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Petteri Alahuhta

Technologies in Mobile Terminals Enabling Ubiquitous Services

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tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax + 358 20 722 4374

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Abstract

The vision of ubiquitous computing dates back to the early 1990s. Ubiquitous computing is a model of human-computer interaction in which information processing is seamlessly integrated into everyday objects and environments. During the 2000s the ubiquitous computing vision has extended and blended with wireless mobile communications to become ubiquitous computing and communication. If earlier information processing was done mainly in static office environments, new advances in mobile technologies offer access to the information and services that are relevant to us in this very situation and right now.

In this research an attempt is made to better understand the development of the digital mobile phone as a platform for ubiquitous services. Ubiquitous services are mobile services that are capable of using contextual information and ICT-based resources in proximity to the user of the mobile phone. The hypothesis of the research is that there is a technology trajectory that makes the mobile phone a host, providing gateway and hub functionality to the ubiquitous services.

We introduce a theoretical framework for analyzing the evolution of mobile devices. The framework is based on several theories of innovation. It addresses aspects of the introduction new technology, dominant designs, technology diffusion, and users' needs. According to the analysis of empirical material using our theoretical framework, the mobile phone has the potential to become a gateway to ubiquitous services, largely due to the new technologies integrated with it. New functionalities and technologies, such as local connectivity and sensor-technology in mobile phones play a key role in helping developers implement ubiquitous services utilizing contextual information. Potential challenges for the diffusion of ubiquitous services are privacy and to some extend environmental issues.

Preface

The journey from master's thesis to PhD thesis has not been a straight line and the way I did it is not necessarily the easiest one. Looking back it is easy to say that I could have continued the topic of my master's thesis and finish the PhD thesis 10 years ago. Obviously that did not happen. In what follows I explain some major milestones, notable event, and the role of important people of the process.

The work on this thesis is mainly carried out in four projects; Smart-its, AMI@Life, Idea Movement, and Swami. The Smart-Its project was the first international research projects in which I was deeply involved. The project included many central characters in European ubiquitous computing research community. The project was an important learning process both on how to do research and how to work in international settings. AMI@life-project aimed to foresee the impact of ubiquitous computing technologies and create roadmap to the development of these technologies. That project was followed by Swami-project that focused on the analysis of the implications of ambient intelligence from the viewpoint of privacy, identity and security. These projects contributed four publications to the thesis. Perhaps the most exciting and inspiring project in my career at VTT is a project called Idea Movement (Idealiike), in which Pekka Abrahamsson and I organized a campaign where everyone was given the opportunity of sharing their ideas on mobile services.

I enrolled as a graduate student as early as 1996. However it was in 2005 when I took a more serious step towards the PhD. During the six year process there have been more and less active times. Depending on my daily workload, the thesis has progressed more quickly or marked time. Finally during the spring and summer of 2010, after several meetings and unexpected turns the story started to acquire a shape.

Now the thesis is finally complete, it is time to acknowledge the people who have played a role in the process of producing the final product. The first person to thank is the supervisor of my PhD thesis, Petri Pulli. Petri and I had countless meetings thinking about different aspects of the thesis. Sometimes the progress

was not quite what we had expected but luckily every now and then there were moments of enlightenment. In tour quest for the right focus and story for the thesis, we described a huge circle, ending up very close to our starting point with the final version of manuscript. I would also like to acknowledge the reviewers of the thesis Jukka Vanhala and Do Van Tanh for providing me with comments and remarks on the manuscript. Valuable contributions were also provided by Olli Martikainen, who acted as second supervisor of the thesis.

I am in great debt to two colleagues and friend of mine who also acted as co-author of some of the papers included in the thesis. Pekka Abrahamsson was my partner in Idea Movement-project. Pekka has an extraordinary ability to make things happen and share his enthusiasm with the people around him. Pekka also acted as a co-author of one of the papers. Me and Heikki Ailisto have worked together since the beginning of 2000s and all this time he has been a great colleague. Heikki helped me greatly in acting as co-author in two papers of the thesis and he also provided me wonderful support in thesis project. My third workmate to whom I owe a debt of gratitude is Johan Plomp. Johan and I have been working together almost my entire time at VTT. During our friendship I have learned to respect Johan as a true professional and a great friend.

A number of people at VTT have made my thesis possible. Jussi Paakkari has supported my thesis work greatly by providing me with the opportunity of leave from my technology manager position in 2008. Moreover Jussi has been very supportive throughout the whole thesis process. Elena Vildjiounaite and I worked together in Smart-Its and Swami projects. She made it easy to produce good results on these projects. Elena was also a co-author of three papers included in the thesis. Veikko Seppänen, who has been my role model, since he become my boss at VTT, helped me greatly in finding the right focus for the thesis. He also once explained me how a thesis should be done and how easy it can be. That happened at a time when the progress was quite slow. That was one of the turning points of the thesis process.

The example and encourage of my former colleagues, Pertti Huuskonen, Pekka Isomursu, Kari Kaarela, Panu Korpipää, Matti Kurki, and Tapio Rauma made me decide quite early that one day I will defend my PhD thesis as well.

I would also like to thank my closest workmates of recent years, Veikko Ikonen, Minna Isomursu, Marko Jurvansuu, Teija Järvinen, Eija Kaasinen, Jukka Kiviniemi, Ville Könönen, Timo Laakko, Jaana Leikas, Jani Mäntyjärvi, Marketta Niemelä, Matti Penttilä, Tuomo Tuikka, Timo Urhemaa, and Maini Williams. They have made it so easy for me to do the management that some spare time was left for the thesis. There are also many others at VTT who should be acknowledged but cannot be named in this short preface. I have had a privilege to work in a very fine team at VTT.

Life is not all work. The most important support group for my work has been my family. To my parents Kirsti Helander and Erkki Alahuhta, I am most grateful for all support in my life. My wife Kirsi has been a companion and loved one for so many years. You have been understanding and supportive during the whole process of the thesis. And finally, my children, Veera, Eemeli and Laura. I am grateful to you for helping me put things into perspective and reminding me in so many ways, what is essential in life.

In Oulu, May 2011

Petteri Alahuhta

Contents

Appendices of this publication are not included in the PDF version. Please order the printed version to get the complete publication (http://www.vtt.fi/publications/index.jsp).

List of abbreviations

2G	GSM-based mobile communication solution
3G	3rd generation mobile system
A-GPS	Assisted GPS
AmI	Ambient Intelligence
AMOLED	Active-matrix organic light-emitting diode
API	Application Programming Interface
ASR	Automatic Speech Recognition
BAN	Body Area Network
Bluetooth	An industrial specification for wireless personal area network
BT	Bluetooth
CD	Compact Disc
CMOS	Complementary Metal Oxide Semiconductor
EDGE	Enhanced Data Rates for GSM Evolution. 2,75G
ETSI	The European Telecommunications Standards Institute
Gb	Gigabytes. Used to measure computer memory and storage

GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service. 2.5G
GPS	Global Positioning System
GSM	Global System for Mobile communications
HSCSD	High-Speed Circuit Switched Data
HSDPA	High-Speed Downlink Packet Access
HTML	Hypertext Mark-up Language
ICT	Information and Communication Technologies
ID	Identification
IEEE	The Institute of Electrical and Electronics Engineers
IM	Instant Messaging
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
IPR	Intellectual Property Rights
IrDA	Infrared Data Association
kB	Kilobytes
LCD	Liquid Cristal Display
MAC	Media Access Control
MB	MegaByte
Mbps	Megabits per second
MEMS	Microelectromechanical systems

MMS	Multimedia Messaging Service
MP3	MPEG-1 audio layer 3, digital audio encoding format
NFC	Near Field Communication
P2P	Peer-to-Peer
PAN	Personal Area Networks
PC	Personal Computer
PDA	Personal Digital Assistant
PET	Privacy Enhancing Technologies
RFID	Radio Frequency Identification
RS232	Recommended Standard 232
RSS	Really Simple Syndication
SIM	Subscriber Identity Module
SMS	Short Message Service
TAM	Technology Acceptance Model
TCP	Transmission Control Protocol
TFT	Thin Film Transistor
Ubicomp	Ubiquitous Computing
UI	User Interface
UMTS	Universal Mobile Telecommunications Service
URL	Uniform Resource Locator
USB	Universal Serial Bus

WAP	Wireless Application Protocol
Wi-Fi	Trademark for Wi-Fi Alliance for certified products based on IEEE 802.11 standards
Wimax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
VoIP	Voice over Internet Protocol
WTO	World Trade Organization
WWRF	Wireless World Research Forum
ZigBee	Technology for low data rate wireless Personal Area Network. Defined in the standard IEEE 802.15.4.

List of original publications

The thesis includes the following original publications:

I. Friedewald, M., Da Costa, O., Punie, Y., Alahuhta, P. & Heinonen, S. 2005. Perspectives of ambient intelligence in the home environment. *Telematics and Informatics,* 22 (3), pp. 221–238.

II. Alahuhta, P. & Ailisto, H. 2008. From Technology Prototypes to Ethnographic Studies – A Review of Ubicomp Research. *Mobility'08, International Conference on Mobile Technology, Applications, and Systems.* Ilan, Taiwan, ACM: New York, USA. Article No. 2. 8 p.

III. Alahuhta, P., Abrahamsson, P. & Nummiaho, A. 2008. On Exploring Consumers' Technology Foresight Capabilities – An Analysis of 4,000 Mobile Service Ideas. *ICE-B 2008 – Proceedings of the International Conference on e-Business*. INSTICC, Setubal, Portugal. Pp. 169–176.

IV. Ailisto, H. & Alahuhta, P. 2010. Do scientific publications predict the supply of new mobile technologies? *2010 Ninth International Conference on Mobile Business / 2010 Ninth Global Mobility Roundtable*. IEEE Computer Society, Los Alamitos, CA, USA. Pp. 469–473.

V. Holmquist, L.E., Mattern, F., Schiele, B., Alahuhta, P., Beigl, M. & Gellersen, H.-W. 2001. Smart-Its Friends: A Technique for Users to Easily Establish Connections between Smart Artefacts. *Ubicomp 2001: Ubiquitous Computing: International Conference*. G.D. Abowd, B. Brumitt & S. Shafer (Eds.). Springer-Verlag, Berlin, Germany. Pp. 116–122.

VI. Vildjiounaite, E., Rantakokko, T., Alahuhta, P., Ahonen, P., Wright, D. & Friedewald, M. 2008. Privacy Threats in Emerging Ubicomp Applications: Analysis and Safeguarding. In: S. Mostefaoui, Z. Maamar & G. Giaglis (Eds.). Advances in Ubiquitous Computing: Future Paradigms and Directions. London: IGI Global. Pp. 316–347.

VII. Wright, D., Friedewald, M., Schreurs, W., Verlinden, M., Gutwirth, S., Punie, Y., Maghiros, I., Vildjiounaite, E. & Alahuhta, P. 2008. The illusion of security. Communications of the ACM, 51 (3), pp. 56–63.

The following supplementary publications are closely related to the contents of this thesis but are not included in it; therefore they are separated from the list of references.

S 1 Alahuhta, P., Lothman, H., Helaakoski, H., Koskela, A. & Roning, J. 2007. Experiences in developing mobile applications using the Apricot Agent Platform. Personal and Ubiquitous Computing, Vol. 11, No. 1, pp. 1–10.

S 2 Riekki, J., Huhtinen, J., Ala-Siuru, P., Alahuhta, P., Kaartinen, J. & Roning, J. 2003. Genie of the net, an agent platform for managing services on behalf of the user. Computer Communications, Vol. 26, No. 11, pp. 1188–1198.

S 3 Vildjiounaite, E., Malm, E., Kaartinen, J. & Alahuhta, P. 2002. Location estimation indoors by means of small computing power devices, accelerometers, magnetic sensors, and map knowledge. *Pervasive Computing – First International Conference, Pervasive 2002*. F. Mattern & M. Naghshineh (Eds.). Springer-Verlag, Berlin Heidelberg. Pp. 211–224.

S 4 Vildjiounaite, E., Malm, E., Kaartinen, J. & Alahuhta, P. 2003. Context Awareness of Everyday Objects in a Household. *Ambient Intelligence – First European Symposium, EUSAI 2003*. E. Aarts, R. Collier, E. van Loenen & B. Ruyter (Eds.). Springer-Verlag, Berlin Heidelberg. Pp. 177–191.

1. Introduction

Ubiquitous computing is a model of human-computer interaction in which information processing is seamlessly integrated into everyday objects and environments. The research into ubiquitous computing started about 20 years ago when Mark Weiser introduced the term in the widely cited Scientific American article "The computer of the 21st century" (Weiser 1991).

Weiser introduced a vision for ubiquitous computing, comparing the coming development of information processing to the development of writing and the use of electric motors in industry. Perhaps the easiest way to define ubiquitous computing is to call it a post-desktop computing paradigm, emphasizing the idea of being able to do information processing anywhere. In addition, our everyday environment is embedded with computing capabilities that make it possible to offer various digital services and functionalities that were not previously possible. Broad research areas of ubiquitous computing are related to infrastructures, information capturing, context awareness, embedded intelligence and natural interfaces.

The development of digital mobile communication systems started at about the same time as Weiser introduced the ubiquitous computing vision. The Global System for Mobile Communication (GSM) is globally the most popular standard for mobile telephony systems. The GSM specifications were published and accepted by the European Telecommunications Standards Institute (ETSI) in 1990. Since the first launch in 1991 the GSM system has been subscribed to by 4.5 billion users globally (ITU 2010).

GSM-phone devices have faced significant development from the early voice-only mobile telephones to today's multipurpose internet devices. In fact, we can identify different phases in the development of mobile devices. In the early days, the only features of mobile phones were mobile voice telephony, Short Message Service (SMS) and a contact book. Quite soon, manufacturers started to integrate new features into the devices such as clocks, games and downloadable ringtones.

Perhaps one of the most important enabling technologies in digital mobile phones is the so-called Subscriber Information Module (SIM), which is used to identify the subscriber i.e., the user of the device. Dependable user identification is a prerequisite for charging for all kinds of business transactions. Mobile telecom operators control the content and applications of the SIM. They are able to reliably identify users based on the International Mobile Subscriber Identity (IMSI)-code stored in the SIM. This functionality is a key enabler for mobile service business.

In the second phase, mobile phone users were able to connect to mobile services and the internet through the Generalized Packet Radio Service (GPRS). Around the same time, with the emergence of packet-switched data connection that made continuous data connections feasible, mobile devices were equipped with the capability of local wireless connectivity to peripherals through Bluetooth technology. Mobile phones were also devised with color displays and cameras, which rapidly became a standard feature of all mobile phones. It also became possible for companies other than device manufacturers to create mobile applications for these devices. An increasing number of new applications were added to the devices, including FM-radios, calendars, digital music-players, email, internet browsers and video players.

Despite the changes in the form factor of the devices, the dominant mobile terminal design remained quite similar until the emergence of GPS enabled smart phones. This development can be called a third phase in the development of digital mobile phones. The essential difference from the earlier phase is that the mobile phone became increasingly aware of its surroundings due to new technologies integrated into the device. The most important of these newly integrated technologies are the Global Positioning System (GPS) for positioning the device outdoors, Wireless LAN (Wi-Fi) for local connectivity in the range of wireless hotspots, and built-in sensors such as accelerometers that can be used for example, to detect a user's activity or in adaptive user interface.

The development of mobile phones can be compared to the Swiss army knife. All personal digital electronics seem to be integrated into a mobile phone. Industries dealing with watches, FM-radios, digital music players, video cameras and players, digital cameras, GPS-navigators, dictation recorders, sports measuring devices, mobile games, maps or books, for example, cannot disregard the development of mobile phones.

Information technology has developed greatly from the time the concept of ubiquitous computing was first introduced. We can ask the question: Have we reached the vision? How far have we proceeded?

The original vision of ubiquitous computing includes an assumption that computing will be distributed into everyday objects, devices and places. Furthermore, Weiser talks about different kinds of devices that will play an important role in the coming ubiquitous computing, namely tabs, pads and boards. Tabs are handheld devices, approximately of the size of a mobile phone; pads are the same size as tablet PCs, and boards are large displays attached to walls.

Ubiquitous services in this research are characterized by the ability of a terminal or a system to sense the surroundings in which it is located. This awareness of the context is utilized in applications and user interactions to enable new functionalities, new services and more user-friendly ways to interact with other people and the information system.

There are different alternatives for the evolution of ubiquitous infrastructures, objects, services and devices. One possible scenario of development is that the devices envisioned are interoperable special-purpose devices, such as location-aware and network-enabled cameras, game consoles, or e-book reading devices interacting with a smart environment. A second scenario is that one of the device categories starts to dominate development and becomes a gateway to services and other functionalities. Such a device seems to be an advanced mobile phone, which can become a platform for several applications and functionalities.

Perhaps the greatest challenge to the first approach, in which ubiquitous computing is built mainly on special purpose devices, is the interoperability of devices and services. This is particularly important as the markets expect some design to reach a dominant role before sales start to increase rapidly. Open standards with a large number of stakeholders involved in the standardization process have been considered to be one of the solutions with the greatest potential for meeting this challenge.

There are several reasons that support the second scenario, in which it is the role of the mobile phone to become a host or a gateway to the ubiquitous services. First, the mobile phone has become a powerful computer, capable of storing, displaying and processing a large amount of data and a large number of applications. Second, mobile phones have diffused into the pockets of virtually every person, at least in developed countries. And the same development seems to be taking place also in the developing countries. Third, the mobile phone is a device that is in close proximity to the user practically all the time. This is a very interesting fact with regards to understanding the users' behavior and the use of ubiquitous services.

In this research we try to better understand the latter development scenario using scientific research methods.

1.1 Research questions

The hypothesis of this research is that there is a technology development trajectory that makes the mobile phone a gateway to ubiquitous services. In order to understand the development better and to test the hypothesis, we attempt to answer the following research questions:

1. What are mobile terminal-centric ubiquitous services? How do they differ from mobile services?
2. What are emerging technologies enabling the transition from mobile services towards ubiquitous services?
3. What kinds of new services are likely to become available? What would be the new application fields?
4. Are there other relevant factors impacting the development process of ubiquitous services?

1.2 Research approach

This research consists of seven publications contributing to different aspects of the hypothesis and research questions. In this section we will give a short description of the approach of each of the papers included in this thesis. More detailed discussion of these papers and their role in the thesis is given in Chapter 6.

Järvinen (2001) introduces a taxonomy of research methods for computer science. The taxonomy includes six different research strategies, namely *mathematical, conceptual-analytical, theory-testing and creating, and innovation-building and evaluating approaches.*

In conceptual-analytical studies, existing theories, models and frameworks are identified and used to explain reality. In mathematical approaches, a certain theorem, lemma or assertion is proved to be true. In theory-testing studies, existing theories are tested against, for example, measurements, experiments, or field studies. Theory-creating studies try to answer which kind of model or framework best explains the observations of the subject under study. In innovation-building research some utility aspects are emphasized and a particular development model is applied. In evaluation studies, innovation is tested against certain criteria. (Järvinen 2001).

Innovation building and evaluation research can also be called *constructive research*. Theory testing and theory creating research rely heavily on different kinds of observations on the subject under study. Therefore, they are often called *empirical research*.

Figure 1 illustrates a rough positioning of each original publication in relation to constructive, empirical, analytical and conceptual-analytical research approaches. In the following paragraphs each publication is characterized by its research approach.

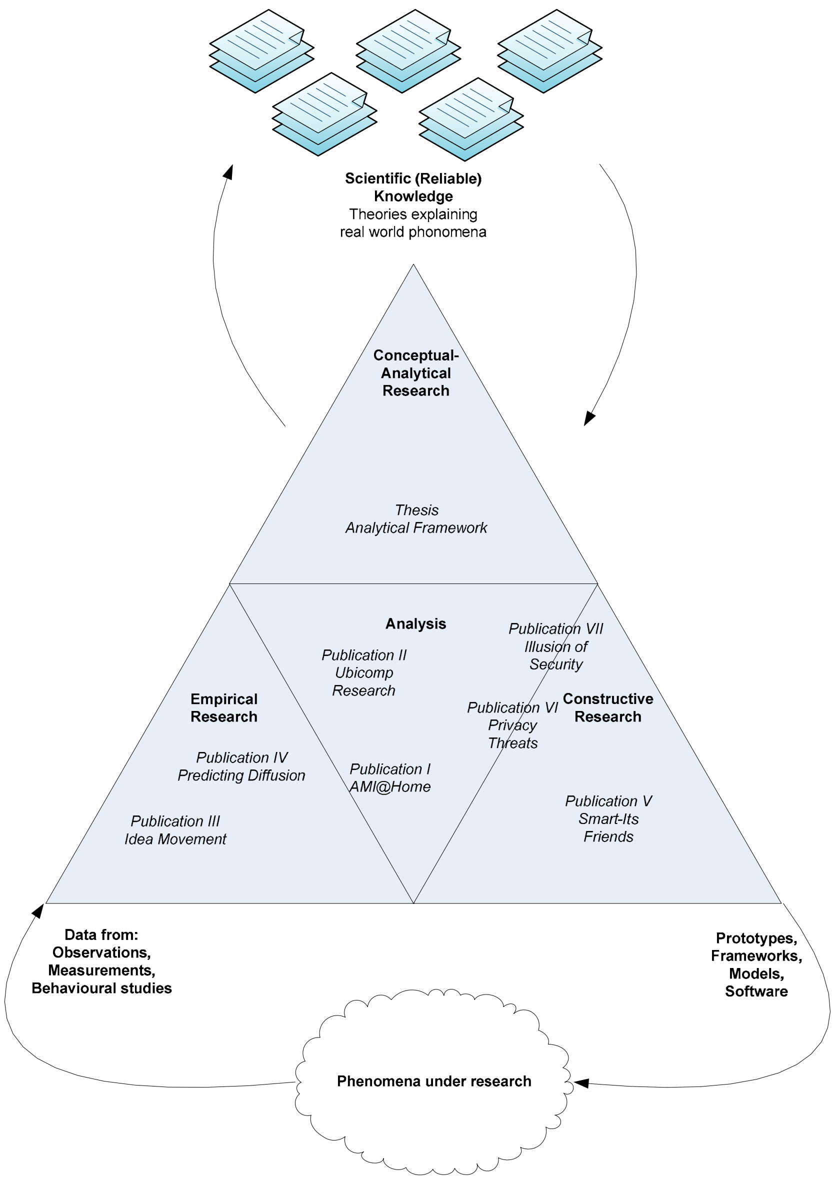

Figure 1. The role of the original publications and their research method.

Publication I discusses the technologies, applications, and social implications of ambient intelligence in the home environment. The paper analyzes applications in future homes enabled by ubiquitous computing technologies. The research approach of the paper is analytical.

Publication II reviews ubiquitous computing research directions based on papers accepted by a leading international conference between 1999 and 2007. The research approach in publication II is mainly analytical. The paper is also partly qualitative-empirical research, as the materials used were published research papers from certain conferences.

Publication III analyzes 4,000 mobile services ideas collected from the general public and discusses the technology foresight capabilities of the everyday user. The research approach in publication III is qualitative empirical research. We collected more than 40,000 mobile service ideas, and random examples of this material were then used as a basis for the analysis.

Publication IV discusses and explores the possibilities of predicting the diffusion of new technologies in mobile phones based on scientific publications. The research approach in publication IV is qualitative-empirical and conceptual-analytical. The data used consisted of accepted research papers and mobile phone launches within a given period of time.

Publication V provides an early example of novel user interface technologies enabled by embedded technologies in hand-held devices. Moreover, the paper provides an interesting illustration of lifecycles of innovation in mobile devices. A similar application to the one presented in this early paper was introduced in commercial use almost 10 years later, when mobile devices were equipped with suitable hardware support. The research approach in this paper is constructive research.

Publication VI discusses privacy threats in ubiquitous applications. The paper identifies gaps in existing privacy-enhancing technologies and proposes a set of design guidelines for ubiquitous applications. Publication VI is a combination of analytical and constructive research.

Publication VII illustrates anticipated privacy, security and identity threats in a society in which ubiquitous technologies have been extensively deployed. Publication VII is a combination of analytical and constructive research. We first constructed a so-called Dark Scenario describing an imaginary future society and then we analyzed the scenario.

1.3 Outline of the thesis

After the introductory chapter, in Chapter 3 we review theories that are relevant for understanding the diffusion of new technologies.

Chapter 3 gives an overview of the current state of mobile services, of mobile terminal technologies and of their development from the introduction of digital mobile phones to the present day.

Ubiquitous computing is explained in Chapter 4. We introduce basic concepts and important application fields related to ubiquitous computing. We also discuss the challenges the research field is facing.

In Chapter 5 we introduce an analytical framework that is used to explain the emergence of ubiquitous services. The migration from mobile services to context-aware ubiquitous services is explained, taking advantage of the framework.

Original publications and their contributions to the thesis are introduced in Chapter 6. Conclusions and contributions as well as limitations of the study will be discussed in Chapter 7. Also remarks on future research directions will be given.

Chapter 8 presents a conclusion of the thesis.

2. Technological change

In this chapter we first review theories and models explaining technological change. These models introduce and define factors for explaining the development of technologies in different phases of the technology diffusion and maturing process.

2.1 Innovation theories

Innovation is often understood as an introduction of a new idea, thing or method. Luecke and Katz (2003) define innovation as *the embodiment, combination, or synthesis of knowledge in original, relevant valued new products, processes, or services*. Put differently, an innovation is an idea that has been put into practice.

At some point in time (in every industry) innovations appear that not only challenge the margins and profits of existing firms and their technological solutions but also the foundations of their existence (Schumpeter 1942). Such innovations depart dramatically from the norm of continuous incremental innovation that characterizes product classes, and they may be termed technological discontinuities. These discontinuities either affect underlying processes or the products themselves. According to Anderson and Tushman (1990), the main phases of technological change are: emergence of technological discontinuity, dominant design and a period of incremental change. These phases follow each other as consecutive cycles.

The technologies behind these discontinuous technologies are sometimes called disruptive technologies (Christensen 1997) due to their impact on existing technologies. Classical examples of disruptive technologies are semiconductors and transistors. Discontinuous innovations are not necessarily based on radically new technology, but they can be an outcome of the diffusion process of a technology reaching a critical mass of adopters. According to Ehrnberg (1995), the characteristics of the technological discontinuations are not clearly defined. She proposes that there are two main components necessary for analyzing discontinuous technological changes. These components are the identification of the actual changes and measuring the magnitude of these changes. To answer the question of what it is that changes, Ehrnberg identifies three dimensions of analysis. These dimensions are competence and the resources necessary for designing and producing the product, physical changes in the product itself, and price/performance changes.

