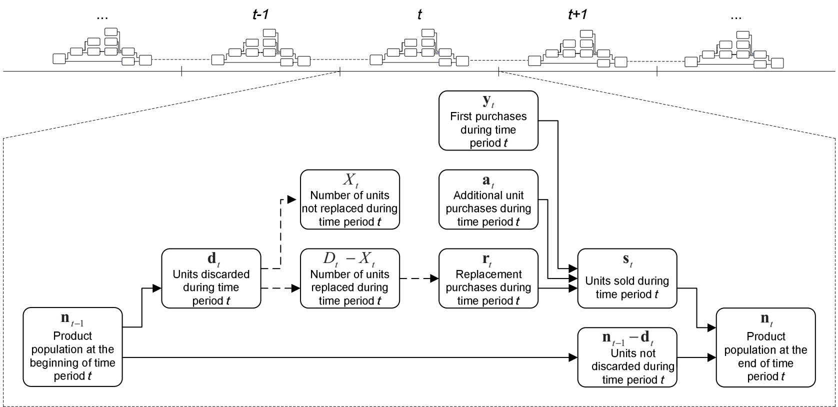

Figure 9 Evolution process of product population (Article IV)

The diffusion of new product features is made possible by the introduction and sales of new product models equipped with these new features. This diffusion progresses as units of new models are purchased and units of older models are discarded. At the aggregate product category level, the number $q_{f,t}$ and penetration $p_{f,t}$ of units equipped with feature *f* within the product population at the end of the time period *t* is given by

$$q_{f,t} = \sum_{i=0}^{t} N_t^i \cdot Z_f(i) = \sum_{i=0}^{t} S_i \cdot [1 - F(t-i)] \cdot Z_f(i)$$
$$p_{f,t} = \frac{\sum_{i=0}^{t} N_t^i \cdot Z_f(i)}{N_t} = \frac{\sum_{i=0}^{t} S_i \cdot [1 - F(t-i)] \cdot Z_f(i)}{P_{sat} \cdot Y(t) \cdot (1 + A(t))}, \tag{4}$$

where S_i is the total number of unit sales during time period *i*, *F(t-i)* is the cumulative probability of unit discard at time period *t* for units sold in time period *i*, $Z_f(i)$ is a function of product feature dissemination function giving dissemination share of units equipped with features *f* within product unit sales S_i during time period *i*, P_{sat} is the size of the total buyer population at saturation, and *Y(t)* is the cumulative proportion of this population that have made a first purchase at the end of time period *t*, and *A(t)* is a function giving the number of additional units per the cumulative buyer population at the end of time period *t*. In other words, the rate of product feature diffusion depends on product category level diffusion, on the replacement behaviour of product users, and on the dissemination of new features to the sold product models.

A new approach for planning and forecasting product feature diffusion is derived from this logic. Accordingly, the developed approach requires three separate phenomena to be modelled, the combination of which enables forecasting of product feature diffusion. First, a product category diffusion model is selected, estimated, and applied in predicting the size of the product population and the numbers of first and additional unit purchases in different time periods. Second, a product unit replacement model is selected, estimated, and applied in predicting the number of replacement purchases in different time periods. Consequently, the unit sales volume of the product is determined by the product category diffusion and product unit replacement behaviour. Third, product feature dissemination model is selected, estimated, and applied in predicting the dissemination share of features among product unit sales in each of the time periods.

This approach can be applied to characterising the evolution process of a product population and to forecasting the diffusion of new product features (see Article IV for a forecasting application). Isolation of the models for product category diffusion, unit replacement, and feature dissemination also allows a meaningful sensitivity analysis, including the analysis of discontinuous changes in each of these phenomena. Therefore, in addition to forecasts assuming that the underlying processes continue at the prevalent rates, scenarios can be constructed to model changes resulting for instance from supply-side planning and decision-making or major external forces such as new regulations or economic downturns.

The use of the planning and forecasting approach was demonstrated and the sensitivity of the mobile handset evolution process studied by evaluating the effects of changes in product unit replacement behaviour and feature dissemination on the diffusion of mobile handset features in the years 2009 – 2014.[5] Effects of such changes were analysed by constructing product feature dissemination scenarios (Minimum, Linear decline, Linear growth, and Maximum) and product unit replacement scenarios for the effects of scrapping bonuses as well as for the changes in the product unit lifetime distribution. Scenarios were constructed for the WCDMA (i.e. 3G) and colour display features because similar features of mobile handsets and other technology products have been topics of previous diffusion studies (e.g. Bayus 1992, Islam & Meade 1997).

In the "Linear growth" scenario the feature dissemination share was assumed to continue increasing at the rate of 10% points per year, also corresponding to the prevalent growth rate of the WCDMA feature, whereas in the "Linear decline" scenario the dissemination share started decreasing at the same rate. In the "Maximum" scenario the feature dissemination share is assumed to reach 100% immediately and, conversely, in the "Minimum" scenario the share reduced immediately to 0%. These extreme scenarios are unlikely yet possible, due to for instance regulatory intervention or manufacturer decisions. In reality, the share of a handset feature among unit sales seems more often likely to follow periods of linear growth, possibly with different slopes and occasional abrupt changes from one level to another. The scrapping bonus scenario was constructed by defining a scrapping bonus campaign to last six months from January 2009 until June 2009. During those months, the hazard rates of handsets sold more than 24 months ago were assumed to increase by 10 percentage points for the duration of the campaign, due to for instance price reductions or other incentives for owners of old handsets. The effect of changes in the unit lifetime on handset feature diffusion was analysed by assuming, after December 2008, an increase and a decrease of 6 and 12 months in the mean

[5] Changes in the third phenomenon, product category diffusion, were found to have negligible effect on mobile handset feature diffusion in the saturated Finnish market, and respective analyses are not reported.

lifetime of all units while keeping the maximum lifetime of all units unchanged.