Several versions of breakthrough technology appear either because the technology is not well understood or because each pioneering firm has its own background and incentives to differentiate its variant from that of its rivals. At the same time, immature designs rapidly improve, and one of the competing designs becomes a dominant design (Anderson & Tushman 1990, Abernathy & Utterback 1978). A dominant design is a single architecture that establishes dominance in a product class (Abernathy & Utterback 1978). Once a dominant design emerges, future technological progress consists of incremental improvements elaborating the standard, and the technological regime becomes more orderly as one design becomes its standard expression. Dominant design reduces variation and therefore uncertainty in a product class. Dominant designs also permit firms to design standardized and interchangeable parts and to optimize organizational processes for volume and efficiency (Anderson & Tushman 1990, Abernathy & Utterback 1978). The emergence of a dominant design reduces uncertainty in the markets and leads to an increase in sales when adopters of the technology can tie their further development into a single design without the risk of investing in a transient technology. The length of this period of time from the introduction of a technology to the dominant design depends on the nature of the technology and the actions of actors in the markets. In the case of competence-enhancing innovation (the technology is built on the existing knowledge base), the dominant design can emerge in a relatively short time (Tushman & Anderson 1986). A dominant design can emerge in several ways. A dominant design can be born with an emergence of a de facto standard. It can emerge from the market demand when a single design includes an acceptable combination of technological possibilities and individual, organizational and governmental factors. The market power of a dominant player may put weight behind a particular design to make it a standard. A powerful user may mandate a standard (e.g. government customers). An industry committee, a standardizing body or an alliance of companies can form a standard that becomes a dominant design. Also, government regulation may lead to the adoption of a standard. (Anderson & Tushman 1990)

Once a dominant design emerges, the focus of development shifts to incremental innovations and elaboration of the retained dominant design. The focus of the competition shifts from higher performance to lower costs and to differentiation via minor design variations and strategic positioning tactics (Teece 1986, Porter 1985). Competitive success then shifts to a whole new set of variables. Scale and learning become much more important, and specialized capital is deployed as incumbents seek to lower unit costs through exploiting economies of scale and learning. According to Teece, in most cases the successful commercialization of an innovation requires that the know-how in question will be utilized in conjunction with other capabilities or assets. Such assets can, for example, be distribution channels, competitive manufacturing, marketing, development and user communities, and after-sales support. The strategic aim of the company should be to position itself so that either its technology or some of its complementary assets become a bottleneck in the value network. In the bottleneck-position the company controls the operations in the network, and has a strong negotiation power comparing to other actors in the network (Teece 1986).

Innovations can roughly be divided into product and process innovations. The introduction of an interesting new technology begins an era of product innovation. During this period of time the innovation effort is focused on products and on achieving the dominant design of the product category. After the emergence of the dominant design, the rate of product innovation starts to decrease, and the main focus of innovation activities is concentrated on process innovations. (Teece 1986, Utterback & Suárez 1993). The rate of process innovations follows the pattern of product innovations with an increasing rate of innovation until maturity is reached and the rate of innovation levels out (Figure 2).

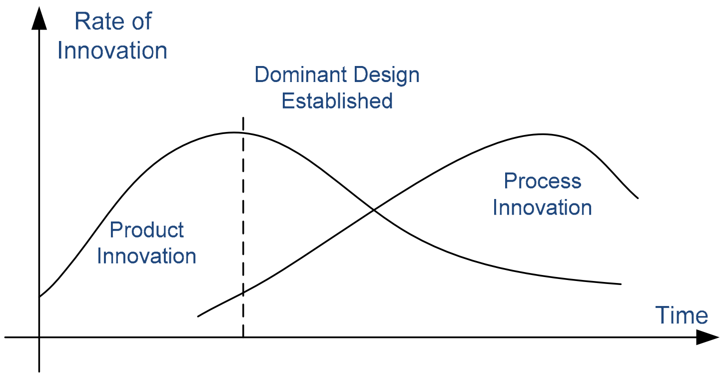

Figure 2. Innovation over product / industry life cycle (Teece 1986).

Everett Rogers pioneered technology diffusion research by publishing a very influential book, *Diffusion of Innovations* (Rogers 2003), the first edition of which was published in 1962. One of Rogers' main contributions to innovation research was the introduction of the concept of the S-curve with the adopter categorization. Other researchers prior to Rogers had also noticed that the diffusion of innovation typically begins slowly and accelerates until it levels out and starts decreasing. However, it was Rogers who discovered that in many cases adoption follows an S-shaped curve, where a few innovators first adopt the innovation, followed by larger group of early adopters who take up the innovations. The number of adopters increases as early majority and late majority users adopt the novelty, and then the curve flattens out as laggards finally take on the innovation. Figure 3 illustrates Roger's diffusion model with the adoption rate and groups of technology adopters.

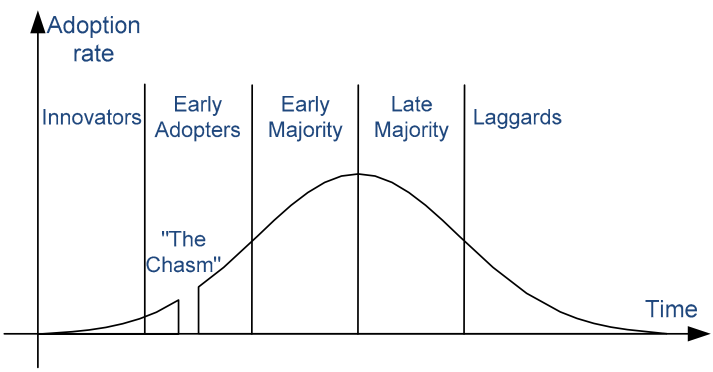

Figure 3. Roger's diffusion model. Adopted from Rogers (2003) and Moore (1995).

Several studies support the assumption that the adopter distribution curve is bell-shaped and can be approximated with a normal distribution. Rogers divided the population into adopter categories according to percentages drawn from the standard deviation of a normal distribution: Innovators represent 2.5% of the population, early adopters 13.5%, early majority 34%, late majority 34% and laggards 16%. Moore (1995) adapted the diffusion curve by adding a space, a so-called chasm, between the innovators and the early majority (Moore 1995). He tried to explain the reason for a number of promising start-up companies thriving among early adopters but failing in the market of the early majority. Moore's explanation is that the markets of the early adopters and the early majority are different in terms of customers' expectations of the technology. Failing companies do not understand the real needs of consumers, and therefore they are not able to design competitive services and product offerings.

The critical point in the process of innovation diffusion is when the S-curve is between 10% and 20% adoption (Rogers 2003). After that point, it is difficult to stop the innovation even if one wanted to. The importance of reaching the limit of 10% and the growth beyond has been discussed by some researchers. Bass (1969) created a model for new product growth in consumer durables. This model explains the decision space of new adopters of an innovation. The main assumption is that the timing of a purchase is related to a number of earlier buyers. This model discusses the innovative and imitative behavior of consumers.

The technology acceptance model (TAM) is a widely used model for explaining and predicting the adoption of information systems. The main determinants of the model are perceived usefulness and perceived ease of use. Perceived usefulness is defined by Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance". Davis (1989) created his model among users of business information systems. Later the model has been widely cited and also enhanced, for example by Venkatesh and Davis (2000) and Kaasinen (2005), to cover utilitarian benefits as Davis described, but also to cover hedonistic values such as fun, brand and enjoyment (Bruner & Kumar 2005). Perceived ease of use was defined by Davis as "the degree to which a person believes that using a particular system would be free of effort; to put it differently: how easy it is to learn to use the system. According to the TAM model these factors determine a person's intention to use the system. The intention to use, according to the TAM model, is a predecessor of the actual use of the system. In the context of mobile internet and wireless services, the TAM model has been used for explaining and predicting consumer acceptance, for example by Lu et al. (2003), Koivumäki et al. (2006), Wang et al. (2006). Kaasinen (2005) extended the Technology acceptance model (TAM) model to analyze user acceptance of mobile services. In Figure 4 Kaasinen's version of the TAM-model is illustrated. The most relevant components of user acceptance for new mobile services are *Perceived value* and *Perceived ease of use* which contribute to the Intention to use. Intention to use, on the other hand, contributes to usage behavior. These components are derived from the original TAM model. The mobile services-specific parts of Kaasinen's model are *Trust* vis-à-vis the services which influence the Intention of use and *Perceived ease of adoption* that dictates whether one takes a service into use.

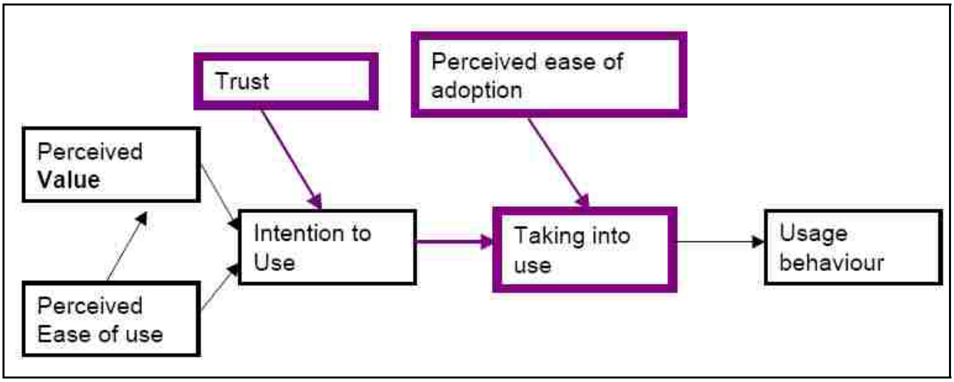

Figure 4. Technology Acceptance Model for Mobile Services (Kaasinen 2005).

The Basic idea of *open innovation* is that, from an organization's point of view, most innovations come from outside the organization. Therefore, systems, conventions and processes need to be developed and emphasized that foster the use of innovations generated outside the organization (Chesbrough 2003). The term *open innovation* is widely used, and the meaning of the term varies from a strict interpretation to an Intellectual Property Rights (IPR)-based business model in which innovations not fitting into an organization's own business model are licensed outbound, and IPR supporting an organization's own business model are licensed inbound the company (Chesbrough 2006). The other extreme of the model is so-called *crowdsourcing*, whereby companies utilize large (countless) numbers of amateurs able to provide ideas and content for their business model (Howe 2006, Bonabeau 2009). Somewhere between these extremes are so-called *lead user innovations,* where advanced amateurs or professional end-users of devices, services or tools improve them so that they fit better to the intended use.

Taking account of the ideas from the lead users is not only a nice gesture from the manufacturing company but also a commercially attractive option for product and services development (Von Hippel 2005). The role of the end-user as innovation actor and content creator seems to be increasingly important in various new business models. Network-mediated innovation brokering (Törrö 2007) and crowdsourcing have become an interesting opportunity, because of the nature of the internet as an open innovation mediation platform.

Stankiewicz (2000) introduced the concept of *Design Space* to describe the clusters of complementary technical capabilities in which the designer is involved at different evolutionary phases of technological development. In Stankiewicz's model there are four main development phases, called regimes, *craft, engineering, architectural, and research regimes.* These describe the increasing degree of knowledge accumulation in different phases. The fourth category is called a *research regime* to indicate that new technological operands defining the regimes are generated by science. Carlsson and Eliasson (2003) further developed the usefulness of the concept design space by making a distinction between three modes of technological growth in the design spaces, namely, the addition of new capabilities and clusters, the integration and structuring of the design spaces through the co-evolution of its various elements, and the accumulation of application-specific know-how linked to the evolutionary trajectories of particular artifacts. Palmberg and Martikainen (2003) introduced a framework of evolving design spaces where the concept of design space as introduced by Stankiewicz (2000) is related to clusters of complementary technical capabilities.

Innovation theories and their characteristics introduced in this chapter have been summarized and concretized with examples in Table 1.

Table 1. Main factors explaining the diffusion of the technology.

Factor	Relevance to this study	Examples	References
Disruptive technology	New technology introduced in the marketplace that changes the product designs and/or manufacturing radically.	Semiconductors Transistor	(Christensen 1997)
Discontinuous innovation	New product design or category that is not compatible with earlier designs and that changes the competition in markets radically	Transistor radio Personal Computer	(Schumpeter & Opie 1934) (Anderson & Tushman 1990)
Dominant design	After the emergence of a new discontinuous innovation, one design reaches more than 50% market share and further development around the innovation is linked to this dominant design.	PC architecture by IBM MS Office tools	(Abernathy & Utterback 1978)
Complementary assets	So that a technology can diffuse to the market, and companies can innovate, some complementary assets (e.g., manufacturing, distribution, sales, and maintenance) are required.	Manufacturing, distribution, sales and maintenance of any product	(Teece 1986)
Product / Process innovation	A broad classification of innovation to product and process innovation can be justified. The product innovation drives the development and process innovations follow.	RF-ID scanners and tags Real-time tracking of goods in a logistics process based on RFID-technology	(Utterback & Suárez 1993) (Teece 1986)
Technology adopter categories	The types of target customers vary from innovators and early adopters to majority and laggards. The expectations of the markets change during the maturation process.	Innovators Early Adopters Majority Laggards Difference between early adopters and majority markets	(Rogers 2003) (Bass 1969) (Moore 1995)
Technology Acceptance	Perceived usefulness reflects anticipated benefits from using a certain technology. Benefits can be utilitarian and hedonistic. Perceived ease of use reflects the user's perception of how difficult it is to use the technology.	Perceived usefulness (e.g., value, benefit, productivity, enjoyment, brand) Complexity of use / usability	(Davis 1989) (Venkatesh & Davis 2000)

Open innovation	The basic principle of open innovation in a broad sense is that most of the resources (e.g., talented people, technology) that a company may need are outside the company and there is a need to be able to utilize them.	Licensing inbound Licensing outbound	(Chesbrough 2003)
Lead user innovation	Advanced end-users improve products to better fit actual use. These improvements are then taken into the product design.	Design of scientific instruments Process equipment Sports equipments	(Von Hippel 1988)
User innovations	Large groups of end-users innovate and share their designs in the user community.	Lego mindstorm designs Threadless t-shirt-designs	(Baldwin et al. 2006, Franke & Shah 2003)
Design space	The concept of design space defines the main challenges that the designers are considering.	Skills needed for the design work	(Stankiewicz 2000)

2.2 Phases of technological evolution

The development of technological solutions experiences a number of consecutive phases necessary to take the solutions from research laboratories into the hands of end-users. In this research we have identified four different phases that each new technology goes through before these new scientific discoveries can be enjoyed by the end-users. The basis of the classification is derived from the thinking of Stankiewicz (2000).

During the *science phase* new phenomena are identified that potentially may help create a better, more productive, or more cost effective means to solving some real-world problem. The work during the science phase can be characterized more as research into a target phenomenon in order to better understand it, rather than as the design of a solution utilizing the phenomenon. The nature of the development is empirical research with measurements, experiments, and research papers. The core challenges during the science phase are to understand the key factors of the phenomenon and to create arrangements to leverage it. The main outcome of the science phase is a formulation of the discoveries of this phase into a set of technologies that will form a basis for further development.

Table 2. Characteristics and dynamics of phases of technology maturation.

Charac-teristics	**Science Phase**	**Engineering Phase**	**Application Development Phase**	**Adaptation Phase**
Description of the phase	Scientific discoveries identify new technologies Focus on understanding physical phenomena	Development of technology enablers Competition towards a dominant design A large number of actors carry out experiments on the technology	Design of business architectures enabled by the technology enabler Focus shifts from the technology development towards service development	Process improvements and services utilizing the technology enabler Focus on business development and creating an impact on markets
Start of the phase	Identification of the potential use of a physical phenomenon	Emergence of a promising new technology enabler	Emergence of a dominant design related to the technology	Emergence of dominant business architectures around the technology
End of the phase	Emergence of a technological enabler linked to a physical phenomenon	Emergence of a dominant application design utilizing a set of functionalities	Emergence of a dominant business architecture	Emergence of a new designs, business architectures and business concepts making the existing technology obsolete
Core challenges	Understanding core factors of the phenomenon Creating systems and arrangements to leverage the phenomenon	Developing the technology enabler to meet the standards of the market place Performance, technical architecture, feature-set	Developing business architecture utilizing the technology Business models, value networks, customer needs	Effective development of services utilizing the technology enabler Methods and tools for effective services production, Identification of process improvement opportunities
Nature of development	Measurements, research papers, reports, demos, experiments, patents	Products, technology components, patents	Service piloting, networking, standardization activities	Services for businesses and consumers, process improvements

The *engineering phase* is followed by the emergence of promising new technologies developed during the science phase. The aim of the work during this phase is to further develop these new technologies to better match the functionalities needed in future products. A key challenge in the engineering phase is to develop technology enablers to meet the needs of the market place. The outcome of the engineering phase is a set of stable technological components that can be integrated into functionalities used by application developers.

Business architecture is a combination of business domains and activities linked to these domains, business functions and concepts and high-level business processes (Versteeg & Bouwman 2006). During the *application development* phase, the focus of development is on designing a business architecture by using emerging technological capabilities and by integrating technological possibilities into applications and services. Key challenges are designing business models, creating value networks, and understanding customer needs.

The last phase of technology evolution is the *Adaptation*, where the technology has diffused widely into use by end-users and surrounding society adapts itself to the applications of new technology. The importance of *user aspects* and the impact on society is emphasized. The technology cannot be treated as merely a technological issue, but must also be treated as a society-level issue. Such technologies are, for example, the mobile communication network or the internet. The focus of development is on an effective deployment of the technology into various areas of life.

Table 2 pulls together the characteristics of different evolutionary phases of technology. A system is a collection of technological solutions or subsystems which are in a different evolutionary phase of the development.

2.3 Summary

In this chapter we introduced and summarized theories of innovation that we considered relevant for understanding the development of mobile services and technologies related to them. These theories will be used in Section 5.1 to create an analytical framework for understanding the development of mobile and ubiquitous services.

In addition we made an attempt to identify different phases of technology development. These phases can be used to roughly estimate the phase of the lifecycle of the technologies. This research attempts to improve our understanding of the evolution of mobile and ubiquitous services and technologies linked to these services. In following chapters we will introduce in details concepts mobile service and ubiquitous computing.

3. Mobile services

The World Trade Organization defines mobile services as radio communications services between ships, aircraft, road vehicles, or hand-held terminal stations for use while in motion or between such stations and fixed points on land (WTO 2009). Even if this definition is very broad, it can be used in this study when we narrow our focus, particularly to hand-held-mobile terminals such as mobile phones. Therefore we can rephrase our definition for mobile services, based on the WTO definition, as follows: *Mobile services are radio communications services between mobile devices while in motion or between such stations and fixed points of services (computer systems / servers).*

In the following chapters we discuss mobile services from three different points of view. A very high level architecture of mobile services systems consists of 3 components: *Wireless communication infrastructure*, *mobile terminal*s and *mobile (content) services*. These components are described in following chapters.

3.1 Wireless communication

In 2001 the Wireless World Research Forum (WWRF) published a collection of vision statements (WWRF 2001) related to the development of wireless technologies, applications and services. The purpose of the publication was to share ideas about future developments in these topics.

One important contribution made by this report was the so-called MultiSphere Reference Model. The purpose of the reference model is to clarify the communication and interaction needs between a user and a ubiquitous system. The original MultiSphere Reference Model, in Figure 5, consists of six different user-centric communication concepts. These concepts are: The Personal Area Network (PAN), The Immediate Environment, Instant Partners, Radio Accesses, Interconnectivity and CyberWorld.

Figure 5. WWRF reference model (WWRF 2001).

In an updated collection of vision papers (Tafazolli 2006) the reference model has been revised. The number of spheres has been decreased from six to three. The spheres in the revised model are:

- The personal sphere indicates interaction with sensors and devices close to the user. This sphere includes interaction between a user and systems in personal and body area networks (BAN, PAN). Current communication solutions that meet the needs of this sphere are, for example, Bluetooth (Bluetooth SIG 2008), ZigBee (ZigBee Alliance 2008) and Near Field Communications (NFC Forum 2008).
- The local sphere includes so-called local services. Users can utilize these local services, for example, through short-range radio communication. These local services correspond to the Immediate Environment and to some extent to the Instant Partners in the original reference model. This communication framework can be realized using such communication methods as Wireless LAN, (Wi-Fi Alliance 2010), Wimax (WiMAX Forum 2010) and Bluetooth.

- The global sphere is a layer that can be said to correspond to global communication solutions, such as GSM, 3G and the internet. This sphere corresponds to the general public's picture of mobile services, where services are provided by familiar telecom operators through 3G cellular networks.

We adopt the WWRF-classification system for communication solutions, as it seems to reflect the current reality in the area of mobile services. Figure 6 illustrates the relationship between the three spheres.

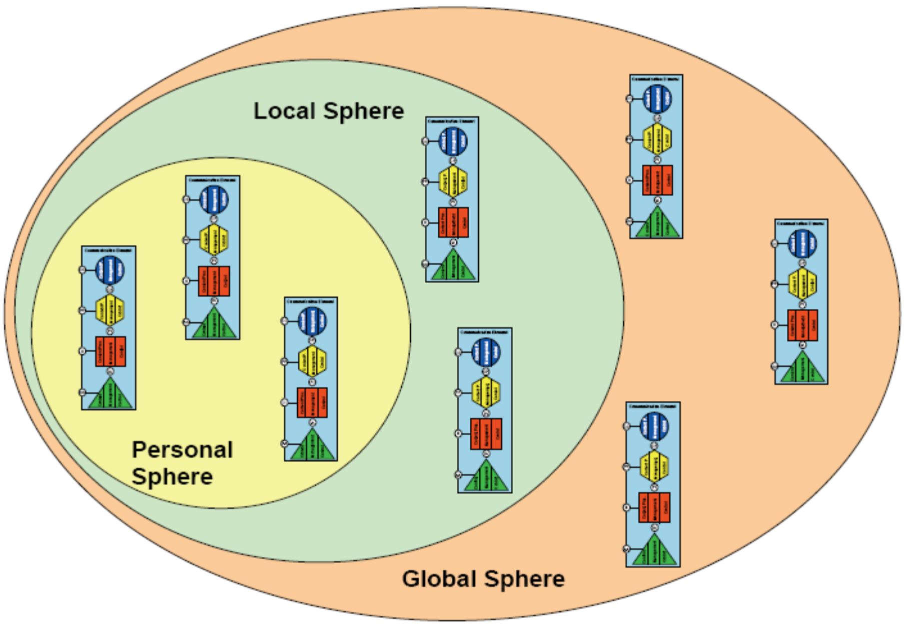

Figure 6. MultiSphere Reference Model of WWRF (Tafazolli 2006).

Mobile services and applications are heavily dependent on mobile cellular networks. There are mobile applications that can be used in an off-line mode that do not need network connections, but the majority of mobile services and applications are based on being online. There are different means to implement the networking of mobile services. The most important way to access mobile services is to use mobile cellular networks such as GSM and 3G. Recently, mobile terminals have been equipped with Wi-Fi capabilities. A large number of Wi-Fi-hotspots could provide an interesting opportunity for mobile services. A third category of wireless communication systems are low-power – short-range wireless communication systems such as Bluetooth, ZigBee and Near Field Communication (NFC). These systems are mainly used for building a wireless link between a mobile device and various accessories and sensors very close to the user. Examples of wireless communication systems and their features are summarized in Table 3.

Table 3. Technologies in the communication spheres.

	Personal Sphere	**Local Sphere**	**Global Sphere**
Examples of communication solutions	– Bluetooth (BT) – ZigBee (IEEE 802.15.4) – Infrared – Near Field Communications (NFC)	– Wireless LAN, Wi-Fi (IEEE 802.11) – Bluetooth – Wimax (IEEE 802.16)	– GSM-data – HSCSD – GPRS (2,5G) – EDGE (2,75G) – UMTS(3G)
Data rates	– 1–3 Mbps(BT) – 20–250 kbps (ZigBee) – 2.4 kbps-16 Mbps (IrDA) – 106–848 kbps (NFC)	– 11–54 Mbps (WI-FI b/g) – 3Mbps (Wimax)	– 56 kbps (GPRS) – 14,4 Mbps (UMTS)
Typical applications	– Connecting a mobile phone to accessories – Synchronizing mobile phone content with a PC – Payment and ticketing (NFC)	– Internet Access in WI-FI hotspots / using Wimax – Voice over IP (VoIP)-calls – Music download	– Voice telephone, messaging – Internet and email access while on the move
Identification of user	– Unique ID for each device	– MAC-address (WI-FI)	– Removable Subscriber Identity Module (SIM) used for user identification
Pricing / Business model	– Product features	– Product features – Subscriptions to hotspots	– Subscriptions based on SIM – Transaction-based billing using SIM (operator billing) or credit card payments

3.2 Mobile terminals

For end-users the most concrete embodiment of mobile services is the mobile phone itself. In order to understand the development of mobile technologies, we have summarized the key features and technologies in one product line of Nokia phones. In the comparison in we have selected a high-end smart phone for business users. This product line, introduced in 1998 as the Nokia 9000 Communicator (Arena Com Ltd. 2010c), has been a flagship product of Nokia phones. In other words, these products represented the state of the art in mobile phones at the time of their introduction. As of the time of writing – the Nokia E7 (Arena Com Ltd. 2011), represents the latest development of the Communicator product line.

Analyzing a single product line is fruitful for a three reasons. First, when these products are intended for the same segment of users, the users' needs tend to be similar, and the manufacturer tries to fulfil their needs as well as possible at that point in time. Phone models in Table 4 mainly attract business users, who value good communication capabilities, access to enterprise information systems as well as the possibility of using the device for entertainment purposes. (Mallett et al. 2006). Second, as the mobile phones under analysis are of a similar form, we can see how the miniaturization and increased integration of electronics increases the number of features and decreases the size of the device. And third, by selecting a high-end device, we can see the development of the state of the art in mobile terminals between 1998 and 2010.

In a decade a great development has occurred in mobile devices. This development is mainly due to the miniaturization and an increased level of integration of electronics. Table 4 gives us an example of this development.

After the introduction of qwerty-keyboard-devices in mobile phones for business users, the product line has developed greatly in terms of the number of cellular bands, the quality of the display, the amount of memory and storage, the variety of data access methods, the capabilities of running mobile applications and the number of features. The size and weight of the devices has decreased steadily until the introduction of touch-based smartphones where, due to the new interaction method and improved user experience, the displays have become larger than earlier.

Table 4. Evolution of high-end mobile terminals in different phases of development (Arena Com Ltd. 2010d).