As a common assumption for all scenarios, the diffusion of mobile handsets (first and additional unit purchases) was assumed to equal the overall growth of the handset population and to follow similar growth pattern in years 2009 – 2014 as was observed for the years 2000 – 2008 (see Article IV for details). Similarly, in the plain product feature dissemination scenarios, the replacement behaviour of handsets in years 2009 – 2014 was assumed to be similar to that observed for years 2003 – 2008 (see Article IV for details). The feature diffusion curves resulting from these assumptions and the plain feature dissemination scenarios are shown as the bold solid lines in all panels of Figure 10.

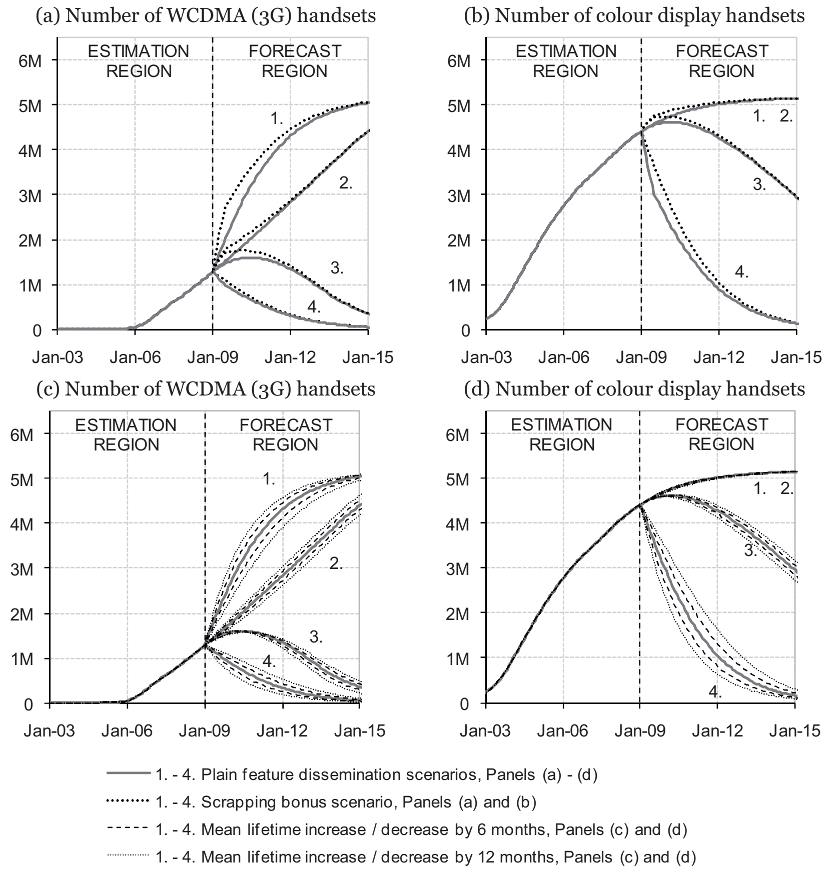

Figure 10 **Effect of a scrapping bonus campaign and changes in handset mean lifetime on feature diffusion (Article IV)**

The evolution of a product population and the diffusion of new product features were found to be fairly slow even in the most extreme “Maximum” scenario of feature dissemination. This is particularly noteworthy, as the mobile handset used as an example product is a relatively fast moving technology product. For instance, even if the dissemination share of handsets equipped with the WCDMA feature rose immediately to 100% of unit sales (i.e. Maximum scenario), it would still take four years before their quantity increased from the December 2008 level of 1,300,000 (i.e. about 26% penetration) to 4,700,000 (i.e. about 90% penetration). This slowness results from the nature of the replacement process, where the oldest units are not necessarily replaced first. Similarly, an abrupt end in sales of a certain feature (i.e. Minimum scenario) takes a long time to affect the total population.

The effect of the scrapping bonus campaign on WCDMA feature diffusion is shown in Figures 10(a) and 10(b). The campaign would result in a unit sales increase of 54% (average 140,000 units per month) and in the replacement of 44% of those old handsets that otherwise would have not been replaced during the campaign period. The effect of scrapping bonus campaign on feature diffusion depends heavily on feature dissemination; the higher the dissemination share of the feature, the higher the effect of the scrapping bonus campaign. For instance, during the six month campaign, the diffusion of WCDMA would effectively increase by 14% points (penetration of 54% instead of 40% in June 2009) under the maximum dissemination scenario, but only 5% points (penetration of 34% instead of 29%) under the linear growth scenario. However, the effect of the scrapping bonus scenario is also somewhat temporary, as the resulting feature diffusion curves begin to approach the respective diffusion curves without the campaign effects after the campaign has ended.

In case of changes in product unit lifetime, the resulting effect on feature diffusion was also found to depend heavily on feature dissemination. Overall, the sensitivity of feature diffusion to changes in the replacement model parameters was found to be relatively low, which also implies that small changes in replacement process are not likely to have a significant effect on forecasts made on the diffusion of mobile handset features.

4.3 Diffusion of Mobile Data Services

The diffusion of mobile data services was studied by inspecting the factual diffusion and usage of the technology components of mobile services in Finland. These components include mobile devices, device application, networks, and content, as identified in Article II.

4.3.1 Mobile Devices

The population of mobile handsets in Finland has evolved constantly throughout the research period, as discussed in Section 4.2. Many features central to the usage of mobile data services have diffused to the mass market. For instance, almost 80% of Finnish mobile handsets support at least simple data services such as WAP browsing using GPRS connections. However, it will still take some time before handsets supporting higher data rates (3G or HSDPA) or standard HTML browsers have widely penetrated the market.

Regulatory means have also been used to speed up the diffusion of handset features. The Finnish regulator allowed the bundling of 3G handsets with mobile subscriptions in April 2006 in order to accelerate the diffusion of the advanced handsets as well as the build-up of 3G networks. The effect of this decision is illustrated in Figure 12, which depicts the share of 3G handsets sold with and without a bundling contract out of total handset unit sales in 2005-2007.

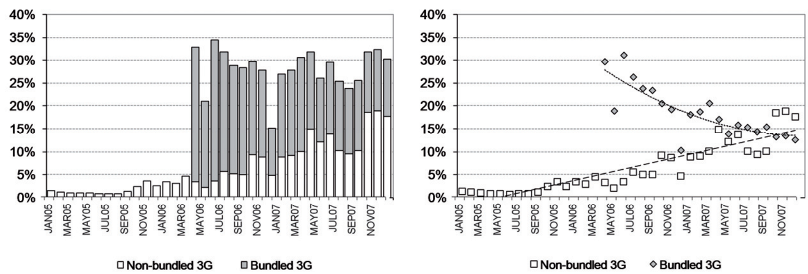

Figure 11 **Share of non-bundled and bundled 3G handsets in Finland (Article VI)**

The handset bundling regulation had a clearly positive effect on 3G handset diffusion in the market. In the pre-bundling era, the popularity of 3G capable handsets was rather low. As bundling became allowed in April 2006, the share of 3G capable handsets jumped from less than 5% up to about 25-30% of handset unit sales, where it remained relatively stably until the end of 2007. First, the majority of sold 3G handsets were bundled with mobile subscriptions, but the share of non-bundled 3G handsets has increased constantly. In addition to 3G, bundling has also had a positive effect on the diffusion of many other handset features. This is because the 3G feature is typically included in relatively capable high-end and mid-range handsets that also contain other features such as high-resolution cameras and colour displays.

Other mobile devices are also used for mobile data, in addition to mobile handsets. The breakdown of mobile packet data traffic by device type is presented in Figure 13. Different devices are grouped into categories "Computer" (e.g. Windows, Mac OS, Linux), "Handset" (mainly Symbian), and "Others / Unidentified" based on the operating system running in the device used by the end-user.

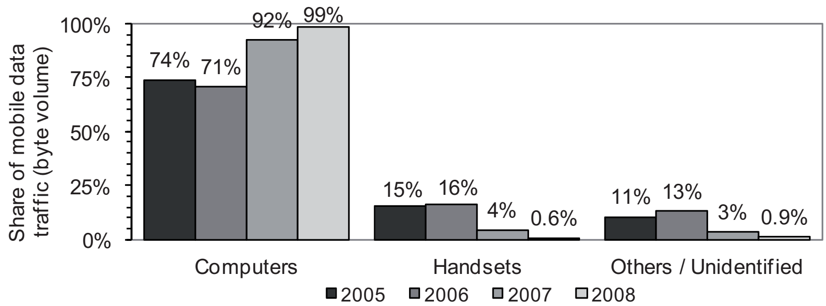

Figure 12 Mobile data traffic by device type in Finland (Article V)

The share of computer traffic in mobile networks has been dominant through the research period, growing from 70-75% in 2005-2006 to over 90% in 2007 and almost 99% in autumn of 2008. At the same time, the traffic share of handsets has dropped from around 15% to less than 1% of all traffic. In absolute terms, a threefold increase in overall traffic volume was observed between 2005 and 2006, as both computer and handset traffic grew in proportion. However, between the autumn of 2006 and the autumn of 2007, the traffic by computers grew by a factor of fourteen, far exceeding the traffic by handsets that grew more moderately and merely tripled. Furthermore, computer traffic grew further by a factor of ten between the autumn of 2007 and the autumn of 2008, while the growth of handset traffic was only 60%. Overall, the growth of computer traffic has dominated other device categories during the research period.

4.3.2 Mobile Device Applications

The applications generating mobile data traffic can be identified, enabling comparisons between the application usage profiles of laptop PCs and mobile handsets. Figure 14 illustrates the differences in these profiles.

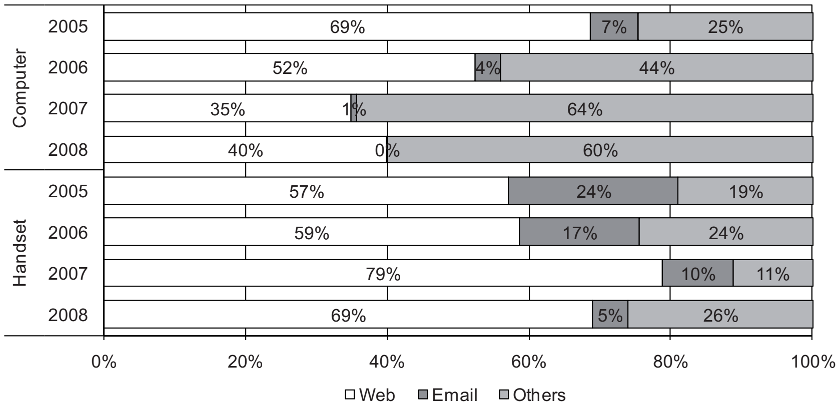

Figure 13 Mobile data traffic by application type in Finland (Article VI)

In the computer generated traffic profile, the share of Web and Email traffic has constantly decreased during the measurement years. The growth of the "Others" category is presumably at least partly explained by the growth of peer-to-peer traffic (see also Heikkinen et al. 2009). Traffic generated by mobile handsets has a somewhat different profile, as the share of Web and Email traffic is considerably higher compared to computers. Moreover, in handset traffic the volume of identified peer-to-peer traffic has been insignificant.

The usage of individual smart phone (i.e. Symbian S60 handset) applications was also studied. Although these findings cannot be generalised to the whole Finnish market, they, nevertheless, give early indications of the possible future market developments. In 2007, the usage of various applications by the panellists is shown in Figure 15.