Announced	**9000** 1998	**9110i** 1999	**9210**	**9500** 2004	**E90** 2007	**E7** 2010
2G Network	GSM 900	GSM900	GSM900 / 1800	GSM 900 / 1800 / 1900	GSM 850 / 900 / 1800 / 1900	GSM 850 / 900 / 1800 / 1900
3G Network	No	No	No	No	HSDPA 2100	HSDPA 850 / 900 / 1700 / 1900 / 2100
Size (mm, g)	173x64x38 397 g	158x56x27 253 g	158x56x27 244 g	148x57x24 230g	132x57x20 210 g	124x62x14 176 g
Display	Grayscale LCD, 640x200 pixels	Grayscale LCD, 604x200 pixels, 4,5”	TFT, 4096 colors 640x200 pixels, 4.5”	TFT 65K colors 640x200 pixels 4,5”	TFT 16M colors 800x352 pixels, 4”	AMOLED capacitive touch-screen, 16 M colors, 640x360 pixels, 4”
Sound	Monophonic ringtones	Downloadable monophonic ringtones, composer	Downloadable monophonic, WAV ringtones	Downloadable polyphonic, monophonic, MP3/AAC ringtones	Vibration; Downloadable polyphonic, MP3 ringtones	Vibration; MP3, WAV ringtones
Memory	Internal 8MB No Card Slot	Internal 8MB MMC card slot	Internal 16MB MMC, 16MB included	Internal 80 MB MMC card slot	Internal 128 MB microSD Max 8GB	Internal 16 GB storage & 256 MB RAM, 1GB ROM microSD Max 16GB
Data	Infrared	Infrared	HSCSD, Infrared	GPRS, EDGE, Wi-Fi 802.11b, Bluetooth 1.1InfraredUS B(POP-Port),	GPRS,HSCSD, EDGE, HSDPA (3.6 Mbps), Wi-Fi 802,11b/g, Infrared, BT2.0, USB	HSDPA (10 Mbps), HSUPA (2 Mbsp), Wi-Fi 802,11b/g/n, BT, USB 3.0
Camera	No	No	No Digital camera connectivity	VGA, 640x480 pixels	3,15 MP, autofocus, LED flash	8 MP, fixed focus, dual- LED flash
Operating system			Open Symbian, based on Symbian v6.0, Series 80 UI, Java	Symbian OS v7.0, series 80 v 2.0 UI Java MIDP 2.0	Symbian OS v9.2, S60 rel 3.1 Java MIDP 2.0	Symbian ^3OS Java MIDP 2.1
CPU	Intel 386 processer	AMD 286 processor	ARM 9 52 MHz, 32-bit RISC	TI OMAP 1510 150 MHz	ARM, 330 MHz	ARM 11, 680 Mhz
Features	SMS, Email, Fax, HTML, Telnet, Terminal	SMS, Email, Fax, WAP, HTML Telnet, Terminal, Organizer, Help, System & Security	SMS, Email, Fax WAP, HTML	SMS, MMS, Email, Fax, WAP/xHTML, Opera HTML Browser, MP3, MPEG4 (AAC), RA, MIDI	SMS, MMS, Email, Instant Messaging WAP2.0/xhtml, HTML A-GPS Push to talk MP3/WMA/WA V/RA/AAC/M4 A music player, Voice command/dial	SMS, MMS, Email, Push Email, IM xHTML, HTML, RSS feeds A-GPS, digital compass, MP3/WMA/WaV/ eAAC + music player TV-Out, HDMI Flash player
Battery	Standby: 35 h Talktime 3 h	60–170 h 3–6 h	230 h 4–10 h	300 h 6 h	330 h 5 h	432 h 9 h
Support for ubiquitous services				Wi-Fi, BT, Camera	Wi-Fi, BT, Camera, A-GPS	Wi-Fi, BT, Camera, A-GPS, digital compass, Accelerometer sensor, proximity sensor

For the purpose of using these devices for context-aware services, we can make a distinction between the basic capabilities and the enablers of context awareness. For the former category, we classify capabilities such as data communication, display and keyboard, and the possibility of running applications (computing power). Enablers of context-aware services are features that make the device aware of its surroundings. Such features are, for example, short-range radio accesses (such as Bluetooth, WI-FI) and sensors (such as accelerometers, GPS and cameras).

3.3 Mobile content and services

Mobile services can be classified in different ways. In this thesis we will use two different dimensions to classify the services. We will first discuss the basic technology architectures and implementation technologies of mobile services, and then attempt to classify them based on the purpose of the services from the end-users' point of view.

3.3.1 Technology architectures of mobile services

From a technical point of view, we can make a distinction into several different types of mobile services, including messaging, mobile applications and browsing-based services.

Messaging services are intended primarily for sending and receiving messages to and from other users of mobile terminals. Messaging services, particularly Short Message Service (SMS) is a widely adopted standard feature of all mobile subscriptions. The possibility of sending and receiving SMS-messages is a built-in feature of virtually all mobile phones. Therefore SMS can be used as a communication backbone for a large variety of services. In addition to sending messages to friends, SMS has been used for querying information from a service, registering for services, paying for (mobile and internet) services, and identifying users. In European mobile internet systems, the primary messaging system is SMS, whereas in Japan (e.g., in DoCoMo's highly successful iMode), the primary messaging system is email. Even though there are lots of similarities between email and SMS-services, according to Saarikoski (2006) the fundamental difference is in their ability to create scale -free networks. This ability is partly technical, but even more importantly techno-economical; email is typically based on flat-rate pricing models and virtually free of charge, whereas SMS is typically based on transaction-based business models i.e. messages are unit-priced.

Mobile applications are programs running on a mobile device capable of communicating and changing information with the service in the network. The operating system in the mobile terminal dictates different possibilities in implementing applications. Applications are typically implemented using a programming language such as Java or C++. An application-based approach to mobile services has some advantages over the messaging and browsing-type of mobile services. Most importantly, applications can access a device's resources and application programming interfaces (API) such as phonebooks, calendars, GPS and sensors. The most significant challenges are the development of applications for a diverse set of terminals, making the end-users download applications and maintain the installed base of applications. Mobile internet is based on a browsing paradigm similar to internet browsing. These services are based on a mobile internet browser in the mobile terminal. In the browsing paradigm, services are running on a server, and the user accesses them by typing in the Uniform Resource Locator (URL). The communication between the mobile terminal and the server is carried out using Transmission Control Protocol (TCP) over Internet Protocol (IP). The most important advantages of the browsing approach are the compatibility between various mobile terminals and the ease of service maintenance and updates. The main disadvantages in this approach compared to an application-driven approach are relatively poor user experience and very limited possibilities of accessing device resources. They are best suited to such services where all content information (including personal information such as phonebooks and calendars) are located on the internet, and the device is only a computing platform for running the browser.

3.3.2 The uses of mobile services

One of the main findings of publication III is that the "killer" application of mobile services is not a single highly popular service, but it a large variety of services helping and entertaining us in different parts of our lives. Table 5 summarizes the distribution of mobile service ideas proposed by the end-users. The most important service category is various types of information queries (either initiated by the user or automatically delivered to her). The number two category is "others", which includes all possible unclassified ideas. This implies that there is a large variety of ideas that are not big enough to become a mainstream application, but nevertheless there are people that are interested in them (Anderson 2004).

Table 5. Distribution of ideas in application categories (Publication III).

Category	Description	Total
Information pull	Retrieving information for some purpose (possibly based on location)	30%
Information push	Receiving information automatically (possibly based on location)	14%
Locating (persons/objects)	Locating or following some (nearest) person or object	9.2%
Communication	Social discussion channel	7.0%
Service request	Ordering a personal service (possibly based on location)	4.7%
Content production	Producing content	4.3%
Payment	Using a mobile device as a means of payment	4.0%
Identification	Using a mobile device as an identification device	3.4%
Others	Applications that do not fit into other categories	24%

Content, such as news, music, pictures, and movies, is an important issue in mobile services. In addition to various kinds of information queries and processing, content-services are perhaps the most important source of revenue related to mobile services.

From the early days of mobile services, the personalization of mobile devices has played an important role. Users have been able to download ringtones, display background images (wallpapers) and phone themes (combinations of icons, wallpapers, ringtones) easily by sending a short message to the service provider. The service provider has been able to charge a small fee for these downloads.

Games have been quite a popular mobile service category. These relatively simple, downloadable (Java) games cost from one to a few euros and can be ordered by sending a text message to a given number. After the emergence of application stores, the ordering process has changed from an SMS-based ordering process to browsing an online catalogue.

Practically all major newspapers nowadays have both a web presence and a mobile service. News is widely available free of charge in various sources, including TV, Radio, internet, and free newspapers for commuters. Therefore mobile news delivery has not been commercially successful.

Listening to music is something that people can do while doing something else. Therefore music has been seen as one of the content types with the greatest potential in mobile services. Mobile devices have evolved to such a degree that downloading and storing large amounts of music in the terminal becomes feasible. Nowadays mobile phones, ranging from mid-price to high-end, already have the capability to store gigabytes of music in their memory cards and play it back using a music player. Downloading music directly to the device itself is possible, but feasibility is dependent on the data-communication subscription model employed by the user. However, mobile downloads are becoming increasingly attractive, with new devices such as the Apple Iphone (Apple Inc. 2010) and Nokia's new services (Nokia 2009a). In Japan, the majority of digital music sales were of mobile music already in 2006 (OECD 2009). Table 6 summarizes digital music sales in selected OECD countries.

Table 6. Digital music sales in selected OECD countries in 2006 (OECD 2009).

	Total digital sales (incl. mobile music) USD millions	**Mobile music sales USD millions**
United States	1 849	754
Japan	778	709
United Kingdom	201	82
Korea	151	78
France	128	88
Germany	117	54
Canada	51	25
Italy	41	27
Australia	37	20
Spain	32	27
Mexico	17	17
Belgium	16	9
Sweden	14	8
Austria	13	10
Netherlands	13	3

In recent times the large scale distribution of unlicensed (pirated) music through peer-to-peer networks has motivated a number of service developers and music industries to invent new ways of providing music to consumers. There seems to be a transition from acquiring music (e.g., buying CDs) to accessing music (streaming music). A number of such services are already available for consumers (Spotify 2010, Last.fm Ltd. 2010). These services run mainly on PC/internet browser environments, but lately these music streaming services have also become available in mobile devices.

The camera became an important feature of mobile phones in 2000–2004, as indicated in Table 4. An initial assumption was that multimedia messaging would be an instant success story. For various reasons it did not turn out this way. In fact, pictures and video clips are a very marginal content type in mobile services. Still, taking pictures and videos is an important feature of modern mobile phones. Perhaps the camera in mobile phones is considered a replacement for pocket-size digital cameras.

Various actors in the telecommunication business considered mobile TV one of the most promising new mobile service types in 2006–2007. There are a large number of mobile TV users in Korea and Japan. The development of Mobile TV infrastructures (DVB-H) was driven by major actors in the telecommunication business. Even though there are a number of experiments and pilot testing, users have not yet (in 2010) adopted mobile TV in their daily lives. Perhaps the reason for slow diffusion to the market is a lack of devices with mobile TV-capability, a lack of mobile TV-optimized content and low-cost service offering.

Mobile social networks are becoming one of the major forms of mobile services. Services are not only optimized for mobile access, but there are several applications that can be used to access these services. Moreover, device manufacturers are integrating the use of social networking into core applications, such as the phonebook of the device. The very nature of social networking is sharing pictures and status updates with friends and colleagues. The mobile phone meets the needs of this kind of communication. Therefore, it is easy to believe that mobile social networking services have a great potential to become a successful service in terms of the number of users. With regards to the business model of mobile social networks, the challenges are similar to the counterparts on the internet.

Mobile phones and services have also gained popularity in business use. There are various business applications that can benefit from mobile additions to enterprise information management systems. The target uses for mobile systems in enterprise are business processes whereby workers travel outside the office, such as cleaners, maintenance staff, and sales staff. The integration-level of mobile enterprise services to corporate information systems can be quite light, as in the case of mobile email. Integration can also be tighter when an Enterprise Resource Management system (ERP), a Customer Relationship Management system (CRM) or a Supply Chain Management system (SCM) is used outside the office environment.

3.3.3 Application stores

Until 2009 the distribution of mobile applications used to be controlled either by device manufacturers or traditional telecom operators, who gave their subscribers an opportunity to download games, ringtones, mobile phone wallpapers and some utility applications in to their mobile phones. The process of downloading and installing mobile applications acquired from these mobile portals was often considered to be cumbersome and unattractive.

In 2007 Apple launched a new kind of smart phone (Apple Inc. 2007), with a large touch-based user interface, virtual keyboard and sensor technology. The device was optimized for internet communication and services usage. In July 2008 Apple launched the AppStore to promote mobile applications for the iPhone and iPod mobile handsets (Apple Inc. 2008). In November 2009 Apple announced that there are more than 100 000 applications available in their application store and more than 2 billion downloads had occurred since the launch (Apple Inc. 2009).

Recently some mobile handset manufacturers have launched application stores to facilitate the download and use of mobile applications. Based on media attention, the most successful application store is the Appstore from Apple (Apple Inc. 2008). Nokia has also launched its own application store (Nokia 2010a). There is also a application store by Google for applications running the Android-operating system (Google Inc. 2010b). These application stores attempt to integrate applications closely with devices, so that application downloading is simple and easy and the user experience is optimized. In addition to manufacturer and operating system-specific application stores there are stores for cross platform-mobile service offering. Getjar, a large cross-platform mobile application store have announced on their web-site that they have more than 304 000 developers, 48 000 Beta testers and more than 57 000 applications (or games) in their store (GetJar.com 2010).

4. Ubiquitous computing

Ubiquitous computing (Weiser 1991) is a vision of an environment where computers are embedded everywhere in our surroundings, and every individual possesses and uses several computers. The environment is equipped with a large number of computers and computing systems of different sizes. These systems and devices are interconnected, and they provide various information processing and environment control-related services for people inside the environment (Weiser 1991).

Since 1991, when the term ubiquitous computing was introduced, the research into this topic as well as into interlinked topics has expanded considerably, and it can be considered to be one of the main directions in ICT related research. Often work related to the ubiquitous computing vision is carried out under a different name. Terms closely linked to this thesis are *pervasive computing* and *ambient intelligence*. Other closely linked visions and concepts have been reviewed in Tuulari (2005). The relationship of ubiquitous computing and related terms has been illustrated in Figure 7.

Pervasive computing is a vision based on ubiquitous computing. The core of the vision is in the creation of environments saturated with computing and communication capabilities, yet gracefully integrated with human users (Satyanarayanan 2001).

In the world of *ambient intelligence* embedded electronics and communication capabilities come together to form digital electronic networks of intelligent devices that are integrated into their surroundings and provide information, communication services and entertainment wherever they are. These ambient intelligent environments will be context-aware, personalized, and able to adapt to and even anticipate the wishes, needs and behavior of users. (Aarts & Marzano 2003)

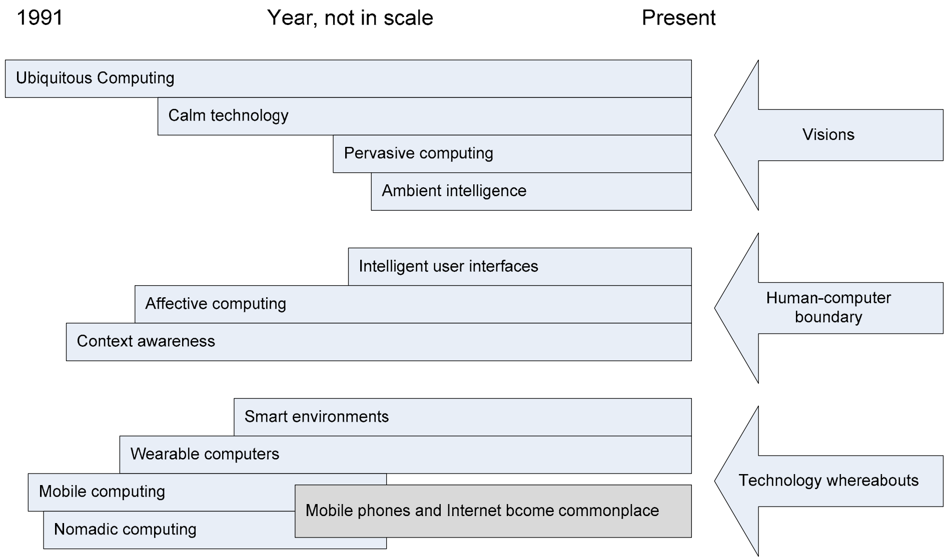

Figure 7. Hierarchy of ubiquitous computing. Modified from (Tuulari 2005).

Many papers defining ubiquitous computing (Weiser 1991, Satyanarayanan 2001, Aarts & Marzano 2003, Want et al. 1996, Weiser 1993) tend to describe ubiquitous computing from a computer science point of view. They define the functionalities these environments incorporate and a set of infrastructure services or resources that application developers can use when creating services for their users.

In this thesis the term ubiquitous technologies is used as a general noun for systems and technologies used in creating ubiquitous computing environments and end-user services.

In this chapter, we will discuss ubiquitous computing-related technologies, systems and applications.

4.1 Technologies for ubiquitous computing

The evolution of ubiquitous systems has been reviewed by Abowd and Mynatt (2000), Rogers (2006), and Bell and Dourish (2007). They all classify ubiquitous systems from their own points of view. Furthermore, they each propose a research agenda for ubiquitous computing research. All of them propose quite similar new research agendas; Abowd and Mynatt (2000) talk about “Everyday Computing”, Rogers (2006) is interested in “Engaging user Experiences” and Bell and Dourish (2007) propose “Ubicomp of the Present which takes today’s complexity of ubicomp-infrastructure as a central research theme”. In this study we are more interested in their analysis than in their new proposals. Therefore, we will merge their categorizations about ubicomp-systems and use them as a basis of our analysis.

Abowd and Mynatt (2000) propose that development in ubiquitous systems can be classified into four categories: *infrastructures*, *natural interfaces*, *context-aware computing* and *automated capture*. Rogers’ (2006) classification also includes context awareness and capturing (recording, tracking and monitoring). In addition she adds a category for *information processing* technologies (ambient / embedded intelligence).

We do not claim that this is a comprehensive and final categorization of ubiquitous computing systems, but it seems to be useful for the analysis and for describing the essence of ubiquitous computing systems at the same level of details as we did for mobile services in Chapter 3.

We will summarize the ubiquitous technologies in the following generic categories.

- *Service infrastructures* – The basic technical components needed for ubiquitous services to be developed and implemented. Particularly communication capabilities such as mobile cellular networks, Global Positioning System (GPS), WI-FI-hotspots and the internet in general. In addition, there are several other components, such as access control systems, video surveillance systems, Smart-card based services (Weiser 1991, Satyanarayanan 2001, Want et al. 1996).
- *Information capturing* – The automated capturing of live experiences (movements, habits, health and mishaps) of persons in order to provide flexible and universal access to those experiences later (Abowd & Mynatt 2000, Rogers 2006).
- *Context-Aware Computing* – Focuses on detecting, identifying and locating people’s routines or actions with a view to using this information to provide relevant information that may augment or assist a person or persons (Abowd & Mynatt 2000, Rogers 2006).
- *Embedded Intelligence* – Information processing and computational intelligence that is linked to both the physical and digital worlds. This approach follows on from work in artificial intelligence (Rogers 2006).

- *Natural Interfaces* – Interfaces that facilitate a richer variety of communication capabilities between humans and computing systems. Examples of natural interfaces are speech input and pen-based input (Abowd & Mynatt 2000).

In order to further explain the classifications, we will give an example of a simple yet typical ubiquitous scenario and use the classifications above to explain the mapping of technologies to the storyline.

In the Steven Spielberg movie *Minority Report* (Spielberg 2002) based on a novel by Philip K. Dick, there is an illustrative example scenario of a typical ubiquitous system:

> *When John Anderton, the main character in the movie, enters a supermarket, he is provided with information (advertisements) about products that, according to his personal profile, he might be interested in buying.*

The phases of the short example scenario have been described in Table 7.

Table 7. Example scenario explaining the use of ubiquitous technology classification.

Class	Actions in the ubiquitous system
Service infrastructure	The ubiquitous system is aware of Anderton's whereabouts all the time or whenever needed. This information may be based, for example, on the positioning of a mobile phone.
Information capturing	When Anderton enters a shop, his entry is captured by the system, possibly based on face recognition or identification from his mobile phone. The captured information is stored in access control and customer relationship management databases.
Context-awareness	Based on the information captured from Anderton's mobile devices and the sensors in the shop, his current context is derived and communicated to the shopkeeper.
Embedded intelligence	Based on the derived context information and predefined personal profile (in the loyal customer program), the advertisements are selected to be sent to Anderton.
Natural interface	Mobile advertisements will be displayed for Anderton via public displays and audio messages.

In the following chapters we will briefly review the advances and anticipated developments of these technologies in the context of ubiquitous systems.

4.1.1 Service infrastructure

Researchers and authors have envisioned a ubiquitous computing future in which there are a numerous digital services available, ranging from simple mobile services accessed by mobile phone to a comprehensive ubiquitous world as also described in Publication VII. The requirements these services set for the services infrastructure range respectively from very basic communication capabilities to advanced sensor systems and "intelligent systems" responsible for data processing and profiling.

Baldauf et al. (2007) and Endres et al. (2005) have surveyed context-aware systems and software framework for such systems. In the literature, perhaps the best known middleware solutions for context-aware systems are Xerox Parctab (Want et al. 1996) from the early 1990s, Context toolkit (Salber et al. 1999) from Georgia tech in the end of 1990s, Gaia (Roman et al. 2002) from the University of Illinois in the early 2000s. Publication S1 also introduces an early attempt to create a system for managing context-aware mobile systems. All these systems can be called research infrastructures, as they have not really existed outside experimental laboratory conditions or been distributed to a platform of popular commercial services.

According to our experiences (Publication S1) and the review of service infrastructures by Endres et al. (2005), we can identify the basic components of a ubicomp service's infrastructure. These are a) communication, networking and messaging, b) service discovery, c) services, d) system data storage and e) authentication. These components have been discussed in the following paragraphs.

Communication, networking and messaging between human beings, objects and services is at the core of the ubiquitous computing vision. There is a need for different kinds of communication solutions in ubiquitous computing services. Global communication solutions include cellular mobile communication such as GSM/GPRS and Wimax. Local communication, covering distances from a few meters to a few hundred meters, are capabilities using technologies such as Bluetooth and WI-FI. Personal area communications ranging from a few centimetres (touching) to a few meters, can be implemented using, for example, Near Field communication (NFC) and proprietary low-power RF-communications. Important design characteristics in communication infrastructures are network coverage, available bandwidth, latency-time, communication costs, security and energy consumption of communication protocols.

The purpose of *services discovery* is that the user of ubiquitous systems is aware of the availability of digital resources that she can use in order to carry out her tasks. For example, a service discovery system might advertise the availability of a printing service to the user when she enters a meeting room.

One approach of ubiquitous systems is that they are built from a set of *services* that can be used by applications. Therefore, the availability of different kinds of services is an essential part of ubiquitous systems. Positioning services such as GPS (Global Positioning System) are one of the most cited ubiquitous computing-related services as they enable service developers to use location information. Similar services are for example, wireless sensors advertising their readings to the other services.

There are various needs for *data storage* in ubiquitous systems. User profiles, ontologies/vocabularies, log files are needed for many personalized services. Some part of this data can also be stored by applications and services, rather than by the infrastructure, but there is also a need for system-wide data management. Recently this trend, also known as cloud computing, has become mainstream in information processing. The essence of the concept is that all processing, applications and data is provided for users through services that are physically located in interconnected computer centers all around the world and these services can be accessed through the internet.

Computing resources can be an open system; thus, they are available to anyone. In most cases, however, an information system requires some kind of *identification and authentication of the user*. A user may authenticate herself in the actual services she is using, but there is also a need for 3rd party authentication carried out by the system.

In literature some researchers are proposing a comprehensive ubicomp world, with all components playing in harmony, for example, in Publication S2 as well as in articles by Warren (2004), Pinhanez (2007) and Weiser (1991). In practice however, systems develop gradually and the focus of development may change for various reasons. We can say that from the days when the ubiquitous computing vision was introduced by Mark Weiser (1991), the world of ubicomp has changed incrementally. Advances have been achieved in the infrastructure of ubicomp; for example, wireless communication coverage in the early 1990's was only available to very few people compared to today's situation, where virtually everyone carries a mobile phone.

There are global standards for internet services, cellular mobile communication and various short range communications. These systems represent a large part of the ubicomp infrastructure. However, work on introducing interoperability platforms for local services such as sensor networks or other services (e.g., the printing services example above) is still in progress. Different kinds of service architectures have been proposed for use as a basis of ubiquitous systems. Some of these architectures are deeply integrated and others incorporate the lightweight integration of components. The ubiquitous computing vision is built on the assumption that systems are interconnected and that they can use each other's resources. Therefore, there is a need for interoperability solutions in the ubicomp infrastructure. This is a particularly important issue in small, battery-operated devices where TCP/IP-based solutions are not energy-efficient enough.

4.1.2 Information capturing

The possibilities for recording information, tracking people and things, and monitoring various kinds of activities have significantly improved in recent years. Advances in mobile communication, the internet, sensor technology, and networked embedded systems have made it possible to locate information-capturing capabilities in almost any device and place.

The mobile phone is a device that is in close proximity to its user round the clock. This device also incorporates many capabilities that make it a good device for monitoring its users' activities. We can relatively easily monitor the use of a mobile phone's applications such as phone calls, messaging, games and calendar. The time and duration of these activities can be recorded using dedicated software (Publication VI). Sensors in mobile phones can also be used for various purposes, such as identifying the user of a device based on the walking style of the user (Mäntyjärvi et al. 2005).

The geographical position of the phone can be tracked, based on a GPS-receiver, which is already available in advanced mobile phones. The approximate position of the phone can also be derived from the cell ID of the mobile communication system, as described in Publication VI. It is also possible to ascertain whether the keyboard is in use or whether the Bluetooth connection is active. When a Bluetooth communication channel is open for search, one can monitor and record Bluetooth device names (unique identification) at close range. For example, based on Bluetooth names, a mobile phone could determine how many persons there are in the proximity (O'Neill et al. 2006).

Naturally, there are also other means to collect information besides a mobile phone. For example, city centers, supermarkets, shopping centers, underground rail systems, working places, schools, airports and train stations are equipped with surveillance cameras and access control systems. These systems generate large amounts of data which can be used, for example, when investigating criminal acts or traffic accidents.

Our daily activities, such as shopping, internet service usage, visits to the doctor and business with the authorities generate data in different databases. These databases contain personal information such as medical records, bank transactions, and records in social security systems and customer profiles.

In short, it can be said that we are generating increasing amounts of data in all activities of our life. Technically, this information could easily be recorded, communicated and merged. The fusion of various seemingly harmless data sources can provide a very comprehensive picture of someone's lifestyle and habits. Therefore, a great challenge in ubiquitous services is not only technologies for making this possible, but also making sure that the outcome of the process is one that can be accepted by everyone. The development of *User-friendly privacy-enhancing technologies* is one of the main challenges in order to ensure user acceptance of these systems (Publication VI).

4.1.3 Context awareness

Context awareness is one of the core concepts of ubiquitous systems. The surroundings of the user of the ubiquitous system are typically heterogeneous and diversified. Furthermore, the interfaces between the user and the system as well as the resources are typically limited. Utilization of the context information of the user has been proposed as a solution to overcome these usability challenges. Dey and Abowd (2000) define the term context as follows: 'Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves'.

Furthermore, they provide a general definition for the term context-aware: 'A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task'.

According to Mäntyjärvi (2003), the main sources of context information are *location, device processes, context sources over networks, time* and *sensing elements* in a device. Location and time are perhaps the most commonly used contexts in mobile information systems. Time can be absolute or relative to a certain incident. Outdoor location information acquired by means of GPS is emerging as a standard feature in high-end mobile phones (e.g., the Nokia N95, introduced in 2006). Indoor positioning systems do not have such a strong influence on the technologically dominant design. Indoor positioning solutions have been studied based on wireless LANs (Prasithsangaree et al. 2002, Madigan et al. 2005), RFID-tags (Välkkynen et al. 2003) or even using activity sensing based on accelerometers and magnetic sensors (Publication S3). Device processes and device status as a context source has been discussed by Raento et al. (2005). Context sources over networks can be something that is accessed over the internet, such as presence information in a social networking service or it can be a local context service in proximity of a device using the context (Dey et al. 1999).

Despite intensive research since the mid-1990s, context awareness has not yet become an essential part of mobile systems. At the moment, context awareness is available for end-users in the form of location-based services (based on GPS positioning), presence information (manually input context information) in instant messaging and social networking services and in simple sensor-based product features of some mobile devices. Advanced features, such as automated context adaptation or service selection, are still mainly found in research laboratories.

4.1.4 Embedded intelligence

In the original vision of ubiquitous computing, Mark Weiser's focus was on the ubiquitous computers with which we increasingly interact daily (Weiser 1991). So that the overload of interaction between computer systems and individuals would not be too demanding for humans, Weiser later proposed a concept of calm computing, where the computation and computers would disappear into the background and become a calming technology (Weiser & Brown 1997).

In the ubiquitous computing environment, for every computer with which we consciously interact there are already many others embedded in our surroundings with which we do not interact or with which our interaction is not of a classical information processing kind (Warren 2004).

According to Coutaz et al. (2005), the interaction space between the user and ubiquitous systems is ill-defined, unpredictable and emerges opportunistically. Therefore, the context is too complex to be pre-programmed as a fixed set of stable variables. The same problem has also been recognized by Biegel and Cahill (2004) when developing a framework for mobile, context-aware applications. Recognition of a context at a given instant with sufficient confidence in a resource-restricted computing platform is a challenging task in itself. Unfortunately, from the user's point of view, even this is not enough. According to Coutaz et al. (2005), the context system must behave correctly during the whole process in which the user is involved. To make things even more complicated, the user's model of the interaction with the system should not vary from the system's model of the same incident. In practice this can happen when the user expects the system to adapt to the situation where she *plans* to be shortly, while the system can only recognize the situation, where the user is *now*. The user expects the system to predict her intentions, which is usually next to impossible to do. Coutaz et al. (2005) state that the main challengesin context-aware computing is to find an appropriate balance between implicit and explicit interaction for providing the feedback required for development.

We adopt Warren's (2004) definition for embedded intelligence, where he states that in the embedded intelligence model, interaction is primarily between the devices, and there is no interaction with individuals, or at least only very occasional interaction. This approach has also been studied in publication S4.

In our classification, context-awareness is restricted to the measuring of context-related information and reasoning about the data in order to recognize the context of an entity, the entity being a device or a person. Put differently, the aim of context awareness is to make an entity aware of its own context. How the context information is used is called context-aware computing.

Embedded intelligence is the computational co-operation of entities that are aware of their own context. In some approaches this is called collective awareness (Publication S4). In embedded intelligence the aim is to make the system act intelligently by using information sources such as personal profiles, context information of devices and social context. The intelligent behavior can, for example, be an adaptation of service offerings for the user based on their location or context, or an adaptation of the environment based on the users' preferences, contexts and wishes (Aarts & Marzano 2003).

Embedded intelligence is an important part of most of the comprehensive ubiquitous computing visions. However, not many projects have been able to realize these ubiquitous intelligence features satisfactorily (Rogers 2006, Bell & Dourish 2007, Lueg 2002). Ubiquitous intelligence incorporates difficult challenges and at least the following areas will remain as important research topics for years to come: a) Technical interoperability solutions in ubiquitous computing environments including communication, and data portability (Warren 2004), b) Anticipating users' intentions, plans and actions, c) Semantics and ontology used in ubiquitous computing environments and d) Reliability of the reasoning of the ubiquitous system, fault tolerance and recovery from faulty actions (Publication VII).

4.1.5 Natural interfaces

Ubiquity, the fundamental characteristic of ubiquitous computing systems, implies that these systems are embedded in the everyday environments of people and we must therefore be able to use them anywhere, including outside the reach of the well-defined interaction locales such as desktops.

The natural way for people to communicate with other humans is to use spoken or written language and gestures. One of the main directions of ubiquitous computing development addresses interaction between human being and the smart environment where the physical environment is altered according to our needs and wishes. This kind of interaction is more natural to execute using means other than a keyboard, mouse and displays. The ubiquitous computing vision assumes that the physical interaction between humans beings and ubiquitous, invisible, computers will be more like communication between two human beings.

These natural interaction methods, sometimes called natural interfaces, include voice and gestures as well as the altering of physical objects. Concepts and technologies necessary to implement and use these natural interfaces as well as challenges incorporated in these solutions are discussed in the chapters following.

The discussion of natural interface is organized around the following subtopics: *input*, *output* and *linking the physical and digital worlds*.

Voice- and speech-based interaction is a potential solution for interacting with ubiquitous computing environments. Speech could be used as an input to the computing systems in smart environments. Speech interface requires automatic speech recognition (ASR) technologies embedded in the environment. Even though such systems have been available for a long time, they do have limitations. The technical quality of the interface is dependent on the correct recognition of words and commands. The confusability of words is a major reason for poor speech recognition. Acoustic confusability (phonetic similarities of pronunciations in vocabulary) as well as the processing of background noise are the challenges the designers encounter (Alewine et al. 2004). In addition to the technical challenges, social aspects in speech input are of great importance. Speech is socially interruptive and hard to ignore (Starner 2002); therefore the use of speech input around other people may not be a preferable way to communicate with computing systems.

Speech commands are typically considered to be an explicit means to control the system. The ubiquitous computing vision relies on the assumption that the computing is in the background and therefore carries out tasks for the users of the environments. Speech and voice can also be used as in implicit input (Schmidt 2000). Speech or voice can be used to recognize the context of a user (Eronen et al. 2006) and the context information recognized can be used to controlling the ubiquitous system.

The use of hand gestures has also been proposed as an interaction method in smart systems. The work in gesture control systems can be classified into two main categories, camera-based (Starner et al. 2000) and movement sensor-based (Kela et al. 2006). The former is more suitable in stationary environments, whereas the latter can also be considered in mobile systems. The latter approach has also been tested in Publication V.

Weiser described the form factor of ubicomp technology in three scales – the inch, the foot and the yard (Weiser 1991). The foot scale is similar to a standard laptop and desktop displays. Mobile phones, personal digital assistants (PDA)-devices and Wi-Fi-enabled MP3 players that incorporate handheld displays represent the small scale (inch) displays. Wall-sized displays represent the large end of the scale (yard).

Mobile devices are limited in size and form factor by the need to be mobile. In many applications this is not a problem, but the user experience in many services would obviously benefit from a bigger screen size than the 2–3.5 inch of current mobile phones. One solution to the shortcomings of limited output capabilities caused by the small screen size of mobile terminals is the use of multimodal user interfaces (Ringland & Scahill 2003).

Compared to the screen size of mobile devices, the displays of laptop and desktop PCs with 12–15 inch and 19–30 inch screen sizes (Weiser's foot size) provide much better capabilities in delivering a good user experience in services. Naturally the increased size of the display also has an impact on the mobility of the device.

Large display-related experiments have been discussed and compared by Russell et al. (2005). They compare common issues in three different projects concentrating on using large displays in ubiquitous computing environments. The most important design guidelines proposed are: a) Heterogeneity, meaning that despite a number of different kinds of devices being used in these kinds of environments, they must be interoperable and work together; b) Dynamism, meaning that the ubiquitous computing environments are highly dynamic. As wireless and communicating devices come and go to and from the environment, devices and systems will be updated, without great impact to other systems; c) Robustness, the system should "just work" and failures should be considered an exception rather than the common case; d) Interaction techniques need to suit the environment and tasks to be executed there.

Researchers have also explored the trend towards peripheral output for a particular class of displays called ambient displays. Such displays require minimal attention and cognitive effort and are thus easily integrated into a persistent physical space. An early example of such a display is a concept called the Dangling String (Weiser & Brown 1997), where the amount of the traffic in an ethernet cable is converted into the movement of a plastic wire using an electrical motor. The more traffic there is in the network, the more the wire dangles and causes noise.

One of the next developments in mobile phones is linking the digital world with physical places and devices, for example, using Near Field Communication (NFC) identification tags, visual codes or related methods (Ailisto et al. 2006). Ailisto et al. (2006) introduced a concept of physical selection which is a "sequence of actions taken by the user to select an object within the physical environment using a mobile terminal". Physical selection using a mobile device is based on the idea of augmenting physical objects with information tags (small and inexpensive unique identifiers). Furthermore, they introduce communication concepts based on scanning, pointing and touching. Scanning is acquiring information about existing tags in the vicinity. Pointing is selecting and interacting with a tag by pointing to it from the distance. Touching means to select the tag and interact with it by touching it (Ailisto et al. 2006, Välkkynen 2007, Rukzio et al. 2006).

Connecting the physical and digital worlds has been one of the central user interface challenges in ubiquitous computing system. One approach to tackle this is to overlay digital information onto the real world, creating *augmented reality* (Feiner et al. 1993). Another approach to integrating physical information is so-called *tangible interfaces* (Ishii 1999), where digital artifacts are manipulated using real world objects linked to these digital artifacts. The goal is to bridge the gaps between cyberspace and the physical environment, as well as between the foreground and background of human activities.

As the number and variety of these displays keeps growing, two trends will emerge. First, a solution will be derived to coordinate the interaction between multiple displays, and second, displays will become less demanding of our attention (Abowd et al. 2002).

4.2 Examples of ubiquitous services in the home environment

There are different ways to classify ubiquitous services. One option is to look at the application domains where ubiquitous technologies will make (or are making) a strong impact. We can classify the applications based on context source and type of application (Dey & Abowd 2000). We can also take the type of environment an application operates in as the basis for classification (Hong et al. 2009), or we could analyze the usage of service from various viewpoints, including type of device, applications, network and content (Smura et al. 2009).

Publication I discusses ubiquitous computing applications in the home environment. Furthermore, the paper introduces taxonomy of home-related ubiquitous applications. Publication I describes home-based ubiquitous applications in general. In this section, based on Publication I, we take a look at home-related application fields and try to understand the possible role of advanced mobile phones and situation awareness in these applications.

4.2.1 Home automation

Home automation functions cover basic housing support functions, security functions and functions to increase autonomy and support independent living. Table 8 summarizes the classification and potential home automation-related applications where mobile phone-based ubiquitous applications may play an important role. The summary is based on Publication I.

Table 8. The role of an advanced mobile device in home automation applications (Publication I).

	Role of mobile phones	Role of sensors and context-awareness	Other issues
Basic housing supportive functions	- Mobile devices (with local connectivity) as a possible remote-control and communication device for housing support systems	- Mobile devices as input and user interfacing devices for housing control - Mobile phone as a platform for identification and activity monitoring	- Multi-user personalization - Automatic decision making - Privacy
Security	- Locking and access control - Advanced mobile device as an identification device (NFC or Bluetooth) - Hands-free operation of doors	- Mobile sensors as platforms for user identification (Biometrics or Gait-style recognition (Ailisto et al. 2005))	- Industrial environments - Office buildings - Special care homes - Regular homes not likely in near future
Support for independent living	- Compensation for functional impairments (remote control of devices and environment) - Mobile device as a gateway between health services and measuring devices such as blood pressure and blood sugar.	- Monitoring and communicating vital signals and health status - Activity monitoring (and e.g., fall detection) - User identification in home care services	- Drivers: Ageing population, scarcity of labor, social security deficit

Housing supportive functions will become increasingly intelligent (ICT-controlled). Mobile devices with local connectivity will be one possible remote-control and communication device. Home functions can be controlled and adjusted according to a user's preferences. The mobile phone provides a platform for user identification and activity monitoring for personalization, as well as for advanced user interfaces such as gesture or face recognition-based interaction. Personalizing multi-user environments according to users' preferences raises a question of automatic decision-making over multi-user preferences and the privacy of the users of the space.

Security in the home environment is often linked to locking and access control systems. Advanced mobile devices can be of assistance in this use, for example by being an identification device using NFC or Bluetooth. Local connectivity can also provide users with hands-free operation of doors. Context awareness of mobile devices could be practical in future locking systems by providing a platform for user identification by means of biometrics or walking-style recognition (Ailisto et al. 2005). The development of locking systems in home environments is not very rapid. The mobile phone has more potential as an essential component of a locking system in industrial environments, office buildings and in special care homes rather than in regular homes.

Support for independent living and compensation for functional impairments may be considered one potential application field of mobile devices in the home environment. In such services local communication is required, for example in the remote control of various electronic devices and environments. Local mobile connectivity can support independent living, for example by acting as a gateway between health services and measuring devices such as blood pressure and blood sugar. Or they can improve the quality of life by providing new kinds of service such as advanced meal delivery service for the elderly (Häikiö et al. 2007). The drivers for this development are the increased need for home care services due to the ageing population, and the scarcity of labor and funding in social security services.

4.2.2 Communication and Socialization

Home is the location of various kinds of communication and socialization activities. ICT has an increasingly important role in these activities. The role of mobile devices in this category of applications is continuously increasing. Publication I is based on a technical report by Alahuhta and Heinonen (2003). At that time, concepts such as social media and Web 2.0 were only vague ideas for the future. This can be seen, for example, in Publication I where we could not use the current terms "social networking" and "social media" for the person-to-community and new forms of socialization applications. In this chapter communication and socialization applications in the home domain have been discussed and categorization of this application field is given. The main categories derived from Publication I are *person-to-person communication*, *person-to-community communication* and *new forms of socialization*. Table 9 summarizes, based on Publication I, the role of advanced mobile device in these applications.

Table 9. The role of advanced mobile device in communication and socialization applications (Publication I).

	Role of mobile phones	**Role of sensors and context awareness**	**Other issues**
Person-to-person	- From house-to house-communication to person-to-person communication - Free-of-charge communication of content through local connectivity (e.g., Bluetooth)	- Sharing location and activity with a friend	- Communication increasingly personal - Privacy concerns on location and activity communication
Person to community	- Free-of-charge communication of content through local connectivity (e.g., WiFi) - Access to internet hotspots through WiFi networks	- Sharing location and activity with a community	- Social media / Web 2.0, Blogs - The importance of mobile devices in communicating with the community is increasing
New forms of socialization	- Local ad-hoc peer-to-peer communities (within a few meters to tens of meters)	- Applications and services using location and activity	- Social media / Web 2.0, Blogs - Easier and richer ways to create new connections and communities

Person-to-person communication in the home environment has evolved greatly from the time of the "one phone-one house" concept where every house and apartment had a fixed line phone, and phone calls were between these fixed stations, to the current situation in which every person has their own personal mobile phone. This change in person-to-person communication enabled by mobile phones has been a transformational change. Compared to the importance of voice communication and messaging, the role of the advanced features of mobile phones in person-to-person communication tends to be limited to the communication of content, such as digital music and pictures between mobile phones. Sensors have a role in person-to-person communication when we are sharing our location (Google Inc. 2010c) or current activity (Nokia 2009b) with our friends.

In *person-to-community communication* the role of mobile phones is increasing. This is due to the trend towards nomadic lifestyles, where people move and travel increasingly and live physically apart from their families and communities. Using mobile technology, they are able to be connected with their communities in real time no matter where they are. In person-to-community communication the role of mobile connectivity through global communication systems such as 3G is far more important than local connectivity-based applications. There is however a role for local connectivity technologies, for example in providing cost-effective solutions for internet connection or Voice-over- IP calls in mobile devices. The role of sensors in person-to-community communication is mainly related to sharing one's location and activity similarly to person-to-person communication.

In Publication I one of the subfields of communication and socialization applications was called *new forms of socialization*. New forms of socialization include the tools and means for easier and richer ways to communicate and create communities on the internet. The development of social media falls into this category. There have been some experiments where the potential of local connectivity has been tested (Nokia 2005). Sharing one's location and activity information on the internet with one's family, friends, colleagues, and communities is an example of using the sensor in mobile devices to create new ways to communicate.

4.2.3 Applications for relaxation

Relaxation is a diverse collection of activities that is important in people's everyday lives. Such activities include rest, refreshment, entertainment and sport. These activities are largely carried out in homes, but they can also be done outside the home. The role of mobile devices in these activities is changing from unimportant to an essential component of the specific activity. In this chapter we have revisited Publication I and analyzed identified application examples from the viewpoint of advanced mobile devices. Table 10 summarizes the analysis from the viewpoint of advanced mobile devices based on Publication I.

Table 10. The role of advanced mobile devices in relaxation-related applications (Publication I).

	Role of mobile phones	Role of sensors and context awareness	Other issues
Rest and relaxation	- Mobile device as a (automatic) remote controller of home automation / appliances	- Analysis of status of the sleep and optimizing the wake up signal	- Publication I mainly presents ideas for stationary ubiquitous systems
Refreshing and hygiene	- Scale disseminating daily measurements to a health monitoring service through mobile device	- Sensor-based indicators in hygiene devices such as toot brush	- Application ideas mainly stationary ubiquitous system and simple electric appliances
Entertainment and hobbies	- Mobile devices as gaming controllers	- Sensor-based gaming controllers - Combining games and activity measurement in real life	- New forms of participation in radio and TV - Richer experiences when different contents are linked together
Sport and fitness	- Use of mobile devices as a data collection and device	- Sport and Activity monitoring through GPS and accelerometer sensors	- Sport and fitness activity recognition and monitoring - Physical exercise coaching

Rest and relaxation is an application field that is not necessarily considered a potential area for ubiquitous mobile service. Also in Publication I, the main part of the discussion covered a concept of building stationary ubiquitous systems in the home. However, there are example applications where mobile devices have been used to support rest and relaxation. For example (Smart Valley Software Ltd. 2010) uses sensors (Microphone) in mobile devices to monitor the sleep of a user and adjust their wake-up time according to the phase of their sleep.

In the *refreshment and hygiene* application area there are several electronic appliances, such as shavers, hairdryers and electric toothbrushes. Some of the potential applications are discussed in Publication I. From the viewpoint of an advanced mobile phone providing services for users that are enabled by local connectivity and sensor technology the applications are few. Perhaps a scale with local connectivity might use a mobile phone to communicate daily measurements to a weight management service.

In Publication I *entertainment and hobbies* were considered as areas in which there is a lot of potential for ubiquitous computing technologies. For example, TV and Radio will have new possibilities due to improved interaction between the broadcasting companies and the audience. The possibility of creating "mash-ups" using different kinds of content, such as movies, web-sites, music, and, pictures will create richer experiences for consumers. There is also a role for advanced mobile devices in this application area. Mobile devices with local connectivity capabilities can, for example, be used as gaming controllers. Sensor-based user interaction and activity monitoring using sensors in mobile devices provides interesting possibilities, for example, when linking games and real world activities into "augmented reality gaming".

Sport and fitness is an application area where advanced mobile devices have a lot of potential for interesting applications. In Publication I, the sport and fitness area is also considered an interesting field of applications. In particular, the publication discusses integrating physical exercise capabilities into "ordinary furniture" and into the environment. The publication also points out the demand for "a sport and fitness assistant" that would coach the user in exercise both in and outside the home. A mobile phone could be a platform for this kind of "assistant", as it could be used to keep a diary of exercises (Nokia 2010b), it could recognize the sports we are participating in (Ermes et al. 2008) and monitor exercises, for example through GPS (Nokia 2009b).

4.2.4 Working and learning

The home is increasingly expected to provide a location for work and learning. Work in the home is partly related to household and maintenance work, but also to other professional work such as paid office work, study and entrepreneurship. Central viewpoints of this application field have been summarized in Table 11.

Table 11. The role of an advanced mobile device in working and learning applications (Publication I).

	Role of mobile phones	Role of sensors and context awareness	Other issues
Household work	- Household objects communicating with the mobile device (e.g., shopping lists, preferences)	- "Weasley family clock"-type applications	- Proposed examples mainly stationary ubiquitous systems such as robotics
Maintenance work	- Local connectivity-based access control for maintenance businesses	- Improved security in maintenance work	- Stationary ubiquitous systems proposed, such as robotics and smart materials
Home office work and learning	- Basic mobile connectivity	- Automatic reasoning and dissemination of presence and context information	- Basic ICT-based capabilities, such as internet access and communication capabilities are needed

Household work aims at keeping the house a comfortable and appropriate place for its occupants to live in. Household work includes a diverse set of activities including, laundering, cleaning, cooking, washing up and preparing meals. Many innovations have been introduced to help with household work, but there is still scope for more convenient technologies and applications. Publication I mainly proposes applications that require advances in robotics (e.g., cleaning and service) and smarter, functional materials (self-cleaning surfaces). Proposed information technology-based applications, such as an automatic inventory of the refrigerator or a database of friends' preferences and allergies, are mainly for stationary use. Advanced mobile phones have a role only in very few applications. Such applications might, for example, be an aware kitchen automatically communicating items to the shopping list in a mobile device through local connectivity, or a family communication application, similar to the *Weasley family clock* in the Harry Potter novel, where the location and context of each family member is presented in a single display (Rowling 1998).

Similar to household work, anticipated applications of *Maintenance work* are also mainly based on advances in robotics and material sciences. This is not necessarily the most fruitful application area for advanced mobile devices from the viewpoint of the occupant. There might, however, be a role for mobile solutions, if we consider maintenance businesses. Maintenance companies could benefit from mobile solutions, for example in guidance, reporting, access control and management of maintenance staff. Mobile solutions can also be used for improving security of persons working alone.

The main requirements for *home office work and learning* at home are internet access, communication capabilities such as telephony and personal computer equipment. When these basic capabilities are available, advanced mobile phones with local connectivity capabilities and sensors do not necessarily improve our possibilities of carrying out our duties with regard to home office work or studies.

5. From mobile services towards ubiquitous services

In this chapter we describe the dependency between the new technologies emerging in mobile handsets and the ubiquitous services enabled by these technologies. Ubiquitous services are characterized by mobile services that have the extended capability of recognizing the context they are in. In the literature these services are sometimes called context-aware mobile services. In practice, context awareness includes context recognition based on sensors and other information sources as well as local connectivity solutions.

In this chapter we will first introduce a framework for analyzing and understanding the evolution of mobile technologies. Then technologies enabling mobile services will be discussed. After the technologies of mobile services have been analyzed, we will look at the enabling technologies of ubiquitous services. In addition to technology enablers, we will discuss factors impacting the diffusion of ubiquitous services, including privacy, business model support and environmental issues. Finally, we will take a look at the diffusion rate of the essential ubiquitous service enablers.

5.1 An analytical framework

In Section 2.1 several theories related to innovations were briefly introduced. Each theory or model attempts to explain some part of the technology change process. In this section, we attempt to use these theories to create an analytical framework for better understanding and predicting the process of technology diffusion, from the introduction of new technology until the adoption of applications taking an advantage of this technology by end-users. In particularly, we are interested in technologies and services at the crossroads of mobile communication and ubiquitous computing.

In this section we define a framework of conceptual layers, namely, *User aspects*, *Applications/Services*, *Functionalities*, and *Technologies*. The components and their relationships to each other have been illustrated in Figure 8. The framework, its components and relationships to theories of innovation introduced in Section 2.1 are discussed in more details in the coming subsections.

In practice, the model can be considered as a hierarchical construction of technology abstractions. Each level of the framework combines a set of outputs of underlying objects (technology, functionality, application) and processes this information into a more meaningful form.

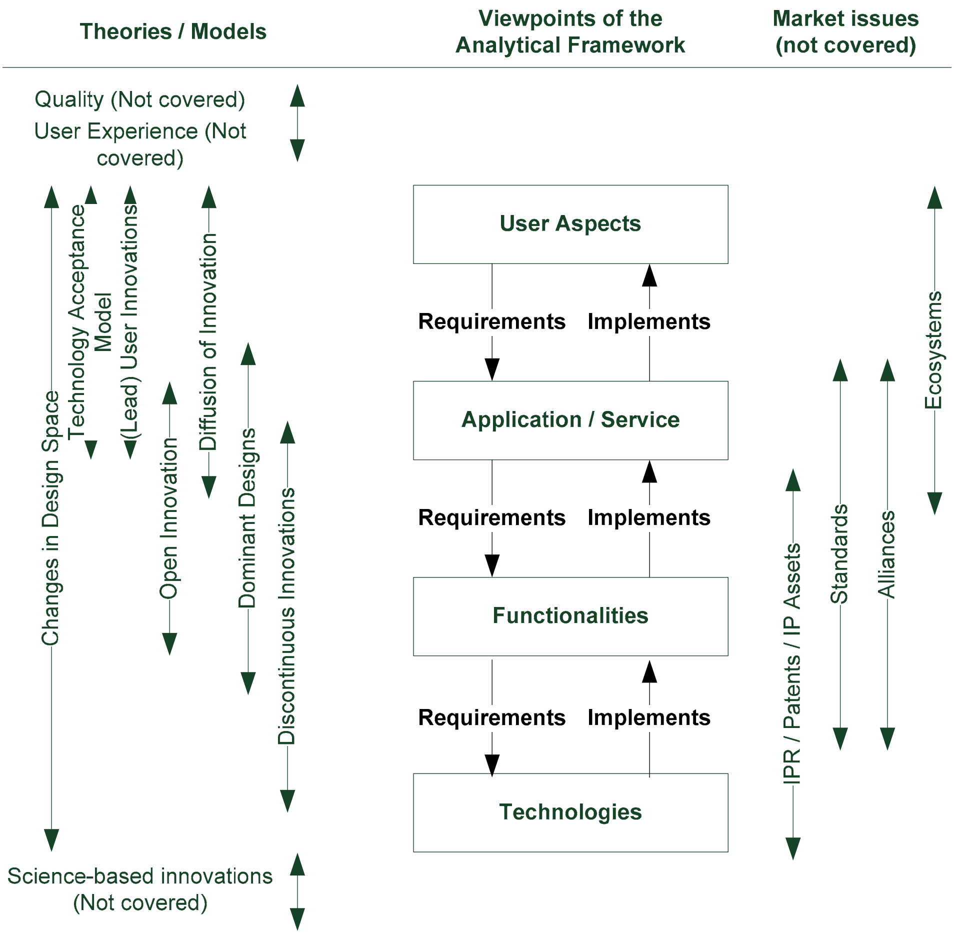

Figure 8. Components of the analytical framework.

5.1.1 Technologies

According to Encyclopedia Britannica Online dictionary technology is the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment. (Encyclopedia Britannica 2011). The first step of the development, so-called science-based innovations, is taken when basic research produces scientific discoveries in a manageable form so that they can be applied in various uses. In the early days of the development of a technology the progress occurs due to the scientific discoveries. The development often requires large resources, and uncertainties regarding the outcome of the work are high. Therefore, the main actors in this phase of development are universities, research institutes and large companies. The creation of IPR is considered important and it is active.

New technologies are a result of the scientific discovery process, where researchers see the possibilities of new materials, new ways of doing things or new ways of combining existing technologies. These kinds of innovations can be called "discontinuous innovations" (Anderson & Tushman 1990) and technologies enabling these changes are called "disruptive technologies" (Christensen et al. 2004). The nature of technologies can either be competence-enhancing or competence-destroying innovations (Anderson & Tushman 1990). An example of a competence-enhancing discontinuous innovation is how digital mobile communication systems emerged from analogue mobile communication systems. The emergence of the PC as a text authoring device instead of the mechanical type writer is an example of a competence-destroying discontinuous innovation.

In order for technologies that are not compatible with incumbent solutions to be accepted by product developers and customers, they must provide some clearly communicated benefits, such as performance, cost, or reliability advantages that are superior to existing solutions (Anderson & Tushman 1990).

In mobile phone technologies such benefits might, for example be new kinds of interaction methods or battery technology providing superior performance. In our framework we are mainly interested in technologies that enable these new features. As this research is focused on mobile technologies, we are particularly interested in new technologies recently integrated into mobile phones or soon to be an essential part of mobile handsets.