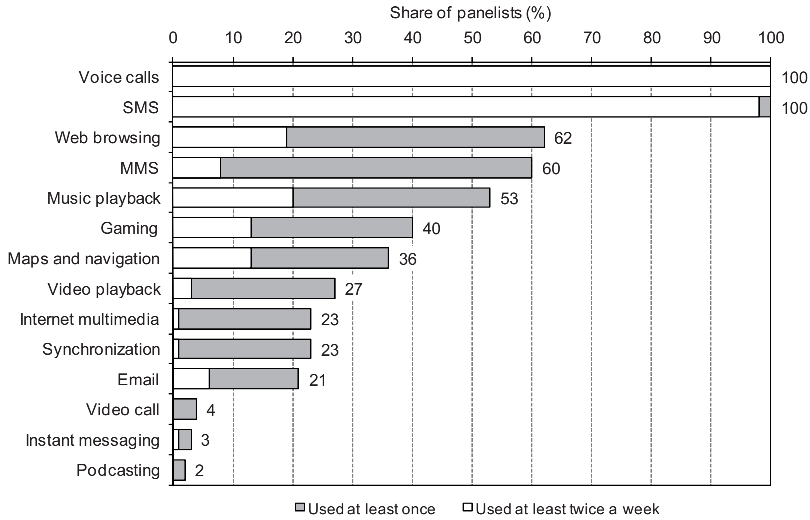

Figure 14 Usage of different smart phone applications in Finland (Article VI)

The results in Figure 15 indicate that the web browser was the most popular data application among Finnish smart phone -equipped consumers, as 19% of the panellists browsed regularly and 62% at least once during the panel. Internet multimedia applications (e.g. Internet radio or video streaming) and email were less commonly used with only around 20% of panellists using them. Applications such as video calls, mobile instant messaging, and podcasting were used by very few people. Browsing accounted for 63% of the cumulative packet data traffic generated in the panel, whereas the share of multimedia applications was 25%.

4.3.3 Mobile Networks

Mobile networks have been traditionally dimensioned and planned based on the coverage and capacity requirements of mobile voice call traffic. In order to support the emerging demand of mobile data services, the Finnish operators (Elisa, Sonera, and DNA) have made substantial investments in 3G networks in the past few years. The coverage of 3G networks has constantly expanded, as illustrated in Figure 16 that shows both the number of localities as well as the percentage of the Finnish population living within 3G network coverage. At the end of 2008, around 80% of the Finnish population lived within areas having 3G coverage.

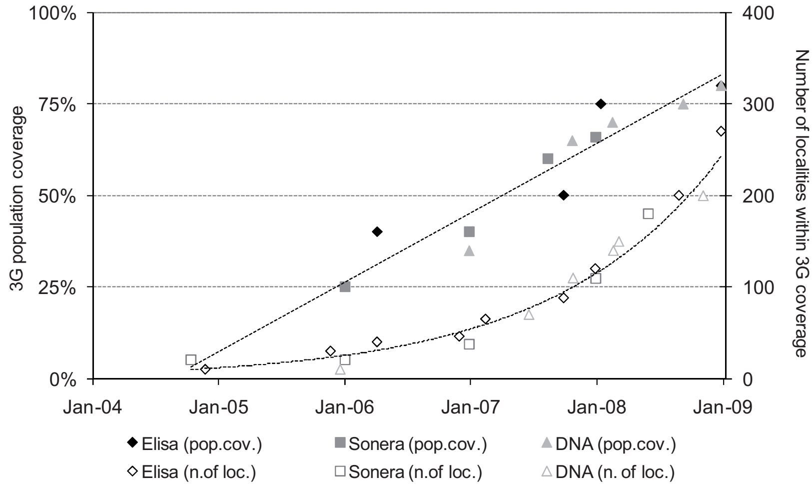

Figure 15 3G network coverage in Finland (Article VI)

The increased data transmission capacity of mobile networks is reflected by the growth in mobile data consumption by the end-users. This growth is illustrated in Figure 16, where the publicly available statistics from FICORA and Statistics Finland are combined with the research data collected in this research.

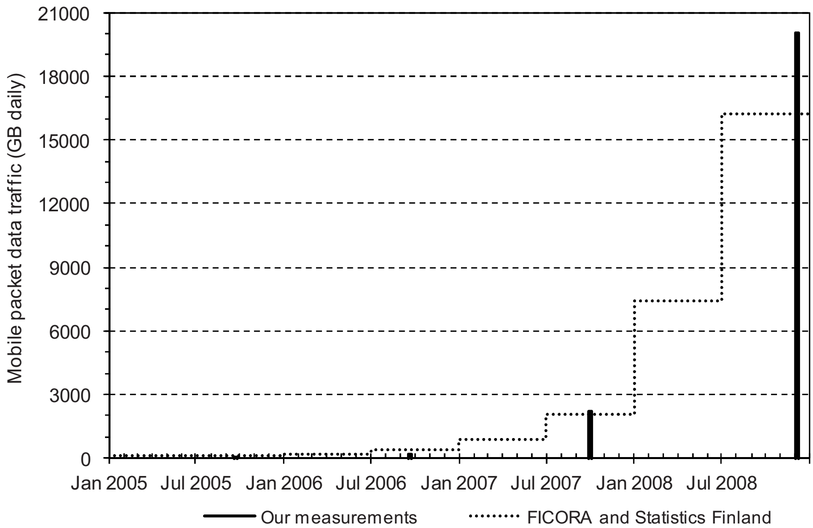

Figure 16 Mobile data traffic volume in Finland (Article V)

The volume of packet-switched data transferred in Finnish mobile operators' networks was around 4200 terabytes (TB) during year 2008, corresponding to 2.28 megabytes (MB) per day per capita, and an eightfold increase compared to the previous year. A major change in the rate of traffic volume growth took place in the autumn of 2007, when operators started to aggressively market their mobile broadband subscriptions bundled with HSDPA-capable USB dongles for laptops.