In electronic devices a large number of new features can be implemented as software modifications. Quite often though, new features require new designs and hardware components to be realized. The basis for the integration of certain new technical components into mobile terminals is dependent on the technical and economic feasibility of the integration work. In mobile handsets technical feasibility, includes, for example, such factors as the size of the component and energy consumption. Economic feasibility deals with the manufacturing costs of the new feature as well as new business generated relying on this feature and technology.

Justification for integration of a technology into mobile handsets is generally derived from the functionalities that are required to implement applications that users are predicted to be interested in.

5.1.2 Functionalities

Functionalities are operations or product features that make the underlying technological capabilities available to developers, for example through Application Programming Interfaces (API's). Application developers use them when creating applications and services for end-users. In the optimal case an application developer should not need to consider how to access and process the information that is provided, for example, by a GPS-transceiver component. Quite the contrary, at the application level, the designer should be provided with location information functionality through an application programming interface to location information. Functionalities are realized using a set of technologies.

When new technologies are embedded in mobile devices, dominant design theory (Abernathy & Utterback 1978) explains the dynamics of the evolution of functionalities in the product class. After early market probing exercises, an optimal set of functionalities is selected as a dominant product feature i.e. dominant design.

The dynamics of the evolution of functionalities can be partially explained by the model of innovation adopter classifications introduced by Rogers (2003). Functionalities can be classified according to the target user groups they are intended for. Some functionalities are basic features that are needed in mass market products, whereas some other functionalities can only be found in devices targeted at innovator markets.

The discontinuous innovations theory (Christensen 1997) explains the development of functionalities by providing a framework for analyzing the approaches where functionalities are implemented using incremental and interoperable technologies or discontinuous and incompatible technologies.

The essence of the complementary assets theory (Teece 1986) is that success in the commercialization of technology is dependent on the control of critical complementary assets linked to a technology-implementing functionality. In the case of new mobile technologies, such complementary assets may, for example, be manufacturing capability, access to a large developer community leveraging a new functionality or control of map and navigation technology in the context of location-based services.

Functionalities can be relatively simple features, depending on few technologies or they may need a complex ecosystem of collaborating business networks. An example of a simple functionality in mobile devices is the capability to create a Bluetooth technology-enabled personal area network with peripheral devices such as wireless headsets. In order to be operational, it only requires a Bluetooth chip in a device and corresponding software. An example of a complex functionality is a global positioning system, which only requires a single chip and software in a device, but a fully operational satellite positioning system orbiting the globe. Functionality may also need a complex business ecosystem to be operational. Such is the case in payment-related functionalities.

Alliances and partnerships in developing new functionalities can play an important role, for example through standardization, where a large number of industrial parties negotiate the standards, procedures and rules to implement certain functionalities. In standardization, large international companies play a central role.

5.1.3 Applications and services

Mobile devices include a limited number of different functionalities such as mobile telephony, SMS-messaging, WAP-Browsing or GPS-positioning information. Application developers attempt to create applications and services that use the functionalities available in devices and meet the expected needs of the end-users. Publication III analyses mobile service ideas collected from the end-users of mobile phones. The ideas were collected in quite a short period of time mainly from students and school children. Even if there are lots of similar ideas in the database, there is a very rich variety of different ideas as well. One of the lessons learned from that project is that whenever end-users are encouraged to express their ideas on, for example, mobile services, they are able to provide a large number of versatile ideas. This observation seems to be well aligned with user innovation and lead user theories (Von Hippel 1986, 2005). Not all of these ideas can be implemented with current technologies but according to a statistical analysis of 4,000 ideas, almost 95% of these ideas can be developed already now or in the near future.

Based on the success of the Idea Movement-project (VTT 2010), it can be argued that using a relatively limited set of functionalities, a large number of developers can generate a very large and diverse collection of applications and services for various fields of life.

The mobile industry, which includes mobile terminals and networks as well as telecommunications-related businesses, has faced rapid changes due to open innovation (Chesbrough 2003) through mobile application stores. Application stores have perhaps been some of the fastest growing businesses in recent years. Inspired by the success of Apple, many other application stores have been launched, including Android by Google (2010a) and Ovi from Nokia (2010a). Most of these application stores are meant for a single operating system. Therefore an application developer needs to commit to a single mobile ecosystem or handle the cross-platform development challenges. Understanding the dominant designs (Abernathy & Utterback 1978) of the mobile platforms and devices is of great importance for application developers. In application and services development markets mastering the lifecycle of mobile technologies and platforms is not enough. A successful application developer needs to be aware of user aspects, such as different types of customer groups in terms of technology adoption capabilities and willingness (Rogers 2003) and take into account product characteristics that users value such as perceived ease of use and perceived usefulness (Davis 1989).

Functionalities are available for application developers through application programming Interfaces (API) and operating systems such as Windows (Microsoft 2010) in PCs or the Symbian operating system (Symbian Foundation 2010) in mobile phones. These operating systems and programming platforms make several functionalities easily accessible for application programmers.

In comparing the development of new technologies and functionalities, the application and service development provides opportunities for a larger number of actors. In application development business, large companies attempt to integrate all the necessary functionalities into their operating system (application platforms) so that application programmers have the possibility of creating different applications using the general platform. The application designers can then concentrate on implementing applications that integrate customer needs and assume that the application platform takes care of basic computing routines. This platform-based architecture becomes feasible when the dominant design has been reached and the performance of the platform is adequate (Christensen 1997, Christensen & Raynor 2003).

The driving force in application development business is in building applications for end-users that take advantage of available functionalities in APIs and programming platforms. Even if the most common application platforms are controlled and provided by large international companies such as Microsoft, Apple, Google and Nokia, small- and medium-sized companies and even individuals can also benefit from these programming platforms and build businesses based on them.

5.1.4 User aspects

Technology brings value to users when it is taken into use. Respectively, technology changes society when it diffuses to the markets and changes people's behavior.

Applications are developed to fulfill either anticipated or known user needs. One quite widely used generalization of the sources of innovation is to classify them either as technology-driven or demand-pull innovations. In the real world this model is too simplistic. A starting point for service or product development can be the needs of the lead users (Von Hippel 1986, 2005) or the end-users in general (Leikas 2007). On the other hand, development can be initiated as new technologies become available (Publication IV). In practice the adoption of an application by end-users is an interactive process including both new technology enabled applications becoming available and users adopting them to fulfill their needs.

In the Technology Acceptance Model (Davis 1989, Venkatesh & Davis 2000), the main factors explaining the adoption of applications and services are perceived ease of use and perceived usefulness. The product of these factors explains the intent of a user to use the system. Intent precedes the actual use of the system. The research on adoption is quite active research field and it is considered as an important tool for understanding the behavior and expectation of end-users. This understanding is naturally important for businesses to be able to develop products that meet the needs of end-users.

In recent years the participation of end-users in the development of services has become an interesting issue from the business perspective as well. There are several examples where the internet has played a crucial role in enabling (lead) users' participation in the development of services (Von Hippel 1986). An example of such lead user innovations are the Linux operating system and the Wikipedia web encyclopedia, with their enormous numbers of voluntary end-users. Some companies also provide their customers a possibility of modifying the design of products and sharing these modified designs with other end-users over the internet (Lego Group 2010).

5.1.5 The framework applied to technologies enabling mobile service

The essential technologies and functionalities used in mobile services have been discussed in detail in Chapter 2.3. Based on the definition of mobile services, we can identify several required functionalities that can be considered as standard features and parts of mobile service platforms. The most important of these functionalities are mobile telephony and messaging, wireless access to services and the internet, user authentication, content storage capabilities, browsing capabilities and, the possibility of running applications. These functionalities and some examples of the applications they enable are presented in Table 12.

Mobile telephony, or voice phone calls through cellular mobile networks, is the most important and primary mobile service. The impact of mobile phone connectivity wherever we go has had a great impact on our everyday lives. This development was enabled by the large scale adoption of mobile cellular networks and handsets capable of connecting to the cellular network. The emergence of mobile phone connectivity can be categorized as a disruptive innovation. Compared to the later developments in mobile technology, the impact of mobile voice telephony is significant. However, the importance of incremental innovations should not be undervalued. In the case of the car, for example, the disruptive innovation was introduced about 100 years ago. After countless incremental innovations to the design of the car, today's vehicles are far more comfortable, safe and effective than those built in early times.

The emergence of cellular networks was not only important because of the mobile voice service. In digital cellular networks, particularly in GSM and 3G networks, the messaging service such as Short Message Service (SMS) is an important part of the GSM-specification. In many countries SMS-based services such as personal communication, ring tone downloads and mobile phone wallpaper image downloads have been highly popular, mostly because of their perceived usefulness and ease of use. In addition to being popular, these services have been the most important segment of data communication services in many countries.

Table 12. Technologies in mobile terminals and examples of functionalities and the applications they enable.

	Technology	Functionality	Applications	User Aspects
Mobile / Cellular networking	GSM (2G) WCDMA (3G)	Mobile telephony SMS MMS Cell-based positioning	Phone call Voice mail Voice-based services SMS-based services (ringtones, wallpapers)	Anywhere telephony Anytime reachability Unobtrusive messaging Personalization of mobile evices
Wireless data communication	GPRS, EDGE, HSDPA, Wi-Fi	Access to the Internet Access to services	Internet browsing Instant messaging Content streaming Content delivery	Access to information anytime Keeping in contact with friends and family Sharing experiences
Memory	Flash-memory	Store information Read and write content to and from memory	Information storing Music players Image players Camera and image storage	Entertainment through music and multimedia Storing memories through pictures and videos
Subscriber Identity Module (SIM)	Smart-card technology in mobile handsets (SIM)	Authentication of a user Storing service subscriber (IMSI) key Loyalty cards	Subscriber identification for billing Caller identification Personal Identification in many services and even countries	Easy and trustworthy way to identify oneself in services Convenience in telephone (callers identity)

Data communication services in mobile phones have been largely linked to the internet access and access to digital services, either using mobile phone browsers or laptop computers utilizing mobile phones as wireless modems. Lately, mobile broadband in laptops through USB-based 3G modules or laptop PCs with built-in 3G capabilities have become very popular. Packet-switched mobile data communication services such as General Packet Radio Service (GPRS) enable telecom operators to provide subscribers with reasonably priced data communication services by which they can always be connected to the network and access Internet Protocol (IP)-based services with their mobile devices.

One of the most important innovations in digital cellular networks is the Subscriber Identity Module (SIM), which is located in a mobile handset and used to securely store a subscriber's identity information. In practice SIM enables billing for mobile telephony services and messaging services. It can be used as an identification module in mobile commerce and has even been considered for use as a personal identification in some countries.

5.2 Technologies enabling ubiquitous services

At the beginning of Chapter 3 we defined mobile services thus: Mobile services are radio communication services between mobile devices while in motion or between such stations and fixed points of services (computer systems / servers). In this study, ubiquitous services are extensions to mobile services where a mobile device is capable of sensing and recognizing its context and local device environment, and that information can be and is used in these services.

In this section we discuss technologies that enable context-aware services in mobile terminals. The Global Positioning System, enabling location awareness in mobile phones is perhaps the most important of these technologies. However, there are other interesting technologies emerging in mobile handsets as well. The most influential and interesting ones from the ubiquitous services point of view are local connectivity solutions such as Bluetooth, Wi-Fi and Near Field communication, as well as sensors integrated into mobile phones. These sensors include, for example, accelerometer sensors and magnetic compasses. These technologies are discussed in this section.

5.2.1 Global Positioning System

In recent years several mobile device manufacturers have introduced new phone models with technologies that make the realization of ubiquitous services feasible. For example, the diffusion of GPS technology to mainstream mobile phones started in 2002, when Motorola integrated a GPS transceiver into a mobile phone. Subsequently, all major manufacturers have followed Motorola. Table 13 summarizes the GPS-enabled product announcements from five major mobile phone vendors between 2002 and 2008.

Table 13. Summary of the announcements of GPS-enabled mobile phones from the five major mobile phone manufacturers. Data collected from (Arena Com Ltd. 2010a).

	2002	2003	2004	2005	2006	2007	2008
LG			1	2	6	15	16
Motorola	1	1	8	13	8	17	14
Nokia		3	2	0	6	8	12
Samsung		1	1	4	11	21	26
Sony-Ericsson			1	0	1	2	19
TOTAL	**1**	**5**	**13**	**19**	**32**	**63**	**87**

The NAVSTAR Global Positioning system (GPS) (U.S. Government 2010) of the United States was the only fully operational Global Navigation Satellite System (GNSS) in 2009. The European Union's Galileo positioning system is in its initial phase; the Russian GLONASS is has yet to begin full operation. and China has indicated its intent to expand its regional navigation system to a global scale. A small electronic GPS-chip receives signals from several GPS satellites orbiting the earth and calculates its position by precisely timing the signals. The accuracy of GPS is a few meters. The location is expressed in longitude, latitude and altitude. Geometric trilateration is used to combine these distances with the location of the satellites to determine the receiver's location. So called Assisted GPS (A-GPS) is typically used in GPS-capable mobile phones. A-GPS improves the performance of stand-alone GPS, particularly in poor signal conditions, by using the positioning capabilities of a cellular network. With GPS, users do not need to subscribe to the service before they start using it. The system is operational providing the GNSS provider keeps the system running.

Table 14 illustrates examples of applications the GNSS systems enable. Location information provided by GPS functionality can be used, for example, in determining the velocity and the direction of a car. Navigation is perhaps the most popular GPS-based end-user application. Tracking of all kinds of objects and assets has considerable business value in, for example, logistics. There are also many end-user applications that are based on location information. Location-based service provisioning and information delivery as well as geocaching games or GPS-based tours are examples of applications enabled by GPS-technology. Location can also be an important information source in sport-related applications such as the Sports Tracker (Nokia 2009b).

Table 14. Summary of emerging technologies in mobile phones and functionalities they enable.

	Technology	Functionality	Applications	User Aspects
Positioning	GPS	Geographical position of the device Map processing / display	Navigation Tracking goods and people Location based services	Finding the right way when driving or walking Security through tracking objects and people Easy access to relevant information and services
Personal Area Network	Bluetooth	Local P2P communication Personal Area Networking (Indoor) positioning User Identification	Content-transfer between devices Connecting accessories Mobile Marketing	Easy content-transfer between devices Convenient means to connect devices together wirelessly Unobtrusive user identification
Local Area Network	Wi-Fi	Wireless networking Peer-to-peer communication Positioning	Access to internet hotspots Multi-user gaming and applications Media sharing Local resource (e.g., printing) discovery	Easy access to internet services Easy way to use local resources Convenient means for connecting home appliances Improved productivity through indoor positioning
Touch-based communication	NFC RFID	Card emulation Read / Write tags Peer-to-peer connection	Mobile payment Ticketing in events and public transportation Access control Creating links to objects (e.g, pairing mobile phones)	Convenience of payment and ticketing applications Convenience of information access and access control Secure access control and information access

Imaging	CMOS Camera sensors	Digital imaging Environment sensing Bar-code reading	Picture taking Video recording Image messaging Reading bar-codes (QR codes) Augmented reality	Sharing experiences Easy access to information New ways to experience places
Activity sensing	MEMS sensors (and sensor accessories)	Motion classifier Position / orientation detection	Activity monitoring Fall detection service for elderly Gait (walking style) detection Mobile device feature adjustments Gesture based user interfaces	Sense of security Convenience through user interaction adaptation Unobtrusive user identification Novel ways for interacting with systems

From the users' point of view, GPS-based services can be quite simple and easy to understand in stand-alone applications such as car navigation systems, where a customer buys a navigation device together with maps. In addition to convenience of finding the route to the destination, the technology and applications it enables increases the sense of security of the users of the technology.

5.2.2 Bluetooth

Bluetooth is a wireless technology that can be used for short-range communication between different Bluetooth enabled devices. It was originally developed as a wireless alternative to RS232 data cables. Bluetooth operates on an unlicensed 2.4 GHz short-range radio frequency bandwidth. The Bluetooth specifications are developed and licensed by the Bluetooth Special Interest Group, consisting of companies in telecommunications, computing and consumer electronics. Depending on transmitting power, the range of Bluetooth is 1 to 100 m. Data rates are between 1–3 Mb/s.

The Bluetooth technology itself is a product of low-power, short-range Radio Frequency (RF)-communication technology and networking protocols suitable for this purpose. Due to the identification code (i.e. Device name), Bluetooth devices can be used as identification devices and they can be positioned in the range of a Bluetooth network. A Bluetooth-enabled device can simultaneously connect to several other devices, creating a Wireless Personal Area Network (PAN). Devices can also communicate directly to each other through peer-to-peer (P2P) communication capability. Bluetooth can also be used for positioning devices indoor.

Local peer-to-peer functionality can be used in various applications, such as connecting and exchanging digital information like music, pictures and video clips, between various devices including mobile phones, laptop computers, tablet computers, digital cameras and video game consoles (Table 14). Personal networking is in use when Bluetooth-enabled devices are connected in peripheral devices such as headset, wireless keyboard and mouse, measurement devices or remote controller. A Bluetooth-based positioning system can be used, for example, for object tracking within the range of the Bluetooth network. Bluetooth can also be used in access control or navigation systems. An example of a location-based service built on the Bluetooth technology is a mobile advertisement systems for examples in airports.

The main value proposal for the end-users Bluetooth offers is convenience. Bluetooth provides an interoperable communication channel for file and information transfer between devices. Being able to easily connect devices together also improves productivity. In the case of hands-free systems in a car one can also talk about improving safety, when the driver can respond to an incoming phone call through the hands-free system.

5.2.3 Wireless LAN

Wireless Local Area Network (WLAN, Wi-Fi) links two or more devices together wirelessly and enables communication between these devices within a limited area. The specifications and standards of Wi-Fi were developed by the IEEE 802.11 working group for Wi-Fi. As Wi-Fi was first developed as a wireless broadband solution for PCs, the diffusion of the technology has developed further in PCs than in mobile phones. Wi-Fi has been integrated into mobile phones on a large scale since 2004. Diffusion of Wi-Fi to mobile phones may also be restrained by mobile operators reluctant to harm their wireless data and voice call businesses.

Using Wi-Fi technologies, one can quite easily and cost effectively build a wireless network infrastructure for providing internet access and other network-based services such as printing. Due to this fact, wireless hotspots are widely available in homes, public buildings and airports. Even some municipalities and cities provide Wi-Fi-access in certain parts of city centers. In addition to wireless networking infrastructure, Wi-Fi can be used in an ad-hoc mode (also called as Wi-Fi Direct) for creating a direct communication between Wi-Fi-enabled devices. This functionality is particularly useful, for example, in multi-user games, transferring or streaming data from one device to another or discovering local resources, such as printers or media servers. Furthermore, Wi-Fi -technology can be used for indoor positioning within the range of the Wi-Fi coverage. GPS positioning can only be used outdoors and at the moment Wi-Fi-based positioning is one of the most promising complementary positioning technologies for indoor environments. Positioning- and location-aware services enable, for example, tracking goods and assets, navigation in large buildings and location-based services and information delivery. Table 14 summarizes the functionalities and application examples of Wi-Fi technology.

The use of Wi-Fi is an interesting option for using data-intensive applications such as internet browsing or Voice Over Internet Protocol (VOIP)-calls using mobile phones. This is particularly interesting when the user is travelling outside their home network roaming fees can be very expensive. The popularity of Wi-Fi in the PC-market is due to convenience, cost-efficiency, and the ease of integration with other networks and network components. The majority of (laptop) computers sold to consumers today come pre-equipped with all the necessary wireless LAN technologies.

5.2.4 Near Field Communication

Near Field Communication (NFC) is an extension to contactless card standard ISO 14443. It was first introduced in mobile phones in 2004 when Nokia launched an NFC-enabled cover for their 3220 model (Arena Com Ltd. 2010b). NFC has been promoted as a solution for mobile payments and ticketing, for example in public transportation. Some researchers have also designated the use of NFC as a new interaction paradigm (Ailisto et al. 2006, Välkkynen 2007, Rukzio et al. 2006). Diffusion to mobile phones seems to be slower than, for example, the case of Bluetooth or Wi-Fi. This could be due to the difficulty of identifying a single application that is attractive enough for a consumer to choose an NFC-enabled phone. On the contrary, for NFC-technology to attract end-users, it requires an ecosystem with a large number of different independent actors utilizing the technology so that NFC-based services will diffuse into markets.

Near Field communication technology provides three main functionalities: First, card emulation during which the NFC-enabled phone appears to external devices much the same as a contactless smart card. Second, read and write functionality provides the possibility to read from and write to an electronic identification tag. And third, peer-to-peer functionality offers the possibility for two NFC-enabled devices to exchange data with each other's (Table 14).

The focus of NFC-developments has been on leveraging card emulation functionality. There has been a particular interest in payment solutions, ticketing applications and access control. Mobile payment and ticketing of public transportation may not be attractive enough applications for end-users to choose to invest in a new device equipped with NFC technology. Tag reading functionality provides an easy and intuitive way to connect objects in the physical world to information in digital space. One of the most prominent early visions of this idea is the CoolTown project from HP (Kindberg et al. 2002). Through peer-to-peer functionality one can, for example, transfer information between devices and pair them together.

The value proposal typically linked to NFC technology is convenience and ease of use. These kinds of promises are planned to be redeemed through very easy mobile payment and ticketing, for example in public transportation. Also pairing devices with the help of NFC should be very easy and also improve the productivity of users. Even if NFC standardization has suffered from difficulties in agreeing about the architecture of secure NFC transactions, for the users the technology will bring convenient and secure means for small payments and information transfer.

5.2.5 Camera

The development of the camera component is dependent on advances in three main areas: CMOS (Complementary metal–oxide–semiconductor) image sensors, optical lenses and module assemblies. As of the time of writing, the best camera components in mobile phones can produce pictures with 12 million pixels. Camera components provide three main functionalities for application developers and end-users: digital imaging, environment sensing and bar-code reading.

The application of digital imaging in mobile phones is very similar to that in digital photography in general. We want to take pictures to remember situations, record videos from events that are meaningful to us and document the state of things. A natural addition to these applications is picture messaging, which combines imaging and communication. The camera can be used as an image sensor, for example in detecting movement within the range of the camera or recognizing individuals in the picture. There is also increasing interest in using mobile phones in augmented reality applications. In these applications the camera and contextual awareness can provide end-users interesting new views of the objects and places. In addition to taking pictures and sensing the surroundings, camera phones are increasingly often used to read visual codes such as 2D barcodes and Quick Response-codes (QR). The combination of visual codes and wireless connectivity makes a camera phone an interesting enabler for ubiquitous services. Table 14 illustrates functionalities and application examples of digital imaging technology.

From the user's point of view, digital imaging in mobile phones provides the means to express creativity and share memories with other people. It also enables users to conveniently link digital information to physical places and objects through visual codes. Photo- and video-based applications can be used for improving productivity in business applications.

5.2.6 Embedded sensors

The development of micro-electro-mechanical systems (MEMS) technology has made it possible to integrate sensor systems in mobile devices. Some sensors have been integrated into mobile handsets for many years. These sensors have mainly been used for optimizing functions of the device. Examples are illumination and temperature sensors as well as microphones. Accelerometer sensors were originally used for video stabilization and tracking photo orientation. Application programming interfaces for sensors are quite new addition to the collection of ubiquitous service technologies.

Sensors, and particularly programming interfaces making it possible for programmers easily to access the sensor input, are relatively new additions to mobile terminals. The research into sensor-based context awareness (Mäntyjärvi 2003) started to increase at the beginning of the 2000s. Among the first mobile phones with an API for an accelerometer sensor were the Nokia 5500 Sport released in 2006 and the N95. In 2006 the Java Community Process an Expert Group JSR 256 finalized a standard for Mobile Sensor API (JSR 256 Expert Group 2006).

The lead applications for motion sensors were the Step counter (Nokia 2008). Motion input can also play a crucial role in activity monitoring and fall detection applications. Motion input can also be leveraged in the user interface adaptation.

Accelerometer sensors can be used to sense the orientation of a device or determine, whether it is not actively used. There is also a smart phone application for pairing mobile phones based on motion input (Bump Technologies 2010), as foreseen in Paper V almost 10 years earlier.

For the user of mobile device applications and product features enabled by accelerometer sensors, adaptation of the user interface is mainly offered in the form of toggling the orientation of the display. There are, however, applications that provide the user with a sense of safety, improve productivity, and offer new dimensions, for example in gaming applications.

Table 14 summarizes functionalities and example applications enabled by sensors embedded in mobile phones.

5.3 Factors affecting the adoption of ubiquitous services

In this section we discuss several factors that are relevant for the evolution of ubiquitous services. The first of these factors is privacy, which is a highly relevant issue when it comes to the adoption of ubiquitous services, leveraging sensitive personal information. Second, the prerequisite of advancement in any business sector is the existence of the enablers of business models. The third topic that is discussed briefly is environmental concerns.

Contrary to the technology enablers discussed earlier, the nature of these factors is not so much one of enabling diffusion but potentially inhibiting development if not handled properly. These factors are not the core topic of the study, but as they are highly relevant for the diffusion of the ubiquitous services, they are introduced and discussed in following subsection.

5.3.1 Privacy concerns related to ubiquitous computing

Ubiquitous services are based on the idea that the system is aware of the user's immediate environment and context, such as location or current activity. This is the very nature of ubiquitous computing. As the information processing is distributed to smaller scale devices, understanding the user's context is one of the most promising solutions for handling the shortcomings of the interaction capabilities of the system.

We create large amounts of data whenever we consume services, use information systems or even move around in urban areas. The data is generated through different kinds of information sources such as access control systems, video surveillance system and credit or loyalty card usage. We also generate information in the logs of web services whenever we use them. Sometimes we intentionally reveal information about ourselves on web-sites, blogs and social networking services. Moreover the sensors in our mobile devices such as GPS, accelerometer sensors, and microphones generate information that can be used to characterize our everyday life (Publication VI). If the databases used for collecting the data generated by our use of information systems were combined and correlated together, they would reveal a very sharp image of our life.

There are several researchers who have discussed the privacy-related aspects of ubiquitous systems (Bohn et al. 2004, Günther & Spiekermann 2005, Lahlou et al. 2005, Lehikoinen et al. 2008). Publications VI and VII also discuss the privacy challenges in ubiquitous systems.

In order to serve the user better, a servant needs to know the needs and wishes of the person for whom she is providing services. The nature of this kind of knowledge is sensitive. Every now and then we read stories about former assistants or bodyguards telling sensitive stories of the needs and desires of a celebrity they had been working for. The same principle applies to ubiquitous services. As the nature of these services is such that sensitive material is handled in the process of producing services for the user, it is essential that all possible measures are taken to ensure that such information is not being delivered intentionally or accidentally to anywhere other than to where it is needed. Moreover, system design principles should be applied so that in the case of accidental leakage of such information or someone breaking into the system with hostile intent, the information would be in such a format that the implications of the leakage would be as mild as possible.

In Publication VI we proposed 8 guidelines for designing privacy-preserving ubiquitous systems. The proposed principles were as follows:

- *Real-time data processing* – avoiding unnecessary storage of raw data.
- *Encrypted or relative location stamping and time stamping* – Location and time stamping (tagging) should be linked to an event to which it is relevant.
- *Data deletion or editing after an application-dependent time* – Avoiding unnecessary storage of user-related information.
- *Data processing in a personal device instead of sending the data to the environment* – for example, more generic queries to services providers and anonymous payment procedures whenever possible.

- *Choice of communication technologies which do not use permanent hardware IDs in their protocols, or at least have control over access to these IDs* and which allows the communication range to be controlled – For example in Bluetooth communication, the device communicates the unique hardware ID.
- *Detection of hardware removals and replacements* – the user should be aware of the changes in the hardware and potential implications of these changes.
- *Transparency tools* – user-friendly ways of warning the users about possible privacy violation problems which might result from the technologies deployed around him/her and ways to configure technology settings easily.
- *Means to disconnect gracefully* – a user should be able to switch off or delete a service completely or be able to switch off some functionalities of the service in such a way that other people do not consider it as hiding, and in such a way that the device is still usable.

5.3.2 Business model support in mobile and ubiquitous services

The development of new services and applications requires that there is an economic incentive for companies and developers to bring these solutions to the end-users. The discussion of this kind of matter is typically linked to business models. There is lots of literature on business models, but in short their purpose is to explain how the enterprise works (Magretta 2002). In this subsection one of the main enablers of business models, user identification, is discussed.

The Subscriber Identification Module (SIM) is a major business enabler in mobile telecommunication and services business. The SIM is a smart card used for securely storing the International Mobile Subscriber Identity (IMSI) code that is used as the unique identification of a subscriber i.e. the user of a mobile phone. When users are identified by the telecom service provider, they can also be charged by the service operator for the services they consume. The mobile telecom-based services business has been driven by telecommunication companies since the inception of the business until recent times. The IMSI-based user identification has been a dominant solution in mobile businesses, and has given the telecom operators a very strong position in mobile services businesses.

Before the launch of Apple's mobile application store (Apple Inc. 2008), the major mobile application portals were operated by mobile operators. One of the cornerstones of Apple's success in their AppStore was the existing internet-based infrastructure for their digital music distribution business. The AppStore is based on the same concept and technology as the iTunes music store. User identification in the iTunes music store is done through a login and a password instead of an IMSI key. The payments in iTunes and the AppStore are carried out through a credit card stored in the Apple's service instead of through a mobile phone bill.

The SIM card and IMSI key-based technologies have been a dominant identification and billing infrastructure in mobile services businesses. Recently new internet-based solutions, such as the AppStore, have challenged the predominant telecom-based identification and payment solutions. It is still too early to say whether internet-based payment solutions will prevail over the SIM/IMSI-based payment solutions or if they will live side by side.

In ubiquitous computing applications outside of mobile services there does not seem to be a dominant user identification standard. As long as the business model of ubiquitous services requires user identification and billing capabilities, mobile phones with SIM/IMSI-key based identification provide one of the best potential solutions for this.

5.3.3 Environmental concerns related to ubiquitous computing

One of the ideas of ubiquitous computing is that there will be a vast number of electronic devices in our surroundings. Even if these devices are low-power electronics that only need a battery replacement or charging quite rarely they may raise some environmental concerns. The two most obvious concerns are the use of energy needed for the operation and the production of these devices.

According to the vision of ubiquitous computing the information processing concept will change from a situation where we only use one personal computer to one where we can utilize tens or even hundreds of small -scale computing devices continuously. These devices can, for example, be wireless local sensors or hotspots offering local content services. Probably the majority of these devices can be considered low-power devices that may be operational for a long time without battery replacement or charging. Despite advances in energy harvesting technologies, low-power electronics and more power-aware algorithms, it is likely that in the near future the total amount of power required by the global information processing infrastructure including networks, servers, personal computers, mobile devices, wireless sensors and actuators, will increase. It is possible that increasing awareness of climate change due to energy production and the recently initiated debate on the energy consumption of the ICT-infrastructure have an effect on the ways the development towards the ubiquitous computing vision takes place.

In addition to awareness of the energy consumption of the global ICT-infrastructure, increasing amounts of electronic waste caused by upgraded consumer electronics could also become a hot topic in coming years. Small electronic chips are produced and distributed in large quantities in our everyday environment. Also the supply of new consumer electronic products, such as mobile phones providing improved functionality and better user experience over the previous generation devices, leads to a development where the amount of electronic waste is increasing at an accelerating rate.

The increasing amount of consumer electronic waste may increase pressure on alternative developments in order to reduce or avoid the need for rare natural resources. The development of ubicomp also increases the motivation for recycling rare natural resources. Increasing the environmental and societal awareness of the general public has a high possibility to impact the development of ubicomp. It is also a possible scenario that the environmental issues of ubiquitous computing will provoke movements counter to its development.

5.4 Diffusion of new technologies in mobile phones

In Chapter 5.2 we introduced technologies that make the mobile terminal aware of its environment. In this section we take a look at the data illustrating the diffusion of these technologies. The data used in the diffusion analysis is based on the data provided by the GSMArena.com- website (Arena Com Ltd. 2010a), a publicly available website and discussion forum that lists and ranks discontinued, cancelled and available handset models and currently (14 July, 2010) keeps data on 3,381 mobile devices. Other websites used were those providing information about mobile phone models by specific brands as well as commercially available database collected, managed and sold by Informa (Informa plc 2011). The information was subsequently cross-checked and from this data the information required for this study was derived.

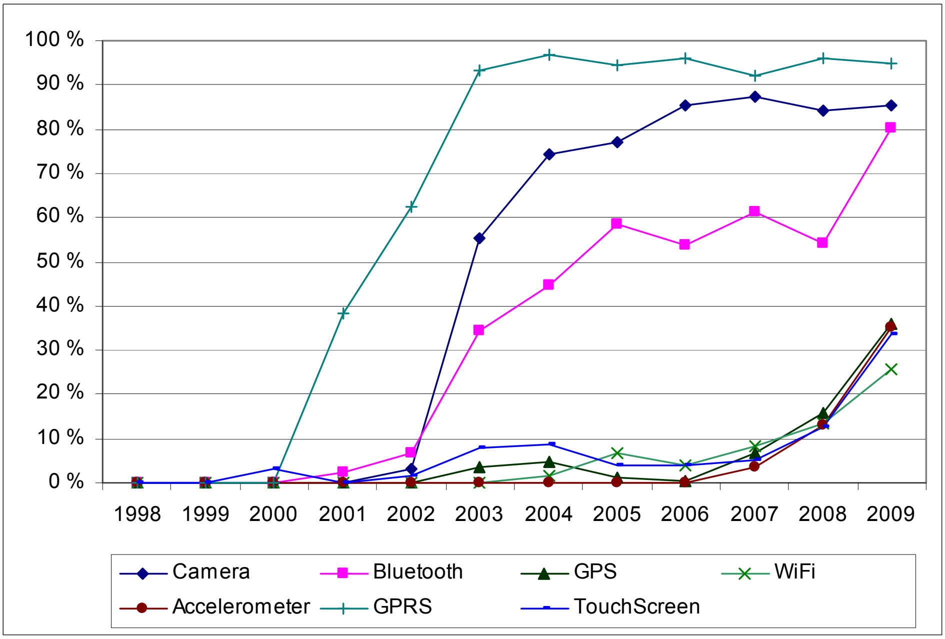

Figure 9. Diffusion of some technology enablers in mobile phones between 1998 and 2009. Data from (Arena Com Ltd. 2010a).

Figure 9 illustrates the diffusion of some technology enablers in mobile phones between 1998 and 2008. The enablers presented in the figure are cameras, Bluetooth, GPS transceivers, Wi-Fi, Near Field communication and accelerometer sensors. It is possible to identify three separate phases in the development of mobile phones. During the first phase, starting from the inception of the digital mobile phone until the turn of the millennium, mobile phones can be considered as voice-only devices. The second phase started with the launch of packet-switched data communication through GPRS enabling mobile phones to connect to the internet. The dominant design of mobile phones during this phase also included Bluetooth and camera technologies. The new dominant design of mobile phones started to emerge due to the advances of so called *smartphones*. Smartphones are mobile phones with an operating system enabling third-party software development. The new phase is determined by the ability of the device to be aware of its context. Key enablers of this phase are the global positioning system (GPS), Wi-Fi and accelerometer sensors integrated into mobile phones. Table 15 summarizes the key advances in mobile phone technologies in phases I–III.

Table 15. Development of the dominant design of digital mobile phone.

	Phase I: VoicePhone	**Phase II: DataPhone**	**Phase III: ContextPhone**
Description	Mobile phones are considered primarily as mobile voice-based communication	Mobile phones are devices with packet-switched data access, camera and Bluetooth	Mobile phone becomes aware of its surroundings through various radio accesses, sensors and GPS
Time	–2001	2002–	2008–
Start of the phase	Launch digital mobile phones	Diffusion of packet-switched radios, Bluetooth and cameras in mobile phones	Diffusion of positioning technology, Wi-Fi and sensors in mobile phones
Technology	GSM cellular networks SIM card	GPRS, Camera, Bluetooth Memory cards	GPS, WI-FI Accelerometer sensors
Functionality	GSM-voice SMS, Circuit-switched data	Internet access, wireless accessories Camera Multimedia recording and playing	Positioning Ubiquitous internet access (3G & Wi-Fi) Context awareness Activity sensing
Application	Mobile telephony, messaging internet access,	WAP and mobile browsing Email access Mobile applications SMS-based services Multimedia players	Navigation Activity monitoring Automatic UI orientation People tracking Location based services
User Aspects	Voice communication and messaging anywhere Simple personalization (animations)	Internet access anywhere Entertainment	Convenient navigation Ease of use and improved user experience (e.g., automatic adaptation)

In the subsections that follow we discuss the diffusion of some technologies making the transition from the DataPhone phase to the ContextPhone phase possible. The most crucial technologies to be discussed are Global Positioning System (GPS), Wireless LAN (Wi-Fi), Near Field Communication (NFC) and sensors embedded in mobile phone.

The data about the supply of given technologies was derived from information on mobile phones having the technology in question that were launched by five major manufacturers, namely, Nokia, Ericsson (later Sony-Ericsson), Motorola, Samsung and LG.

5.4.1 Diffusion of the Global Positioning System

Figure 10 illustrates the diffusion of GPS transceivers in the phone models of 5 major mobile phone manufacturers. First models with the technology were announced in 2003. There were a couple of early models, particularly from Motorola, between 2003 and 2005. The technology did not take off until 2006–2007 when Nokia announced several mobile phone models with a GPS transceiver integrated into them.

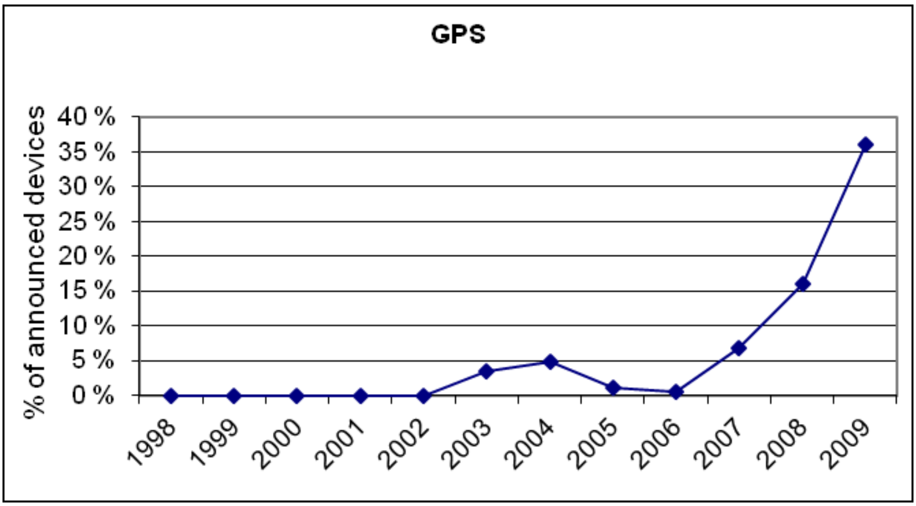

Figure 10. The diffusion of GPS in mobile phones in 1998–2009 among 5 major mobile phone manufacturers. Data from (Arena Com Ltd. 2010a).

In 2008 GPS was integrated into 16% of the newly announced mobile phones from 5 major manufacturers. By 2009 the share of GPS-enabled phones was already 36%.

Following the Rogers diffusion model it can be argued that in 2003–2006 GPS was part of the innovator market products. In 2007 and 2008, GPS rapidly became a part of the early adopter and early majority market products. Based on the data of the 2009 announcements, where 36% of the new phone models were devised with the technology, it can be predicted that GPS will become a part of the new dominant design of mobile phones.

5.4.2 Diffusion of local communication technologies

Wireless local communication technologies such as Wireless Local Area Network (Wi-Fi) and Bluetooth in mobile devices are mainly used to connect the devices to the internet, to other devices in their range or to accessories such as wireless headsets.

Wi-Fi and Bluetooth can also be used to position the devices where these technologies are integrated. Both Wi-FI and Bluetooth chips have a unique identification code (MAC Address). In the case of personal devices such as mobile phones, these technologies can also be used for identifying the actual user of the service.

Bluetooth was introduced in mobile phones by Ericsson (later Sony-Ericsson) in 2000. The diffusion of Bluetooth was quite rapid. As soon as 2003, three years after the first products were announced, the technology was integrated into 40% of the newly announced phones. In 2009 the technology was integrated into all phone models excluding the very simple entry-level devices. Figure 11 illustrates the announced provision of Bluetooth technology.

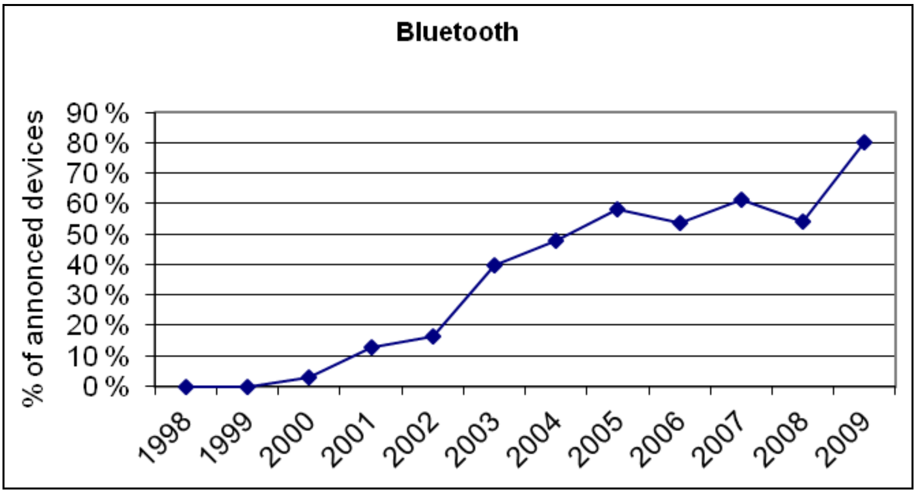

Figure 11. The diffusion of Bluetooth in mobile phones in 1998–2009 among 5 major mobile phone manufacturers. Data from (Arena Com Ltd. 2010a).

Figure 12 illustrates the diffusion of Wi-Fi technology in mobile phones. The first mobile phones with built-in Wi-Fi technology in the dataset used were models from Nokia and Motorola in 2004. In the following year 7% (12 phone models) of the mobile phones from 5 major manufacturers had Wi-Fi. In 2004 and 2005 Wi-Fi-enabled phones were penetrating the innovator and early adopter markets. In 2007, after a small decline in the diffusion of Wi-Fi the technology seems to be an essential part of advanced mobile phones. In 2009 as many as 26% of the announced mobile phones were equipped with Wi-Fi technology.

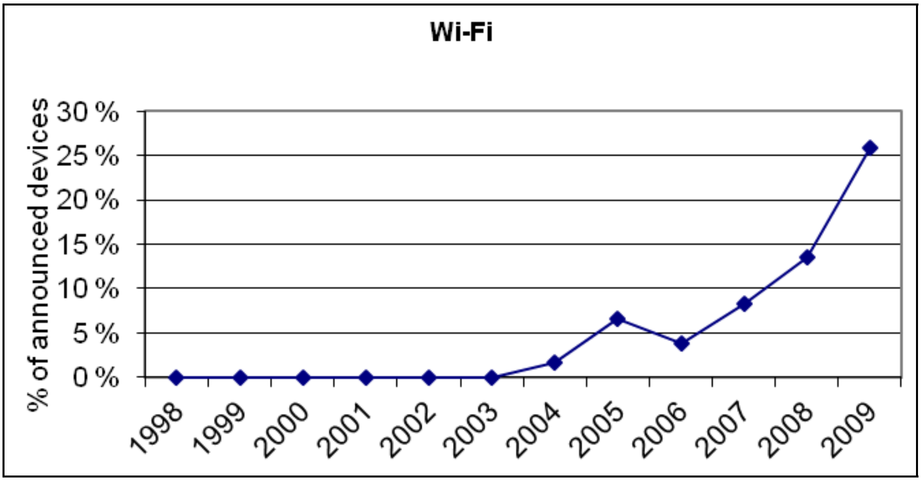

Figure 12. The diffusion of WI-FI in mobile phones in 1998–2009 among 5 major mobile phone manufacturers. Data from (Arena Com Ltd. 2010a).

5.4.3 Diffusion of Near Field Communication

Radio Frequency Identification (RFID) technology, and particularly Near Field Communication (NFC) (NFC Forum 2008), has been considered one of the most promising technology enablers for ubiquitous services. NFC is considered a future solution for payment and ticketing. In addition, the technology may have a transformational impact on user interaction with mobile devices and the way mobile services are used. Despite its great potential – or perhaps because of it – manufacturers, credit card companies and other actors have not been able to create the preconditions for the fast diffusion of the technology into devices. In fact, the development has been a disappointment to most of the actors who are active in NFC-related developments.

Figure 13 illustrates the diffusion of Near Field Communication technology in mobile phones between 1998 and 2009. There are very few models announced by 5 major mobile phone manufacturers. In fact, as illustrated in Figure 13, by the end of 2009 the 5 major manufacturers had launched or announced only very few NFC-enabled phones. This kind of diffusion curve indicates that the technology is still in the development phase and perhaps only used by innovators who are considered to be early adopters. Moreover, NFC was only integrated in products by a single manufacturer (Nokia). Obviously a single major player is not enough for bringing the technology onto markets. As of finalizing this thesis (in February 2011) several phone manufacturers, including Nokia, Samsung and LG, have announced that NFC will be integrated into their new smartphones. This kind of announcement may be a weak signal for a change in the technology diffusion rate.

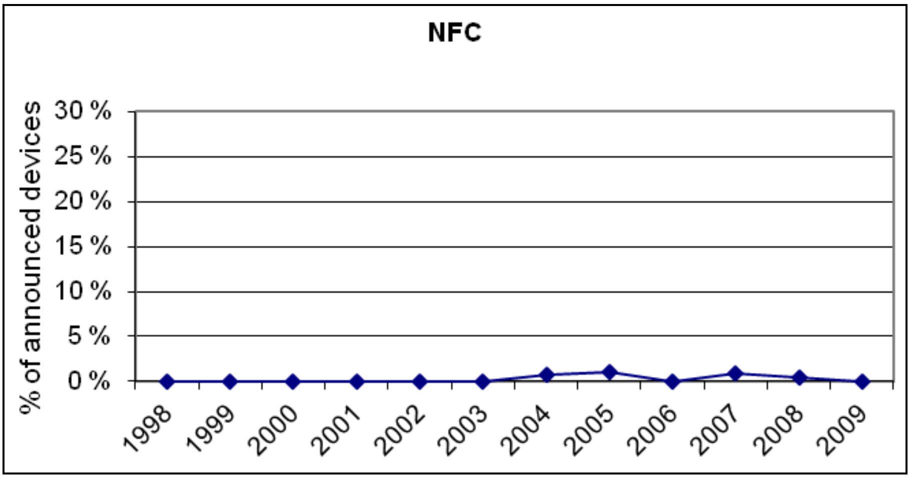

Figure 13. The diffusion of Near Field Communication in mobile phones in 1998–2009 among 5 major mobile phone manufacturers. Data from (Arena Com Ltd. 2010a).

5.4.4 Diffusion of cameras

The diffusion of cameras in mobile phones is illustrated in Figure 14. Among 5 major mobile phone manufacturers, cameras were first introduced as an integral part of mobile phones by Nokia and Ericsson (later Sony-Ericsson) in 2002.

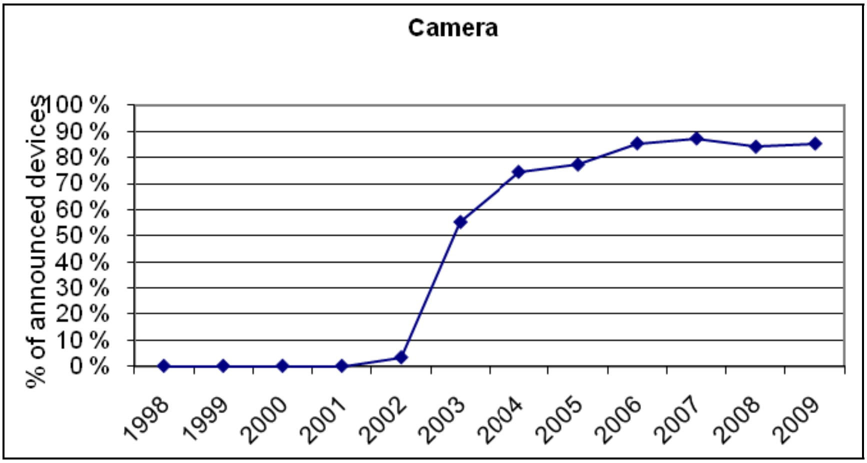

Figure 14. The diffusion of cameras in mobile phones in 1998–2009 among 5 major mobile phone manufacturers. Data from (Arena Com Ltd. 2010a).

Even though the quality of the pictures taken with camera phones was not on par with digital cameras, it was clear that consumers liked the technology. That can be concluded from the diffusion curve in Figure 14. Only one year after the first announcements, cameras became a part of the dominant phone design. After three years the diffusion of the technology levelled out to around 85% of all new product announcements.

In the early days of the diffusion of cameras, actors in telecom markets believed that multimedia messaging (MMS) would be the driver of new more expensive camera-phones. MMS did not turn out to be a success story in the same way SMS had been a few years earlier.

5.4.5 Diffusion of embedded sensors in mobile terminals

There are various sensors integrated into mobile phones. These sensors have mainly been used for different functions in the devices themselves, such as image stabilization of video recording. In addition to their being a support function for device features, some developers have also seen sensors as an interesting functionality for detecting the activity of the user of the device.

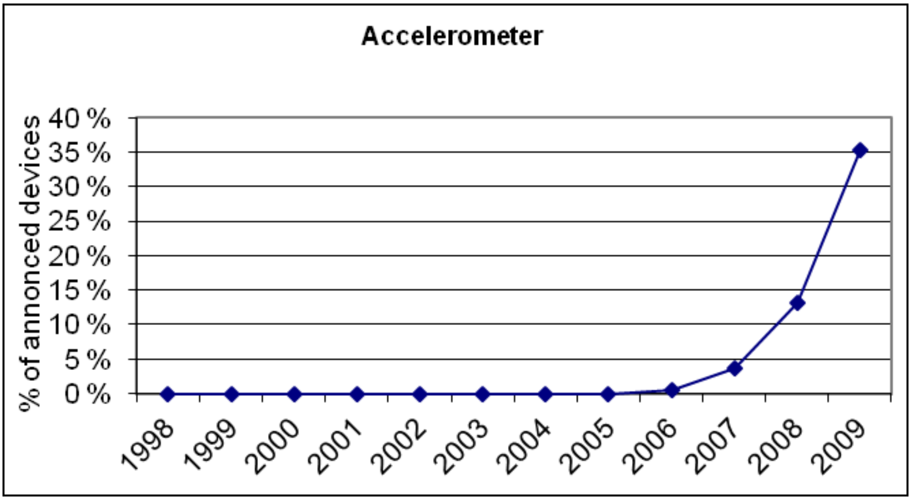

Figure 15. The diffusion of Accelerometer sensors in mobile phones in 1998–2009 among 5 major mobile phone manufacturers.

Accelerometer sensors and application programming interfaces (API) for the sensors are relatively new additions to the functionalities of mobile phones. Figure 15 illustrates the diffusion of accelerometers in the mobile phones of 5 major mobile phone manufacturers. In 2007 Nokia and Sony Ericsson announced 8 models (1% of announced models) with access to accelerometer sensors. In 2007 4% and 2008 already 13% of devices announced by 5 major manufacturers had integrated accelerometers. In 2009 the share of accelerometer-equipped mobile phones from 5 major manufacturers was 35% (86 different phone models).

6. Research contributions

Publications included in this research have been published between 2001 and 2010. They deal with different aspects of mobile and ubiquitous computing technologies and services. Original publications included in this thesis form three interlinked topics.

The first topic discusses the development of ubiquitous computing and services. This topic represents the main part of the research. Secondly, we bring forward some critical aspects related to ubiquitous computing technologies and services that are relevant to its development. In particular we address the privacy challenges related to the technologies. The third topic, consisting of one publication, introduces early experiments in building solutions using ubiquitous computing technologies. The linkages between topics and original papers have been illustrated in Figure 16.

The positioning and role of each publication in the thesis has been summarized and discussed in more detail in sections 6.1–6.6.

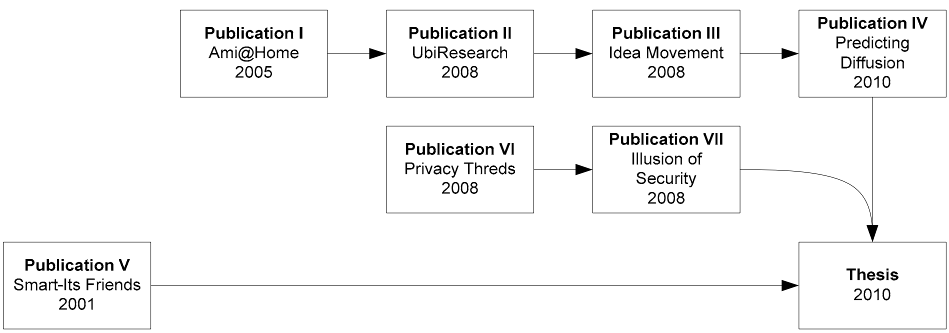

Figure 16. Original publications included in the thesis.

6.1 Publication I: Perspectives of ambient intelligence in the home environment

Publication I discusses the technologies, applications and social implications of ubiquitous computing technologies in the home environment. It explores how ubiquitous systems may change our way of life. It concludes that these systems incorporate great opportunities for supporting modern lifestyles and social developments. The publication, however, proposes that in order to gain wide acceptance one should be cautious in applying these technologies. Designers should pay particular attention to creating reliable and controllable but nevertheless adaptive systems that take into account human habits and their changing contexts.

This publication contributes to the thesis by exploring different application areas in the home environment. Furthermore, the publication analyzes both the pros and cons of applications of ubicomp technologies in the home environment. Moreover, it touches on the effects that these technologies may have on people's everyday lives.

The author of the thesis contributed to the publication by carrying out the main part of the analysis of applications in the home environment together with Sirkka Heinonen. The analysis was first published in the VTT Research Notes in 2003 (Alahuhta & Heinonen 2003). Michael Friedewald, Oliver Da Costa and Yves Punie amended the report to a journal format.