4.3.4 Mobile Content

The content accessed and consumed with browsers and other applications gives further information on the diffusion of mobile data services. The data from mobile network IP traffic measurements provide the list of the 15 most popular web sites accessed by Finnish smart phone (i.e. Symbian S60) users in 2007 and 2008, as shown in Table 4.

Table 4 Most popular web sites accessed by Finnish smart phone users (Article VI)

Rank	2007		2008	
	Domain name (main business)	Share of web traffic	Domain name (main business)	Share of web traffic
1	Mtv3.fi (Finnish TV broadcaster)	4 %	Iltalehti.fi (Finnish newspaper)	4 %
2	Iltalehti.fi (Finnish newspaper)	4 %	Kauppalehti.fi (Finnish business magazine)	2 %
3	Suomi24.fi (Finnish web portal & discussion forum)	3 %	Mtv3.fi (Finnish TV broadcaster)	2 %
4	Nokia.com (Global handset manufacturer)	3 %	Suomi24.fi (Finnish web portal & discussion forum)	1 %
5	Yle.fi (Finnish TV broadcaster)	3 %	Opera-mini.net (Global proxy server for a web browser)	1 %
6	Google.com (Global web search)	2 %	Tube8.com (Global adult content site)	< 1%
7	Kauppalehti.fi (Finnish business magazine)	2 %	Irc-galleria.net (Finnish social media portal)	< 1%
8	Gate5.de (Global navigation & map provider)	1 %	Facebook.com (Global social media portal)	< 1%
9	Subtv.fi (Finnish TV channel)	1 %	Bigbrother.fi (Finnish TV show)	< 1%
10	Sihteeriopisto.net (Finnish adult content site)	1 %	Sihteeriopisto.net (Finnish adult content site)	< 1%
11	Irc-galleria.net (Finnish social media portal)	1 %	Hs.fi (Finnish newspaper)	< 1%
12	Seksitreffit.fi (Finnish adult content site)	1 %	Flickr.com (Global photo/video sharing site)	< 1%
13	Omakuva.org (Finnish adult content site)	1 %	Ilmatieteenlaitos.fi (Finnish weather information)	< 1%
14	Genimap.com (Finnish navigation & map provider)	1 %	Wikimedia.org (Global encyclopaedia)	< 1%
15	Nettiauto.com (Finnish car sales portal)	1 %	Blogger.com (Global blog publishing tool)	< 1%

The top 15 domains accounted for about a third of the total browsing traffic in the year 2007, whereas the rest of the traffic was distributed over a large number of other web sites. In 2008, the traffic was clearly more fragmented, and the top 15 domains accounted for less than 20% of the traffic. Considering all web sites, traditional Finnish media companies attracted the most usage, followed by social media sites, and adult content. Overall, the share of Finnish web sites was notably high, implying the importance of local content in mobile browsing.

A complementary view was achieved by analysing the web browsing domains accessed by the smart phone users of the mobile handset monitoring panels. In the 2007 panel, 10% of all domain accesses were directed to operators' domains, and 90% to the public Internet. The share of public Internet domains increased clearly from the level of the 2005 and 2006 panels, during which it was around two thirds of all accesses. This suggests that the content consumed by mobile devices is moving away from the operators' portals towards the Internet, and that mobile operators' own content is becoming less important as the diffusion of mobile browsing continues.

5 Discussion

The research results obtained on the diffusion of mobile Internet services are discussed in the following sections. In addition to a general discussion of the findings, the generalisations of the results as well as the overall limitations of the conducted research are also discussed.

5.1 Summary of Findings

A range of alternative methods for collecting data on mobile service usage was presented in Article I. Each of the methods has its advantages and disadvantages, and the applicability of a particular method depends on research objectives, as no method is suitable for all purposes. Therefore, multiple methods are often used. In summary, different methods entail a trade-off between sample size and data granularity. Surveys and end-user monitoring provide very detailed sample-based data, whereas wireless network data are typically less granular but can be based on the entire subscriber base of an operator. Server measurements are a compromise between the above, as detailed usage patterns can be uncovered from a fairly focused user population.

Considering the future, all automated data collection methods provide increasingly accurate and granular data on mobile service usage compared to traditional surveys. Nevertheless, as surveys can provide data on issues that are not directly measurable, automated data collection and surveys are likely to complement each other in the future. Mobile handsets emerge as a promising place to measure the micro-level behaviour of individual mobile users, whereas IP traffic measurements that utilise both support data enabling user-level metrics as well as DPI analysis methods at mobile networks seem as the most scalable method for macro-level market research. Server measurements will also be increasingly powerful, especially in the case of large providers of Internet-based services such as Google.

The analysis of mobile service usage requires a holistic view that takes into account the wide selection of devices, applications, networks, and content. The value of the framework suggested in Article II lies in its systematic, explicit and comprehensive way of treating mobile services. As such, the framework helps in interpreting and comparing the results of various service usage studies and in avoiding too broad generalisations based on data that does not provide a sufficient basis for them. By mapping research settings and results to the framework, it is also possible to recognise those areas where further data collection and analysis might be required. The framework is valuable for researchers in selecting the most appropriate methods and measurement points for a given research problem and in designing and communicating the scope of their studies and measurement settings.

Mobile handset features are new technologies that diffuse within the existing population of mobile handsets. Diffusion research generally assumes that the diffusing technologies are independent of other technologies (e.g. Rogers 2003). This assumption is no longer valid for mobile handsets, as many new features are bundled together in modern handsets. These features form a cluster of technologies, and their diffusion is interdependent. Such interdependence was observed in the similar diffusion and sales patterns of different features in Articles III and IV, respectively. The decisions to bundle specific features together and to distribute handset models with specific features are made by handset manufacturers and vendors. Therefore, the diffusion of handset features is largely supply-driven, contrary to the traditional demand-oriented thinking of technology adoption by end-users.