6.2 Publication II: From Technology Prototypes to Ethnographic Studies – A Review of Ubicomp Research

Publication II surveys ubiquitous computing research in between 1999 and 2007. The survey is based on accepted research papers submitted to ubicomp-conferences in a given period of time. The publication observes some trends of changes in research directions, including a decrease of application- and interaction-related papers and an increase in the number of user research-related papers. Furthermore, the paper argues that internet technologies have not been in a very strong position in the papers surveyed. Studies related to the adaptation of ubiquitous systems as well as the analysis of large-scale ubicomp systems are largely missing.

The publication contributes to the thesis by analyzing the evolution of research into ubiquitous computing. The publication finds some trends of changes in the research that, according to the authors, reflect the maturing of the research field. This is directly related to the discussion of the evolution of ubiquitous systems, which is one of the core topics of this thesis.

The author of the thesis was the first author of the publication. The idea for the paper came from the author. The analysis of the material as well as the writing of the paper was, however, a joint effort between the author and Heikki Ailisto.

6.3 Publication III: On exploring consumer's technology foresight capabilities

Publication III analyses 4,000 end-user-generated mobile service ideas from a technological viewpoint. The publication brings an end-user-centric view to the process, where developers are searching for possible business cases based on identified technology opportunities.

The publication contributes to the thesis by shedding light on the end-users' perspectives on mobile and ubiquitous services. The main claims of the publication are that end-users can be involved in the process of creating business ideas, but their contribution is best utilized when it comes to the innovative use of the existing technological base. The results show that end-users produce ideas that are more conservative than novel.

The author of the thesis was responsible for the Idea Movement-project (VTT 2010) in which 40,000 mobile service ideas were collected. He planned and guided the technical analysis of 4,000 ideas presented in the publication. The actual analysis was carried out by Antti Nummiaho. Discussion and implications of the results were carried out by the author of the thesis together with Pekka Abrahamsson.

6.4 Publication IV: Predicting the diffusion of new technologies based on scientific publications

The Publication IV utilizes a bibliometric (Norton 2008) research method to analyze the research effort put into certain enabling technologies for mobile computing, and their diffusion is estimated by looking at the new products that incorporate these technologies. The technologies in question are GPS, supporting location-aware services, cameras, as well as Bluetooth, Wi-Fi, and NFC which support local connectivity. The motivation for the paper was to create easy-to-understand and easy-to-access methods for predicting and understanding the diffusion of certain enabling technologies for mobile computing.

The publication contributes to the thesis by arguing that most of the technologies studied that are considered to be key enabling technologies for context-aware mobile services, are diffusing to the mobile devices and becoming a part of the dominant design of advanced mobile phones. In the case of NFC technology, the publication did not provide support for fast diffusion in mobile terminals.

The author of the thesis was the second author of the publication. The idea for the publication, research design including research questions and hypothesis definitions as well as organization and analysis of the material was a joint effort between the author of the thesis and Heikki Ailisto.

6.5 Publication V: Smart-Its Friends: A Technique for Users to Easily Establish Connections between Smart Artifacts

Publication V introduces an early (published in 2001) attempt to integrate basic ubiquitous core technologies such as sensors, wireless communication and distributed data processing into a user interaction of hand-held devices. In this case the functionality is the pairing of two smart devices. In the project we produced a set of small-size wireless sensor devices, called *Smart-Its*. These devices were meant to be a research platform for designing and testing ubiquitous application scenarios in an immature phase of technology development.

The publication contributes to the thesis by discussing the possibilities of ubiquitous technologies in user interaction and by providing an early example of such an interface.

The publication was one of the first papers the International project (Smart-Its-project 2003) produced and it could be called a kind of statement of the project's aims and approaches. The authors of the paper were leaders of research groups participating in the Smart-Its project. The publication was an outcome of the discussion of the possible use of the Smart-Its technology. Lars-Erik Holmquist had a lead in producing the paper. Michael Beigl was responsible for device development and implementation of the demonstrator. The remaining co-authors, including the author of this thesis, contributed to the idea and commented on the manuscript.

6.6 Publication VI: Privacy Threats in Emerging Ubicomp Applications: Analysis and Safeguarding

Publication VI discusses privacy issues raised by ubiquitous technologies. It identifies a number of privacy threats in emerging ubiquitous applications, and proposes a set of design guidelines for helping the designers in creating services. Furthermore, the publication proposes a framework for analyzing privacy threats. The framework incorporate people's personalities, activities, the environments where action takes place, and technological dimensions such as information flow, system control point and balancing between technological aspects.

The publication contributes to the thesis by discussing the potential privacy threats of ubiquitous systems and by providing guidelines and frameworks for understanding and analyzing the privacy aspects and their implications for technology development in ubiquitous technologies. The framework is based on an analysis of more than 100 roadmap scenarios and research papers.

The author of the thesis was responsible for VTT's part of the Swami-project (Swami Project 2009) where the research for the paper was carried out. He contributed in creating the analytical framework and designing the privacy safeguarding guidelines. During the research, he also provided comments and remarks for Elena Vildjiounaite, who was the primary researcher for VTT on that project. Vildjioiunaite carried out the main part of the scenario analysis and the review of the existing privacy enhancing technologies. Tapani Rantakokko designed and implemented the mobile phone data collection application. Pasi Ahonen contributed to the review of privacy enhancing technologies. David Wright and Michael Friedewald were project partners in the Swami-project and commented on the manuscript.

6.7 Publication VII: The Illusion of Security

Publication VII discusses the security challenges of ubicomp-technologies by introducing a so called "dark scenario" with a fictional story about a future where ubicomp technologies such as networked sensor and identification technologies have pervaded all aspects of life. The publication illustrates possible problems caused by the misuse or malfunctioning of such technologies. Furthermore, it identifies potential social problems, such as digital divide and concentration of power, caused by ubicomp technologies.

The publication contributes to the thesis by illustrating and identifying potential problems of ubicomp technologies as well as trying to foresee the changes in markets and people's everyday lives when ubiquitous systems are extensively present in our surroundings. The dark scenario built into the project is based on an analysis of more than 100 roadmap scenarios and research papers. The dark scenario was reviewed by an international expert panel.

The author of the thesis contributed to the paper by participating actively in the Swami-project where these dark scenarios were developed. The author of the thesis together with Elena Vildjiounaite carried out the technological analysis of the dark scenarios. Wim Schreurs, Michiel Verlinden and Serge Gutwirth covered the legal part of the scenario analysis. Yves Punie and Ioannis Maghiros were responsible for considering the societal implications of scenarios. Michael Friedewald was the manager of the project, and finally David Wright proposed the idea of the paper and acted as the primary author.

6.8 Research contribution mapped to the analytical framework

An analytical framework presented in Section 5.1 has been developed during the research process and was not available at the time of writing of the research papers I–VII. Therefore the mapping between the research papers and the framework has been presented in this section.

6.8.1 Technologies

Technology aspects of the framework have been addressed in Publications III, IV and VI.

Publication III discusses the need for the enabling technologies for service ideas that were proposed by average mobile services users.

Publication IV analyzes the diffusion of technologies, enabling context awareness, into mobile devices.

Publication VI discusses the ways in which technologies enabling context-aware applications should be designed so that they do not compromise their users' privacy.

6.8.2 Functionalities

Functionalities were discussed in Publications I, II, V, VI and VII.

Publication I introduces ubiquitous applications in the home environment and discusses the underlying functionalities and technologies required for implementing these services.

Publication II analyses the development of research in ubiquitous computing. Based on the analysis, we argue that, after introducing potential ubiquitous applications, the focus shifts towards the underlying functionalities and technologies and away from application concepts. This is explained by the maturing of the field.

Publication V discusses the potential application of wireless sensors. The sensor node used in a research prototype includes similar sensing functionalities t to mobile phones today. The paper introduces a new way to put these functionalities together and creates a new way of pairing two handheld devices.

Publication VI discusses the potential privacy problems when linking information about the use of various applications and functionalities. The paper argues that linking different context-related functionalities and the use of applications can lead to privacy problems.

Publication VII identifies a number of functionalities that are critical for the security of large scale ubiquitous systems. These functionalities include: biometrics, networked sensor systems, speech recognition, surveillance systems, networked electronic identification systems, ubiquitous networking, and intelligent software.

6.8.3 Applications

Application-related contributions can be found in Publications I, II, III, V, VI and VII.

Publication I reviews and discusses the potential of ubiquitous technologies for different application domains in a home environment. The paper proposes a classification of application domains including: home automation, communication and socialization, rest, refreshment, entertainment and sport, and working and learning.

Publication II introduces a clear change in the role of application concepts in the research on ubiquitous computing. In the early days of the research field, researchers published papers introducing different applications and potential uses of ubiquitous technologies. In later phases, case studies and user aspects played a central role in research.

Publication III analyzes the application ideas from everyday users. The paper argues that, in the arena of mobile services, there will not be a single “killer application” that will satisfy all the needs of the end-users. On the contrary, a rich variety of applications will foster the industry.

Publication V introduces a simple example application taking advantage of wireless sensor technology. An application similar to one presented in this paper was commercialized about ten years later in smartphones.

Publication VI brings forward a concern related to the privacy of users when seemingly neutral pieces of information such as messaging, Bluetooth activity or voice communication are merged together with context-related data such as time and location. In our experiment this kind of data fusion built a surprisingly comprehensive picture of the user’s behavior.

Publication VII identifies several applications where ubiquitous technologies play a central role. The paper discusses security-related applications, surveillance systems, immigration control, personalization of services, targeted marketing and critical infrastructure protection. The focus of the publication is on the analysis of possible problems that may reside in these applications if they are not designed properly.

6.8.4 User aspects

Contributions to the user aspects of the framework were presented in Publications I, II, III, VI, VII.

Publication I discusses the social implications of ambient intelligence in the home environment. The discussion is not limited to mobile services, but is a more generic analysis of the changes that ubiquitous technologies will make in our everyday lives.

Publication II analyzes the maturing process of ubiquitous computing-related research. In the paper we argue that over ten years the focus of the ubiquitous computing research has changed from technology-driven prototyping to research in which the inclusion of the user aspects and particularly privacy-related issues has been taken into account.

The mobile application ideas used in Publication III are collated from almost 2,000 end-users. They have expressed their needs for mobile services. In this paper we argue that, as users’ needs are so diverse, there will not be a single “killer application”, but the success of mobile services will be based on the availability of a broad spectrum of mobile services.

Publication VI discusses the privacy threats to end-users that location and context-aware mobile services can expose when these are used without proper consideration. Furthermore, the paper proposes a number of design guidelines for designing privacy-preserving context-aware services.

Publication VII is a scenario intended for analyzing the privacy-, security- and identity-related threats to users caused by the large-scale deployment of ubiquitous technologies. The paper also discusses the possible threats to social development, such as the digital divide and the concentration of power in the world where networked ubiquitous systems are in large-scale use.

7. Discussion

In this chapter we summarize the answers to the research questions. We also discuss the use of framework introduced in Section 5.1 and limitations of the research. Finally we identify some future research topics.

7.1 Answers to the research questions

The research questions in this study were introduced in Section 1.1. In this section we summarize the answers to the research questions.

Q1. What are mobile terminal-centric ubiquitous services? How do they differ from mobile services?

Mobile services are digital services that are accessed through a mobile terminal. The mobile terminal may, for example, be a mobile phone, a Personal Digital Assistant (PDA), or a tablet PC. Mobile services are accessed through a wireless communication channel such as General Packet Radio service, 3G or WiFi. The contents mobile services use is stored on service providers' servers, and they are typically connected in the internet backbone network. The user interface in mobile services can be created using a programming language such as Java or C++. They can also be based on mobile browsing using mark-up languages such as hypertext markup language (HTML). SMS-based services are also an important category of mobile services. SMS messaging is often used as a billing solution in mobile services.

The use of mobile services is intentional and static. This implies that the user of the services is actively using the service by accessing it through her mobile device. The mobile services can also be provided to the user based on a static timing or according the preferences of the service provider.

Ubiquitous services are mobile services that utilize communication with the local environment and the awareness of the context of the service users. Sometimes they are called context-aware mobile services.

Ubiquitous services or context-aware mobile services are very similar to mobile services in terms of the technologies and content used in the services. The essential difference between the use of mobile and ubiquitous services is that in ubiquitous services the context of the user is taken into account in the service production and use. Mobile service provision can be activated automatically, based on the users' context, the content a service user is creating can be augmented by contextual information such as time, location, activity or identity, or the service user is provided with information similar to other users in a similar situation. The user of the ubiquitous services can also utilize technical resources in the local environment such as wireless printing, meeting room (audio-visual) services or medical sensors in health care services.

Q2. What are the emerging technologies enabling the transition from mobile services towards ubiquitous services?

There are different ways to implement ubiquitous services. Part of the anticipated context-aware services can be implemented using technologies and functionalities that are already to be found in mobile terminals. This kind of context sensitivity is based on the analysis of the current state of the device and the history of service usage. Smart algorithms for data fusion and personal preference building are utilized in this kind of context-aware service. Utilizing user profiling and analysis of system logs can be very beneficial features in context-aware services. Moreover, this kind of processing does not necessarily need new technologies in a mobile terminal.

Technologies used for interacting with other devices in close proximity are, for example, Wi-Fi and Bluetooth technology. These wireless communication technologies can also be used to position a device or to sense the identifications of surrounding devices. Bluetooth and WiFi can communicate with devices ranging from a few centimeters to tens or even hundreds of meters away. Another wireless communication technology that can be used in positioning and identifying objects and devices is Radio Frequency Identification tags (RF-ID), and in mobile terminals a variant of this technology called Near Field Communication (NFC).

Mobile phones are being devised with a number of technologies that can be used to sense the surroundings of the device. Outdoors, devices can be located using GPS-transceivers; camera sensors can be used to sense light or even objects in the vicinity of the device. Microphones are used to analyze ambient sounds. Accelerometer sensors are embedded in an increasing number of new mobile devices, as they are needed for the proper operation of touch-based displays. Some devices are also equipped with a compass-sensor which, together with positioning functionality, enables applications to know the location and the direction the mobile terminal (or for example, in what direction the camera in the device is pointing).

Understanding the use patterns of a user is an essential part of context-aware computing. User profiles are models that can be correlated whenever a new situation is encountered. Even if some picture of users' behavior can be created, based on the system state of mobile terminals, certain technologies are more valuable than others in creating this picture. Such technologies are those that interact with other devices in close proximity or observe the surroundings through measurements.

Q3. What kinds of new services are likely to become available?

The emergence of terminal centric ubiquitous services will change mobile services. Awareness of one's context is the source of a myriad of new services and product features. Local connectivity makes it possible to offer services to users cost-effectively and directly. These new functionalities can be used, for example, to facilitate the use of mobile devices, making the user interaction more user-friendly or making mobile services, spaces and devices more secure and traceable.

Ubiquitous services are relevant to various areas of life. Publication I discusses the role of ubiquitous computing in the home environment. Moreover, the paper introduces taxonomy for various applications in the home environment. The taxonomy presented in the paper includes the following application fields: home automation, communication/socialization, relaxation, and working/learning applications. The taxonomy reflects the activities that are typical of this very environment. It is obvious that other kinds of environments and activities would have a bit different, but probably equally rich, collection of potential applications. In this thesis the role of advanced mobile phones in the home environment is analyzed. The role of mobile devices in these application fields varies from being a key component to being merely a marginal device.

Publication III represents an analysis of 4,000 end-users' ideas on a possible and desirable mobile service. One of the main outcomes of the analysis is that there is not a single, highly popular application that causes mobile service businesses to be taken up. Instead of such "killer" applications, the end-users expect a rich variety of different kinds of service for different aspects of life. After the publication of Publication III, the success of the AppStore by Apple has supported these findings. After the introduction of the mobile application marketplace, more than 100,000 different applications have been published for the iPhone platform.

Mobile service ideas that were analyzed in Publication III were mainly collected from average mobile phone users. They were experts as regards their everyday lives and familiar with the possibilities of mobile phones. From this background about 2,000 people participated in the Idea Movement-project and contributed more than 40,000 mobile service ideas (VTT 2010). Publication IV argues that enablers of ubiquitous services, such as local connectivity and sensors, are diffusing into mobile devices. Following the example of the Idea Movement-project, we expect that, when people become familiar with the concept of ubiquitous services and the new possibilities they provide, for example through location technologies, they will find potential application ideas for these technologies.

The internet was adopted by the general public at the beginning of 1990s. Nowadays the question of how we might utilize the internet does not sound like a very reasonable question to ask. The answer is that the internet can be utilized in countless applications in various areas of life. The same seems to apply to mobile internet and mobile services. As the enablers of ubiquitous service diffuse into the hands of the general public, they will also enable applications in countless different uses in all aspects of life.

Q4. Other relevant factors influencing the diffusion of ubiquitous services

Ubiquitous services rely on measuring, collecting, processing and disseminating sensitive person-related data. This is the very nature of ubiquitous services. Compared to mobile services, this is one of the main differences. As mentioned in Publication VI, it is possible to create a comprehensive profile of a person by linking together seemingly harmless pieces of information such as time, rough location and use of the services and functions of the mobile phone.

The identification of the users in mobile services has mainly been done through IMSI-code, and a concrete expression of that is the SIM card in mobile phones. The SIM card has been an important enabler of mobile service businesses, as it provides a secure and user-friendly identification of the user. There are plans to devise SIM cards with more functionality, such as credit cards and loyalty cards. It is obvious that the role of SIM cards will remain strong in the future. According to the vision of ubiquitous computing, we will be communicating increasingly with our surroundings. The SIM card is only a single enabling technology located in mobile terminals and thus inadequate to provide identification and secure communication solutions to a broad range of different kinds of ubiquitous services systems. The take-up of ubiquitous systems requires the capabilities to carry out business based on the infrastructure. The end-users assume that the systems they are using do not cause privacy infringements, and businesses for their part expect that there is a cost-effective means of carrying out secure (enough) business transactions in ubiquitous systems. Mobile terminals are equipped with SIM-based secure solutions. For the systems level security, the dominant solution still remains to be seen.

During the transition from the time of mobile services to the era of ubiquitous services, users may not understand all the consequences of disseminating the information the mobile terminals and new kinds of services are capable of producing. New opportunities for interesting services also open up possibilities for people who are interested in intruding into someone's life. These problems can be tackled first by raising awareness of these issues, as proposed in Publication VII, and second, by implementing effective privacy enhancing technologies (PETs) as presented in the Publication VI.

Privacy and security issues are the main concerns of ubiquitous services. In addition to these, other kinds of challenges can also be identified. One challenge is environmental issues. The era of pervasive computing environments with millions of electronic devices will require almost an infinite number of small quantities of energy to operate. Even if the major proportion of the components of ubiquitous system will use energy from the environment, there is a need for energy derived from the electricity supply. In other words, ubiquitous systems may increase the consumption of energy and therefore CO2-emissions. There is a need to improve the energy efficiency of ubiquitous systems. Solutions are manifold, ranging from low-power algorithms, energy-harvesting from the environment to the utilization of green energy sources. Even if the infrastructure of ubiquitous systems consumes increasing amounts of energy, it is important to note that at the same time ubiquitous systems can take a central role in considerable process improvement in all kinds of application fields. The effect of these process improvements will surpass the effect of increased energy consumption.

Another environment-related challenge caused by ubiquitous systems can be due to the electronic waste and the use of natural resources in the production and distribution of the components of ubiquitous systems. Electronic components require rare chemical elements and may disperse heavy metals and other harmful components when left in the environment after their period of active use.

7.2 On the use of the framework

In Section 5.1 we introduced a framework for analyzing the development of technologies. The evolution of mobile devices was analyzed using the framework, which covers user aspects, applications, functionalities and technologies.

The framework is derived from models and theories explaining the emergence of disruptive technologies and innovations, the formation of dominant designs, technology adoption among the users and the role of users' innovations. Since the development of mobile devices and ubiquitous services is dependent on several aspects and viewpoints, there is a need to apply simultaneously several theoretical frameworks for explaining and to some extent predicting technology development to meet existing and emerging user needs.

The framework consists of different abstractions, or components, we can adopt when trying to understand the development of a technological system. Abstractions of the model – *technology*, *functionality*, *application*, and *user aspects* – represent different viewpoints on the same development.

Different abstractions are interlinked in two ways. First, lower level components are required to implement the upper level components. Second, the upper level sets the requirements for the development of the lower level. The lowest level components, technologies, are required to implement upper level functionalities. Respectively applications are created by putting together a number of functionalities, and user experiences are created by offering those applications and services. On the other hand, upper level components set the requirements for the development of components lower down. For example, users have certain expectations of the privacy standard in location-based services. In order to implement privacy preserving services, functionalities and technologies must be used that enable this kind of implementation.

The framework does not handle time explicitly. Instead, one can estimate the possibilities of implementing the upper level by analyzing the maturity and the availability of the components below. The development of Near Field Communication can be used as an example of this. NFC applications have not yet (as of writing the thesis) become available in mainstream markets. The basic technological components such as contactless smart-cards and NFC-readers have already been available and technically feasible for some time. As there has been a debate on the way the secure transactions will be organized, device manufacturers have not been willing to make available devices that may not comply with the emerging dominant secure payment design. As the payment functionality has been lagging behind, application developers and device manufacturers have not been active in the markets either, as they have considered that the underling components are not mature yet. Thus the existence of underlying components is a compulsory but not an adequate condition for the emergence of the solutions above.

7.3 Limitations

This research on technology diffusion and technology acceptance can be carried out from various viewpoints. The topic of the research is quite broad and multi-discipline. In order to focus the research, some limitations have been made.

Even though aspects of market development, including standardization, alliances intellectual property rights (IPR) and ecosystem strategies, are highly relevant for the diffusion of new technologies in mobile services business, these topics have been omitted from this research. All these aspects are important and worthy of their own research. Due to the research material and the background of the author, the approach is concentrated on technology development and user aspects.

Despite the importance of the service offerings and the quality of content to the adoption of new technologies, these factors have only been discussed cursorily. The same applies to the (industrial) design aspects and user experience of services and mobile products. The recent developments in mobile business emphasize the importance of these factors. However, they have not taken a central role in the research of the author of the thesis.

The third topic that would have been relevant for understanding the development of mobile technologies is emerging areas such as nanotechnology, printed intelligence and 3D user interfaces for instance. As in this research the focus is more on applied technologies than emerging technologies, these highly interesting areas have been omitted from the research.

7.4 Future research

The research is limited to analyzing the technologies of ubiquitous services. Even though technologies are an essential enabling component for context-aware mobile services, they do not provide a comprehensive picture of the development of ubiquitous services.

There are three areas that are only mentioned briefly in this thesis, but are worth looking at more closely. One such area of study is market development and the structure of the market for ubiquitous services; the second is the interplay between technology, design and usability; and the third is the role of advances in device technologies in the user interaction.

Formation of the ubiquitous services markets include: device manufacturing, service development and provisioning, ecosystem development and service platform provisioning. Interesting observations are, for example, the strategies different players take in terms of intellectual property, standardization, alliances and the role of development as well as user communities. Ubiquitous services markets are currently in an immature phase. An increased understanding of the subject is needed.

Different actors in the marketplace apply varying strategies as regards new technologies, design, usability, and user experience. Device manufacturers can, for example, put emphasis on cost-effectively integrating as many product features as possible into devices. A device manufacturer can also position himself by creating attractiveness among the end-users through superior user experience. We could even argue that the focus of the competition in high-end mobile devices has shifted from device feature integration to the perfecting of users' experiences of the devices and services combined. A better understanding of the tradeoffs between the technology and design is needed.

Mobile devices are used in heterogeneous environments where the possible information processing needs are numerous. Compared to the desktop PC, connectivity or computing power in mobile devices is not necessarily the bottleneck for reaching effective operation. Interaction capabilities in mobile devices, however, are a major drawback. Small displays and awkward input capabilities do not yet enable the whole potential of ubiquitous services. New technologies, such as MEMS-sensors, touch screens, 3D interfaces and augmented reality can bring user interaction to the next level. The possibilities for bringing these technologies to the end-users are worth exploring further.

8. Conclusions

This thesis summarizes and extends the contribution of seven original publications. The main argument of the thesis is that there is a technology development trajectory that makes it possible for mobile devices to become a gateway to ubiquitous services.

Ubiquitous computing is a model of human computer interaction in which information processing is seamlessly integrated into everyday objects and environments. Ubiquitous computing is a vision, but many of the aspects of ubiquitous computing represent the mainstream of present-day ICT research. Such aspects are for example: mobility, connectivity and the importance of human technology interaction.

Digital mobile phones have evolved from voice-only mobile communication devices through data-enabled phones to context-enabled mobile devices. In each phase there were different enabling technologies that made the transition to the following phase possible. Data-enabled phones became available when packet-switched radio communication (GPRS-technology) was integrated into mobile phones. The age of context-enabled phones began when sensors, such as GPS transceivers and accelerometers as well as local connectivity technologies, such as Bluetooth and WiFi, emerged in mass market devices.

There are important factors supporting the mobile phone's role as a gateway or a platform for ubiquitous service. The most obvious of these reasons is that the mobile phone is a powerful computing platform with many options for connectivity to the outside world. The mobile phone is one of the most widely distributed consumer electronic devices. There are already more than 4.5 billion mobile subscribers in global markets (ITU 2010). Mobile phones provide reasonably good interoperability across the installed base of devices. Moreover, there is a way to identify users through SIM cards, in digital mobile communication systems. This is a major enabler for mobile commerce and service businesses.

In this thesis the evolution of mobile devices was analyzed through a framework that covers user aspects, applications, functionalities and technologies. The collection of theories that explains the development is relatively broad. There are several scholars who have explained some part of the evolution of innovations and technology. The framework includes theories explaining the emergence of disruptive technologies and innovations, the formation of dominant designs, the importance of complementary assets, technology adoption among users and the role of lead users. The framework argues that the possibilities of fulfilling the end-users' needs are dependent on the available applications, functionalities, and technologies. The developer cannot meet the end-users' needs, if there is not a supply of the technologies required to implement the vision of the designer.

Mobile services are those digital services that are used with mobile devices, such as mobile phones. According to Dey and Abowd (2000), context is any information that characterizes the situation of an entity. Ubiquitous services are those mobile services that are capable of taking advantage of the available context information in order to offer the user better services, easier use of the services or a better user experience. Ubiquitous services use resources in the local environment and the awareness of the context of the service user.

The essence of ubiquitous services is the awareness of local resources and the context of the device. Thus technologies making it possible play a key role in the adoption of these services. Local resources are sensed through local connectivity technologies such as short-range wireless communication technologies. Wi-Fi and Bluetooth are the most familiar of these technologies. Other relevant technologies for identification of local resources are RFID-based technologies, in particular Near Field Communication. In addition, cameras can be used to identify local resources through 2D-barcodes and augmented reality. Device context can be sensed either by utilizing the knowledge of the internal state of the device or through sensors. The internal state of the device can be acquired by analyzing the usage of the applications and the device's internal processes. Sensors that are most relevant for context recognition are GPS for location information and accelerometer sensors for activity monitoring.