The evolution of technology products and the resulting diffusion of new product features were analysed in Article IV using the mobile handset as an example product. The phenomena underlying the product evolution process were isolated, consisting of product category diffusion, product unit replacement behaviour, and the previously unexplored product feature dissemination. The evolution process was formulated at multiple levels of analysis, and a planning and forecasting approach linking the separate underlying phenomena was then derived from these formulations. Accordingly, the problem of forecasting the number or penetration of products equipped with a specific feature was decomposed into forecasts for the primarily demand-driven product category diffusion and product unit replacement behaviour, and for the more supply-driven product feature dissemination. This approach is based on an explicit structure of the evolution process, and is applicable comprehensively on all product features. Moreover, the approach is parsimonious as more complex extensions to classical new product diffusion models (e.g. multiple product generations, dynamic population size, and multi-unit ownership) are not needed at the product feature level, but can be used at the aggregate product category level. Furthermore, the approach enables a meaningful sensitivity analysis to be conducted, as the effects of gradual changes in the underlying phenomena on product evolution and feature diffusion can be evaluated separately. Moreover, alternative scenarios can also be constructed to experiment and quantify the effect of more discontinuous changes, resulting, for instance, from supply-side planning and decision-making or major external forces such as new regulations or economic downturns. In consequence, the process of technology product evolution and the phenomenon of product feature dissemination are suggested as extensions to research on product category diffusion and replacement.

The evolution of mobile handsets was characterised and quantified using research data collected from Finland. The accumulation of unit sales and discards during the life cycle of a handset model was found to differ between models and the unit sales of the most popular models were typically spread over longer periods of time. In contrast, no systematic differences between the unit lifetimes were observed over time or in relation to model popularity although the variation between the unit lifetimes of different handset models tended to be higher in the case of less popular models. Scenarios were constructed for the diffusion of mobile handset features in Finland in order to demonstrate the use of the developed planning and forecasting approach. The analysed scenarios showed that feature dissemination is in a dominant role in feature diffusion, and amplifies the effect of changes in product replacement behaviour. This highlights the role of suppliers and regulators that can directly affect the feature dissemination process. However, the overall inertia of product evolution was also evident, as even dramatic changes in feature dissemination will take a relatively long time to affect the whole product population.

The results obtained in Articles V and VI indicate that the technical components enabling mobile data service usage are spreading in Finland. Mobile networks are being upgraded to accommodate the exponential growth of traffic generated mostly by laptop computers. Advanced handset features are also gradually taken into use by the masses, resulting in increased data service usage with mobile handsets. Application and content-wise, mobile data service usage is gradually shifting away from operators' portals and content towards general Internet usage. Overall, it seems that the critical mass in mobile data usage will be achieved soon.

These four technical components of mobile services form an interrelated cluster of technologies. Therefore, market actor dissemination effort directed towards a specific technology component typically has indirect effects on the diffusion of other components. For instance, the regulatory decision in Finland to allow the bundling of 3G handsets and mobile subscriptions has not only led to the diffusion of 3G handsets but also to the expansion of 3G networks by network operators, the increased popularity of data cards and modems as a device category, and the increased consumption of Internet content by mobile devices. On the other hand, such dissemination also often results in an end-user assimilation gap between the end-users' capability to use and the actual use of mobile services, like in the case of data capable mobile handsets and actual data service usage in general, and installed handset applications and their actual usage in particular.

The analytical framework developed in Article II was found useful while studying the diffusion of mobile data services in Article VI. A holistic approach is particularly relevant when tracking and analysing trends in emerging and uncertain markets. In order to enable comparative studies of mobile data service usage between two or more markets, the statistics collected and disseminated by operators, statistics offices, and industry collaboration organisations should be augmented and harmonised. Currently, the publicly available mobile statistics include only overall subscriber numbers as well as voice call and SMS volumes, but very little on data service usage. Country-specific PC-centric web browsing statistics are available from various sources, but these typically neglect the mobile use of Internet. In order to reach a global view on the convergence of mobile and Internet, harmonised data about selected key metrics should be made publicly available. Suggestions for such metrics are provided in Article VI.

5.2 Generalisations

The results obtained under different research topics have potential for generalisation. The results concerning the measurement and analysis of mobile service usage obtained in Articles I and II are considered to be applicable in mobile service usage studies in general. Regarding the framework for analysing the usage of mobile services developed in Article II, a further extension to Internet services more generally would require modifications of the component-specific classifications, while the measurement points and service components are seen to be applicable as such.

The research on mobile handset and handset feature diffusion was conducted using data collected from Finland. However, the formulations and the approach developed in Article IV are more generally applicable to both larger (e.g. European or US market) as well as smaller product populations (e.g. handsets of one mobile operator's subscribers). Moreover, the approach is also applicable in developing markets where mobile handset penetration is growing rapidly, as it takes product category diffusion into account. Finally, the logic used in constructing the formulation of product population evolution and the resulting diffusion of product features is independent of mobile handsets as the type of product being studied. Therefore, the formulation of the evolution process and the logic of the planning and forecasting approach are suggested to apply more generally to other categories of technology products in which the diffusion of new product features requires analysis at a higher level of detail.

The study on the diffusion of mobile data services conducted in Articles V and VI provided observations on the diffusion of systemic innovations and on the cluster of interrelated technology components enabling mobile Internet services. These observations provided indications for future research on the diffusion of systemic innovations, and are not suggested to apply more generally. However, the harmonised mobile market metrics proposed for enabling comparative studies of mobile Internet service diffusion are naturally suggested to apply generally to all mobile markets.

5.3 Limitations

The applicability and validity of the results on the measurement and analysis of mobile service usage conducted in Articles I and II are partly limited in time. In the future, the capabilities of the currently available data collection and analysis methods will evolve while completely new methods will also be developed to cope with the growing amount of digital information available. Therefore, the comparison of the available data collection methods provided in Article I will became gradually less comprehensive and eventually obsolete. Regarding the framework developed in Article II, the general architecture and technical components of mobile services are expected to remain the same in the foreseeable future. Therefore, the measurement points and technical service components identified as well as their fundamental differences are likely to remain valid also in the future. However, for the classifications of service components presented in the framework, the situation differs due to the fast evolution and innovations in mobile devices and networks, as well as in application software and content. Therefore, for all service components, new categories are expected to emerge, requiring changes and additions in the framework.

A further limitation of the research related to data collection methods is the potential effect of new laws and regulations. A brief review of the principles of privacy legislation was provided in Article I. However, legislation typically lags behind the development of technologies, and new laws and regulations will be enacted afterwards to take these developments into account. Furthermore, laws designed to protect the intellectual property rights of (e.g.) content owners and permitting authorities to intercept and collect data in matters of public security, defence, and criminal activity might result in heavy deployment of data collection infrastructure at operators and other service providers. Consequently, this infrastructure could be also used for research purposes focusing on user behaviour and service usage. On the other hand, the increased public concern over pervasive surveillance and the reduction of personal privacy might have a contrary effect. In summary, the potential effect of such developments has not been taken into account in Articles I and II.

The primary limitation of the research on the diffusion of mobile handsets conducted in Articles III and IV is that it concentrates on the diffusion of a single product category. The boundaries of many product categories, like mobile handsets, are blurring due to technological convergence, and the effect of complementary and substitutive categories on product category and feature diffusion can be significant. Furthermore, the results obtained on product feature diffusion essentially apply only to integrated features, and do not cover features that can be retrofitted or installed to individual units by end-users.

Finally, the analysis of mobile Internet services as systemic innovations was also somewhat limited. The influence of different types of market actors (i.e. change agencies) on the technology components of mobile services was not analysed systematically from the actors' perspectives in Article II. Moreover, the nature of the analysis of mobile data service diffusion conducted in Articles V and VI remained largely descriptive, and no notable theoretical contribution was attained in these articles. Furthermore, limited research data were available on the use of substitute technologies, such as laptop computers and WLAN access. Therefore, the significance of the relevant cluster of technologies acting as substitutive technology components of mobile services could not be analysed comprehensively.

6 Conclusions

The diffusion of mobile Internet services was studied in this dissertation. Mobile Internet services were seen as systemic technological innovations, the diffusion of which was found to depend on a cluster of separate but interrelated technology components that diffuse interdependently both due to demand-driven adoption as well as supply-driven dissemination. The research question was approached with research objectives related to three complementary topic areas: measuring and analysing mobile service usage, diffusion of mobile handsets, and diffusion of mobile data services. The objectives were achieved in Articles I to VI, as discussed in Chapter 5. In particular, the results obtained in Article IV related to the second research objective are suggested to apply not only to mobile handsets but also more generally to other categories of technology products.

The scientific and practical contributions of the dissertation as well as suggestions for further research are presented in the following sections.

6.1 Summary of Contributions

The scientific and practical contributions of the dissertation within the three research topic areas are summarised in Table 5. The novelty of research methods and data, the theoretical and substance-area specific findings, and the practical relevance of research results are considered.

Table 5 Summary of contributions

	Measuring and analysing mobile service usage	Diffusion of mobile handsets	Diffusion of mobile data services
Novelty of research methods and data	No new research methods developed *per se* No empirical research data used	Triangulation of two unique data sets, longitudinal and cross-sectional analysis of handset feature diffusion Estimation of handset unit lifetime p.d.f. using discard data	Longitudinal and cross-sectional data on mobile device, application, network, and content usage Application of IP traffic measurements and TCP fingerprinting method to market research
Theoretical findings, constructs, methods and frameworks	A holistic framework for analysing the usage of mobile services	Isolation of unexplored phenomenon of product feature dissemination, and linking it to known phenomena of product category diffusion and product unit replacement An approach for planning and forecasting new product feature diffusion	Observations on the diffusion of systemic innovations related to component technology interdependence, market actor dissemination efforts, and end-user assimilation gaps
Substance area specific findings	Identification of the fundamental differences of the methods to measure mobile service usage and the data provided by them	Handset features form technology clusters and have interdependent diffusion patterns Diffusion of handset features is initially delayed due to premature introduction Diffusion of handset features is slow and driven by dissemination esp. in saturated markets	Diffusion of mobile Internet services is enabled by a cluster of interrelated technology components Suggestions for harmonised mobile market metrics
Practical relevance and applications	Support for research design, method selection, as well as interpretation and communication of research Measurements at mobile handsets for micro-level user behaviour Measurement at mobile networks for macro-level market research	Identification of points of managerial and regulatory influence from structure of product evolution process Experimentation and quantification of managerial and regulatory actions on product evolution and feature diffusion	Factual description of mobile device and data service diffusion in Finland, from early adopters to early majority in 2005-2008

Differences of the three topic areas are reflected in the types and novelty of research methods and data utilised. Research in the topic area concentrating on data collection and analysis methods was based on literature reviews and practical experiences. Therefore, no new research methods or any empirical research data were used. In contrast, the study of mobile handset and handset feature diffusion was based on the triangulation of unique longitudinal and cross-sectional data on the mobile handset population as well as mobile handset retail sales in Finland. These data enabled the direct estimation of handset unit lifetime probability distribution functions using the handset unit discard data that was derived from primary research data. Such estimation has previously been conducted only using separate data on mean unit lifetimes. The topic of mobile data service diffusion was studied using similarly longitudinal and cross-sectional data on mobile device, application, network and content usage. These data treated the broad phenomenon of mobile data service diffusion and while not directly triangulated in this research, such data have not been previously analysed in parallel. Finally, IP traffic measurements in general and the TCP operating system fingerprinting method in particular have not been previously applied to market research oriented studies.

The level of theoretical findings, constructs, methods and frameworks obtained in the three topic areas also varied. In the first topic area on research methods, a holistic framework for analysing the usage of mobile services was developed. Regarding mobile handset diffusion, a more generic contribution was made, as the previously unexplored phenomenon of product feature dissemination was isolated and linked to the known phenomena of product category diffusion and product unit replacement. Moreover, a planning and forecasting approach for new product feature diffusion was also developed. The theoretical findings on the topic of mobile data service diffusion were mainly observations on the diffusion of systemic innovations. Specifically, the component technologies underlying such innovations are interrelated. Therefore, component technology suppliers' dissemination efforts as well as regulatory actions on one specific technology component indirectly affect the spread of other component technologies. Such dissemination also often results in end-user assimilation gaps.

Findings were also made on the specific substance area of mobile Internet. The fundamental differences of the alternative methods to measure mobile service usage, as well as the data provided by these methods were identified. Regarding the diffusion of mobile handsets, handset features were found to form technology clusters that have interdependent diffusion patterns. Moreover, the initial diffusion of specific handset features is often delayed considerably due to premature introductions in pioneering handset models by manufacturers pursuing first-mover advantage in new markets. Accordingly, the dissemination of handset features is supply-driven, whereas product category diffusion and unit replacement are primarily demand-driven phenomena. This applies especially in saturated markets, where feature diffusion is also slow. Finally, the diffusion of mobile Internet services is enabled by a cluster of interrelated technology components that include mobile devices, device applications, networks, and content. Harmonised mobile market metrics regarding these components were suggested in order to enable comparative studies of mobile Internet service diffusion between multiple markets.

Considering the practical relevance and potential applications of the findings, the comparison and synthesis of alternative data collection methods as well as the constructed holistic framework can support researchers and practitioners in research design, method selection, as well as in the interpretation and communication of research results. Moreover, measurements at mobile handsets are suggested for studies of micro-level user behaviour, whereas IP traffic measurements utilising DPI methods combined with the collection of supporting data at mobile networks are most suited for macro-level market research and mobile audience measurements. Additionally, servers with specifically mobile audiences, like mobile versions of social networking services and mobile advertising networks, are also increasingly potent sources of data on mobile service usage. Understanding the structure of the product evolution process and identifying its possible points of influence is valuable for the strategic and operative decision-making of product manufacturers, distributors, third party service providers, and regulators. The effect of such managerial and regulatory actions can be experimented and quantified using the developed planning and forecasting approach. Finally, the factual description of the diffusion of mobile devices and data services in Finland in the years 2005-2008 provides support for short-term operative decision-making for Finnish mobile market actors.

6.2 Further Research

Further research topics on the diffusion of mobile Internet services and on the diffusion of systemic innovations more generally can be suggested. In particular, emphasis should be put on the role of technology clusters in the diffusion of both individual product categories (i.e. product features) as well as multiple substitutive and complementary product categories.

Regarding the diffusion of product features, the effect of feature characteristics, such as their dependencies on other product features (e.g. colour display as a prerequisite for handset camera) or external infrastructure (e.g. 3G handset feature and 3G network coverage) on the feature diffusion is worth further study. Furthermore, the difference between the possession (i.e. purchase, acquisition) and actual usage (i.e. adoption, deployment) of features of multipurpose products, the so-called end-user assimilation gap (Fichman & Kemerer 1999), should be studied.

Further research needs to be conducted to test the external validity of the formulation of the product evolution process and the developed planning and forecasting approach (Article IV) on different product categories and markets. An extension to multiple product categories can also be envisioned, to better understand the substitutive and complementary relations of different product categories. The formulation and the approach could also be extended to sub-categories of products that result from market segmentation and the associated product differentiation. Product sub-categories based on, for instance, unit price or product feature sets can potentially explain the differences between the diffusion rates of different features and life cycles of different product models more accurately. The process underlying the dissemination of product features across different product models should also be studied further.

Another topic of further research relates to the cluster of substitute and complement technologies in different use contexts. Different sets of devices (e.g. PC, TV set, mobile handset, game console) and services (e.g. Internet access, application and content portals) having different characteristics are available for the end-users in different contexts (e.g. home and office, leisure and work). For the end-user, different devices and services are complementary as they are preferred in different contexts and for different applications. On the other hand, they are also substitutive as each device and service could typically be used in multiple contexts. As the use of different devices and services is context-specific, so is the adoption and diffusion of these services. Therefore, some devices and services might never be adopted outside specific contexts, resulting in significantly lower saturation levels. For device vendors and service providers, the bundling of specific devices and services could ensure success in multiple contexts.

Finally, the relation between adopter innovativeness and post-adoption usage behaviour merits further research. Specifically, does innovativeness as a personality trait also explain more frequent or varied usage behaviour, or does the longer usage experience of earlier adopters resulting from innovative behaviour possibly make them heavier users?

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Mobile Internet is an outcome of the merging of two significant domains of technological innovation over recent years: mobile/wireless and the Internet. This merging will lead to new forms of end-user behaviour and also provide business opportunities for companies from the converging telecommunications, IT/Internet, and media industries. The diffusion of technological innovations is widely discussed in the literature. However, applications of the diffusion theory to mobile services have mostly concentrated on mobile telephony, and considered this diffusion to result from end-user adoption decisions that are made independently of other innovations. In contrast, the thesis of this dissertation is that the diffusion of mobile Internet services as systemic technological innovations depends on a cluster of separate but interrelated technology components that diffuse interdependently due to both demand-driven adoption and supply-driven dissemination.

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