Technology development often raise the question, what is the "killer" application of this new technology? Based on an analysis of 4,000 mobile service ideas from everyday users there was not one single "killer" application they would have liked to use. On the contrary, one quarter of those ideas fell into the category of miscellaneous. The distribution seems to conform to the long tail model (Anderson 2004). Therefore, we can argue that mobile and ubiquitous services can and will be utilized in various aspects of life. We have just seen the beginning of the adoption of location-aware mobile services. Mobile phones that are capable of sensing their location and context have only been on the mass market a short time. When the developer and user communities understand the possibilities and limitations of these new technologies, we can expect to see new kinds of services and businesses enabled by ubiquitous technologies.

There are some relevant aspects that need to be taken care of so that ubiquitous services can make it to the mass markets. One of those aspects is privacy. Ubiquitous services are based on the idea of knowing the context of the user as accurately as possible and the utilization of that information in services. This kind of information is highly personal and sensitive. Therefore, it should be handled with caution. Privacy protection should be taken into account at the time of design. It cannot be an add-on-feature that will be implemented if there are resources left in the development project.

Environmental concern is another factor that may have an effect on the diffusion of ubiquitous services. Environmental issues caused by increased energy consumption and electronic waste are the most relevant topics.

References

Aarts, E. & Marzano, S. 2003. The New Everyday: Views on Ambient Intelligence. 010 Publishers, Rotterdam, The Netherlands.

Abernathy, W.J. & Utterback, J.M. 1978. Patterns of industrial innovation. Technology Review, Vol. 80, No. 7, pp. 40–47.

Abowd, G.D., Mynatt, E.D. & Rodden, T. 2002. The human experience [of ubiquitous computing]. IEEE Pervasive Computing, Vol. 1, No. 1, pp. 48–57.

Abowd, G.D. & Mynatt, E.D. 2000. Charting past, present, and future research in ubiquitous computing. ACM Transactions on Computer-Human Interaction, Vol. 7, No. 1, pp. 29–58.

Ailisto, H., Lindholm, M., Mäntyjärvi, J., Vildjiounaite, E. & Mäkelä, S.M. 2005. Identifying people from gait pattern with accelerometers. Proceedings of SPIE – The International Society for Optical Engineering. Vol. 5779, A.K. Jain & N.K. Ratha, (eds.). SPIE, Bellingham, WA, USA. P. 7.

Ailisto, H., Pohjanheimo, L., Välkkynen, P., Strömmer, E., Tuomisto, T. & Korhonen, I. 2006. Bridging the physical and virtual worlds by local connectivity-based physical selection. Personal and Ubiquitous Computing, Vol. 10, No. 6, pp. 333–344.

Alahuhta, P. & Heinonen, S. 2003. Ambient intelligence in everyday life: housing. VTT Technical Research Centre of Finland, Espoo.

Alewine, N., Ruback, H. & Deligne, S. 2004. Pervasive speech recognition. IEEE Pervasive Computing, Vol. 3, No. 4, pp. 78–81.

Anderson, C. 2004. The Long Tail. Wired, Vol. 12, No. 10, pp. 170–177.

Anderson, P. & Tushman, M.L. 1990. Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. Administrative Science Quarterly, Vol. 35, No. 4, pp. 604–633.

Apple Inc., 2010. Apple – iPhone 4 – Video calls, multitasking, HD video, and more. [online] Available at: http://www.apple.com/iphone/ [Accessed: 6/10 2010].

Apple Inc., 2009. Apple's App Store Downloads Top Two Billion. [online] Available at: http://www.apple.com/pr/library/2009/09/28appstore.html [Accessed: 6/5 2010].

Apple Inc., 2008. iPhone App Store Downloads Top 10 Million in First Weekend. [online] Available at: http://www.apple.com/pr/library/2008/07/14appstore.html [Accessed: 6/5 2010].

Apple Inc., 2007. Apple Reinvents the Phone with iPhone. [online] Available at: http://www.apple.com/pr/library/2007/01/09iphone.html [Accessed: 1/10 2011].

Arena Com Ltd., 2010a. GSMArena.com – GSM phone reviews, news, opinions, votes, manuals and more... [online] Available at: http://www.gsmarena.com [Accessed: 7/14 2010].

Arena Com Ltd., 2010b. Nokia 3220 – Full phone specifications. [online] Available at: http://www.gsmarena.com/nokia_3220-801.php [Accessed: 7/14 2010].

Arena Com Ltd., 2010c. Nokia 9000 Communicator – Full phone specifications. [online] Available at: http://www.gsmarena.com/nokia_9000_communicator-16.php [Accessed: 6/5 2010].

Arena Com Ltd., 2010d. Specification of all Nokia phones. [online] Available at: http://www.gsmarena.com/nokia-phones-1.php [Accessed: 6/5 2010].

Arena Com Ltd., 2011. Nokia E7 – Full phone specifications [online] Available at: http://www.gsmarena.com/nokia_e7-3545.php [Accessed: 3/19 2011].

Baldauf, M., Dustdar, S. & Rosenberg, F. 2007. A survey on context-aware systems. International Journal of Ad Hoc and Ubiquitous Computing, Vol. 2, No. 4, pp. 263–277.

Baldwin, C., Hienerth, C. & Von Hippel, E. 2006. How user innovations become commercial products: A theoretical investigation and case study. Research Policy, Vol. 35, No. 9, pp. 1291–1313.

Bass, F.M. 1969. A New Product Growth for Model Consumer Durables. Management Science, Vol. 15, No. 5, pp. 215–227.

Bell, G. & Dourish, P. 2007. Yesterday's tomorrows: Notes on ubiquitous computing's dominant vision. Personal and Ubiquitous Computing, Vol. 11, No. 2, pp. 133–143.

Biegel, G. & Cahill, V. 2004. A framework for developing mobile, context-aware applications. Second IEEE Annual Conference on Pervasive Computing and Communications, PerCom 2004. IEEE Computer Society, Los Alamitos, CA, USA. P. 361.

Bluetooth SIG, 2008. Bluetooth.org. [online] Available at: https://www.bluetooth.org/apps/content/ [Accessed: 5/27 2008].

Bohn, J., Coroamă, V., Langheinrich, M., Mattern, F. & Rohs, M. 2004. Living in a world of smart everyday objects – Social, economic, and ethical implications. Human and Ecological Risk Assessment, Vol. 10, No. 5, pp. 763–785.

Bonabeau, E. 2009. Decisions 2.0: The power of collective intelligence. MIT Sloan Management Review, Vol. 50, No. 2, pp. 45–52.

Bruner, G.C. II & Kumar, A. 2005. Explaining consumer acceptance of handheld Internet devices. Journal of Business Research, Vol. 58, No. 5, pp. 553–558.

Bump Technologies, I. 2010. The Bump App for iPhone and Android | Bump Technologies, Inc. [online] Available at: http://bu.mp/ [Accessed: 1/9 2011].

Carlsson, B. & Eliasson, G. 2003. Industrial Dynamics and Endogenous Growth. Industry and Innovation, Vol. 10, No. 4, pp. 435–455.

Chesbrough, H.W. 2006. Open business models: How to thrive in the new innovation landscape. Harvard Business School Press, Boston, MA, USA.

Chesbrough, H.W. 2003. Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business School Press, Boston, MA, USA.

Christensen, C.M. 1997. The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. Harvard Business School Press, Boston, USA.

Christensen, C.M., Anthony, S.D. & Roth, E.A. 2004. Seeing what's next : using the theories of innovation to predict industry change. Harvard Business School Press, Boston, MA, USA.

Christensen, C.M. & Raynor, M.E. 2003. The innovator's solution: creating and sustaining successful growth. Harvard Business School Press, Boston, USA.

Coutaz, J., Crowley, J.L., Dobson, S. & Garlan, D. 2005. Context is key. Communications of the ACM, Vol. 48, No. 3, pp. 49–53.

Davis, F.D. 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly: Management Information Systems, Vol. 13, No. 3, pp. 319–340.

Dey, A.K. & Abowd, G.D. 2000. Towards a Better Understanding of Context and Context-Awareness. Proceedings of the CHI'2000 Workshop on the What, Who, Where, When, and How of Context-Awareness. D.R. Morse & A.K. Dey, (eds.). Georgia Institute of Technology, Atlanta, GA, USA.

Dey, A.K., Salber, D., Abowd, G.D. & Futakawa, M. 1999. The Conference Assistant: combining context-awareness with wearable computing. Wearable Computers, 1999. Digest of Papers. The Third International Symposium on IEEE Computer Society, Los Alamitos, CA, USA. P. 21.

Ehrnberg, E. 1995. On the definition and measurement of technological discontinuities. Technovation, Vol. 15, No. 7, pp. 437–452.

Encyclopedia Britannica, 2011. technology – Britannica Online Encyclopedia [online] Available at: http://www.britannica.com/EBchecked/topic/585418/technology [Accessed: 2/28 2011].

Endres, C., Butz, A. & MacWilliams, A. 2005. A survey of software infrastructures and frameworks for ubiquitous computing. Mobile Information Systems, Vol. 1, No. 1, pp. 41–80.

Ermes, M., Pärkkä, J., Mäntyjärvi, J. & Korhonen, I. 2008. Detection of daily activities and sports with wearable sensors in controlled and uncontrolled conditions. IEEE Transactions on Information Technology in Biomedicine, Vol. 12, No. 1, pp. 20–26.

Eronen, A.J., Peltonen, V.T., Tuomi, J.T., Klapuri, A.P., Fagerlund, S., Sorsa, T., Lorho, G. & Huopaniemi, J. 2006. Audio-based context recognition. IEEE Transactions on Audio, Speech and Language Processing, Vol. 14, No. 1, pp. 321–329.

Feiner, S., MacIntyre, B. & Seligmann, D. 1993. Knowledge-based augmented reality. Communications of the ACM, Vol. 36, No. 7, pp. 52–62.

Franke, N. & Shah, S. 2003. How communities support innovative activities: An exploration of assistance and sharing among end-users. Research Policy, Vol. 32, No. 1, pp. 157–178.

GetJar.com, 2010. About GetJar. [online] Available at: http://www.getjar.com/about/ [Accessed: 6/5 2010].

Google Inc., 2010a. Android.com – Android at Google I/O. [online] Available at: http://www.android.com/ [Accessed: 8/6 2010].

Google Inc., 2010b. Android.com – Market. [online] Available at: http://www.android.com/market/ [Accessed: 7/15 2010].

Google Inc., 2010c. Google Latitude. [online] Available at: http://www.google.com/intl/en_us/latitude/intro.html [Accessed: 7/11 2010].

Günther, O. & Spiekermann, S. 2005. RFID and the perception of control: The consumer's view. Communications of the ACM, Vol. 48, No. 9, pp. 73–76.

Häikiö, J., Isomursu, M., Matinmikko, T., Wallin, A., Ailisto, H. & Huomo, T. 2007. Touch-based user interface for elderly users. MobileHCI'07 – Proceedings of the 9th international conference on human computer interaction with mobile devices and services. ACM Sigmobile, New York, NY, USA. P. 289.

Hong, J., Suh, E. & Kim, S. 2009. Context-aware systems: A literature review and classification. Expert Systems with Applications, Vol. 36, No. 4, pp. 8509–8522.

Howe, J. 2006. The Rise of Crowdsourcing. Wired, Vol. 14, No. 06, pp. 176–183.

Informa plc, 2011. Informa.com – Home [online] Available at: http://www.informa.com/ [Accessed: 2/5 2011].

Ishii, H. 1999. Tangible Bits: coupling physicality and virtuality through tangible user interfaces. Proceedings of International Symposium on Mixed Reality – Merging Real and Virtual Worlds. Y. Ohta & H. Tamura (eds.). Ohmsha, Yokohama, Japan. Pp. 229.

ITU, 2010. World Telecommunication/ICT Indicators Database 2010 (14th Edition). International Telecommunication Union, Geneva, Switzerland.

Järvinen, P. 2001. On Research Methods. Tampereen Yliopistopaino Oy, Tampere, Finland.

JSR 256 Expert Group, 2006. Mobile Sensor API Specification. Nokia Corporation, Helsinki, Finland.

Kaasinen, E. 2005. User acceptance of mobile services – value, ease of use, trust and ease of adoption. Ph.D. Espoo: VTT. 151 p. + app. 64 p. (VTT Publications 566.) http://www.vtt.fi/inf/pdf/publications/2005/P566.pdf.

Kela, J., Korpipaa, P., Mantyjarvi, J., Kallio, S., Savino, G., Jozzo, L. & Di Marca, S. 2006. Accelerometer-based gesture control for a design environment. Personal and Ubiquitous Computing, Vol. 10, No. 5, pp. 285–299.

Kindberg, T., Barton, J., Morgan, J., Becker, G., Caswell, D., Debaty, P., Gopal, G., Frid, M., Krishnan, V., Morris, H., Schettino, J., Serra, B. & Spasojevic, M. 2002. People, places, things: Web presence for the real world. Mobile Networks and Applications, Vol. 7, No. 5, pp. 365–76.

Koivumäki, T., Ristola, A. & Kesti, M. 2006. Predicting consumer acceptance in mobile services: Empirical evidence from an experimental end-user environment. International Journal of Mobile Communications, Vol. 4, No. 4, pp. 418–435.

Lahlou, S., Langheinrich, M. & Röcker, C. 2005. Privacy and trust issues with invisible computers. Communications of the ACM, Vol. 48, No. 3, pp. 59–60.

Last.fm Ltd., 2010. Last.fm – Listen to internet radio and the largest music catalogue online. [online] Available at: http://www.last.fm/ [Accessed: 6/9 2010].

Lego Group, 2010. LEGO.com MINDSTORMS : Community. [online] Available at: http://mindstorms.lego.com/en-us/community/default.aspx [Accessed: 6/6 2010].

Lehikoinen, J.T., Lehikoinen, J. & Huuskonen, P. 2008. Understanding privacy regulation in ubicomp interactions. Personal and Ubiquitous Computing, Vol. 12, No. 8, pp. 543–553.

Leikas, J. 2007. Idea Movement of Aging Citizens: Lessons-Learnt from Innovation Workshops. Universal Access in Human-Computer Interaction – Applications and Services. C. Stephanidis (ed.). Springer-Verlag, Berlin, Heidelberg, Germany. P. 923.

Lu, J., Yu, C., Liu, C. & Yao, J.E. 2003. Technology acceptance model for wireless Internet Research, Vol. 13, No. 3, pp. 206–222.

Luecke, R. & Katz, R. 2003. Managing Creativity and Innovation. Harvard Business School Press, Boston, MA, USA.

Lueg, C. 2002. On the Gap between Vision and Feasibility. Pervasive Computing – First International Conference, Pervasive 2002. F. Mattern & M. Naghshineh (eds.). Springer-Verlag, Berlin, Heidelberg, Germany. P. 63.

Madigan, D., Elnahrawy, E., Martin, R.P., Ju, W.H., Krishnan, P. & Krishnakumar, A.S. 2005. Bayesian indoor positioning systems. Proceedings IEEE Infocom 2005 – The Conference on Computer Communications. K. Makki & E. Knightly (eds.). IEEE Communications Society, Piscataway, NJ, USA. P. 1217.

Magretta, J. 2002. Why business models matter. Harvard business review, Vol. 80, No. 5, pp. 86–92, 133.

Mallett, C.T., Millar, W. & Beane, H. 2006. Perspectives on next generation mobile. BT Technology Journal, Vol. 24, No. 4, pp. 151–160.

Mäntyjärvi, J. 2003. Sensor-based context recognition for mobile applications. Ph.D. Espoo: VTT. 118 p. + app. 60 p. (VTT Publications 511.) http://www.vtt.fi/inf/pdf/publications/2003/P511.pdf.

Mäntyjärvi, J., Lindholm, M., Vildjiounaite, E., Mäkelä, S. & Ailisto, H.A. 2005. Identifying users of portable devices from gait pattern with accelerometers. 2005 IEEE International Conference on Acoustics, Speech, and Signal Processing. IEEE Signal Processing Society, Piscataway, NJ, USA. P. ii/973.

Microsoft, 2010. Microsoft Windows: Windows 7, Windows Vista, Windows XP, Windows Live. [online] Available at: http://www.microsoft.com/windows/ [Accessed: 6/9 2010].

Moore, G.A. 1995. Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers. HarperBusiness, New York, NY, USA.

NFC Forum, 2008. NFC Forum: Home. [online] Available at: http://www.nfc-forum.org/home [Accessed: 7/28 2008].

Nokia, 2010a. Ovi by Nokia. [online] Available at: http://www.ovi.com/services/ [Accessed: 8/6 2010].

Nokia, 2010b. Wellness Diary | Beta Labs. [online] Available at: http://betalabs.nokia.com/apps/wellness-diary [Accessed: 7/12 2010].

Nokia, 2009a. Nokia Music | Home. [online] Available at: http://www.nokiamusic.co.uk/ [Accessed: 6/20 2010].

Nokia, 2009b. Nokia Sports Tracker Beta. [online] Available at: http://sportstracker.nokia.com/nts/main/index.do [Accessed: 6/6 2010].

Nokia, 2008. Nokia Step Counter | Nokia Beta Labs. [online] Available at: http://betalabs.nokia.com/betas/view/nokia-step-counter [Accessed: 7/29 2009].

Nokia, 2005. Nokia – Nokia Sensor application brings personal pages to phones – Press Releases – Press – About Nokia. [online] Available at: http://press.nokia.com/PR/200506/997857_5.html [Accessed: 7/11 2010].

Norton, M.J. 2008. Introductory Concepts in Information Science. 4th edition, ASIS, Medford, NJ, USA.

O'Neill, E., Kostakos, V., Kindberg, T., Penn, A., Fraser, S. & Jones, T. 2006. Instrumenting the city: Developing methods for observing and understanding the digital cityscape. UbiComp 2006: Ubiquitous Computing. 8th International Conference, Ubicomp 2006. P. Dourish & A. Friday (eds.). Springer-Verlag, Berlin, Heidelberg, Germany. P. 315.

OECD, 2009. OECD Information Technology Outlook 2008. OECD, Paris, France.

Palmberg, C. & Martikainen, O. 2003. Overcoming a Technological discontinuity – The case of the Finnish Telecom Industry and the GSM. ETLA – Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, Helsinki, Finland.

Pinhanez, C. 2007. Ubiquitous Services. 2007 IEEE International Conference on Services Computing. SCC 2007. L.J. Zhang, W. van der Aalst & P.C.K. Hung (eds.). IEEE Computer Society, Los Alamitos, CA, USA. P. 146.

Porter, M.E. 1985. Competitive Advantage: Creating and Sustaining Superior Performance. Free Press, New York, NY, USA.

Prasithsangaree, P., Krishnamurthy, P. & Chrysanthis, P. 2002. On indoor position location with wireless LANs. The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2002. IEEE, Piscataway, NJ, USA. P. 720.

Raento, M., Oulasvirta, A., Petit, R. & Toivonen, H. 2005. ContextPhone: A Prototyping Platform for Context-Aware Mobile Applications. IEEE Pervasive Computing, Vol. 4, No. 2, pp. 51–59.

Ringland, S.P.A. & Scahill, F.J. 2003. Multimodality – The future of the wireless user interface. BT Technology Journal, Vol. 21, No. 3, pp. 181–191.

Rogers, E.M. 2003. Diffusion of Innovations. 5th ed., Free Press, New York, NY, USA.

Rogers, Y. 2006. Moving on from Weiser's Vision of Calm Computing: Engaging UbiComp Experiences. UbiComp 2006: Ubiquitous Computing – 8th International Conference, Ubicomp 2006. P. Dourish & A. Friday (eds.). Springer-Verlag, Berlin, Heidelberg, Germany. P. 404.

Roman, M., Hess, C., Cerqueira, R., Ranganathan, A., Campbell, R.H. & Nahrstedt, K. 2002. A middleware infrastructure for active spaces. IEEE Pervasive Computing, Vol. 1, No. 4, pp. 74–83.

Rowling, J.K. 1998. Harry Potter and the Chamber of Secrets. Bloomsbury, London, Great Britain.

Rukzio, E., Leichtenstern, K., Callaghan, V., Holleis, P., Schmidt, A. & Chin, J. 2006. An experimental comparison of physical mobile interaction techniques: touching, pointing and scanning. Ubicomp 2006: Ubiquitous Computing – 8th International Conference, Ubicomp 2006. P. Dourish & A. Friday (eds.). Springer-Verlag, Berlin Heidelberg, pp. 87.

Russell, D.M., Streitz, N.A. & Winograd, T. 2005. Building disappearing computers. Communications of the ACM, Vol. 48, No. 3, pp. 42–48.

Saarikoski, V. 2006. The Odyssey of the mobile internet: the emergence of a networking attribute in a multidisciplinary study. Ph.D. Taloustieto, Helsinki, Finland.

Salber, D., Dey, A.K. & Abowd, G.D. 1999. The context toolkit: aiding the development of context-enabled applications. CHI '99: Proceedings of the SIGCHI conference on Human factors in computing systems. ACM, New York, NY, USA. P. 434.

Satyanarayanan, M. 2001. Pervasive computing: Vision and challenges. IEEE Personal Communications, Vol. 8, No. 4, pp. 10–17.

Schmidt, A. 2000. Implicit human computer interaction through context. Personal and Ubiquitous Computing, Vol. 4, No. 2–3, pp. 191–199.

Schumpeter, J.A. 1942. Capitalism, Socialism and Democracy. Harper & Brothers, New York.

Schumpeter, J.A. & Opie, R. 1934. The theory of economic development; an inquiry into profits, capital, credit, interest, and the business cycle. Harvard University Press, Cambridge, MA, USA.

Smart Valley Software Ltd., 2010. HappyWakeUp TM – Smart Alarm Clock on Mobile Phone. [online] Available at: http://www.happywakeup.com/en/ [Accessed: 7/11 2010].

Smart-Its-project, 2003. Smart-Its-project, European Union, IST FP6. [online] Available at: http://www.smart-its.org/ [Accessed: 1/6 2007].

Smura, T., Kivi, A. & Töyli, J. 2009. A framework for analysing the usage of mobile services. Info, Vol. 11, No. 4, pp. 53–67.

Spielberg, S. 2002. Minority Report. Twentieth Century Fox Film Corporation, Beverly Hills, CA, USA.

Spotify, 2010. Spotify – A world of music. [online] Available at: http://www.spotify.com/ [Accessed: 6/9 2010].

Stankiewicz, R. 2000. The concept of design space. In: J. Ziman (ed.). Technological Innovation as an Evolutionary Process. Cambridge University Press. Cambridge, MA, USA. P. 234–247.

Starner, T., Auxier, J., Ashbrook, D. & Gandy, M. 2000. Gesture pendant: a self-illuminating, wearable, infrared computer vision system for home automation control and medical monitoring. ISWC – The Fourth International Symposium on Wearable Computers. IEEE Computer Society, Los Alamitos, CA, USA. P. 87.

Starner, T.E. 2002. The role of speech input in wearable computing. IEEE Pervasive Computing, Vol. 1, No. 3, pp. 89–93.

Swami Project, 2009. SWAMI Project – Safeguards in a World of AMbient Intelligence. [online] Available at: http://is.jrc.ec.europa.eu/pages/TFS/SWAMI.html [Accessed: 6/7 2010].

Symbian Foundation, 2010. The Symbian Foundation Community Home Symbian. [online] Available at: http://www.symbian.org/ [Accessed: 6/9 2010].

Tafazolli, R. (ed.). 2006. Technologies for the Wireless Future, 2nd ed. John Wiley & Sons, Ltd, Oxford, England.

Teece, D.J. 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Research Policy, Vol. 15, No. 6, pp. 285–305.

Törrö, M. 2007. Global intellectual capital brokering. Facilitating the emergence of innovations through network mediation. Espoo: VTT. 106 p. + app. 2 p. (VTT Publications 631.) p://www.vtt.fi/inf/pdf/publications/2007/P631.pdf.

Tushman, M.L. & Anderson, P. 1986. Technological Discontinuities and Organizational Environments. Administrative Science Quarterly, Vol. 31, No. 3, pp. 439–465.

Tuulari, E. 2005. Methods and technologies for experimenting with ubiquitous computing. Ph.D. Espoo: VTT. 136 p. + app. 2 p. (VTT Publications 560.) http://www.vtt.fi/inf/pdf/publications/2005/P560.pdf.

U.S.Government, 2010. Global Positioning System. [online] Available at: http://www.gps.gov/ [Accessed: 6/8 2010].

Utterback, J.M. & Suárez, F.F. 1993. Innovation, competition, and industry structure. Research Policy, Vol. 22, No. 1, pp. 1–21.

Välkkynen, P., Korhonen, I., Plomp, J., Tuomisto, T., Cluitmans, L., Ailisto, H. & Seppä, H. 2003. A user interaction paradigm for physical browsing and near-object control based on tags. proceedings of the Physical Interaction (PI03) Workshop on Real World User Interfaces.

Välkkynen, P. 2007. Physical Selection in Ubiquitous Computing. Ph.D. Espoo: VTT. 79 p. + app. 96 p. (VTT Publications 663.) http://www.vtt.fi/inf/pdf/publications/2007/P663.pdf.

Venkatesh, V. & Davis, F.D. 2000. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. Management Science, Vol. 46, No. 2, pp. 186–204.

Versteeg, G. & Bouwman, H. 2006. Business architecture: A new paradigm to relate business strategy to ICT. Information Systems Frontiers, Vol. 8, No. 2, pp. 91–102.

Von Hippel, E. 1988. The sources of innovation. Oxford University Press, New York, NY, USA.

Von Hippel, E. 2005. Democratizing innovation. The MIT Press, Cambridge, MA, USA.

Von Hippel, E. 1986. Lead Users: A Source of Novel Product Concepts. Management Science, Vol. 32, No. 7, pp. 791–805.

VTT, 2010. Idealiike elohopea. [online] Available at: http://www.idealiike.fi [Accessed: 6/7 2010].

Wang, Y.S., Lin, H.H. & Luarn, P. 2006. Predicting consumer intention to use mobile service. Information Systems Journal, Vol. 16, No. 2, pp. 157–179.

Want, R., Schilit, B., Adams, N., Gold, R., Petersen, K., Goldberg, D., Ellis, J. & Weiser, M. 1996. The Parctab Ubiquitous Computing Experiment. In: T. Imielinski & H.F. Korth (eds.). Mobile Computing. Kluwer Academic Publisher. Boston, MA, USA. Pp. 45–101.

Warren, P. 2004. From ubiquitous computing to ubiquitous intelligence. Journal of The Communications Network, Vol. 3, No. 1, pp. 19–27.

Weiser, M. 1991. The Computer of the 21st Century. Scientific American, Vol. 265, No. 3, pp. 66–75.

Weiser, M. 1993. Some computer science issues in ubiquitous computing. Communications of the ACM, Vol. 36, No. 7, pp. 75–84.

Weiser, M. & Brown, J.S. 1997. The Coming Age of Calm Technology. In: P.J. Denning & R.M. Metcalfe (eds.). Beyond Calculation – The Next Fifty years of Computing. Copernicus Springer-Verlag. NewYork, USA. Pp. 75–85.

Wi-Fi Alliance, 2010. Wi-Fi Alliance: Home. [online] Available at: http://www.wi-fi.org/ [Accessed: 7/31 2010].

WiMAX Forum, 2010. WiMAX Forum. [online] Available at: http://www.wimaxforum.org/ [Accessed: 6/9 2010].

WTO, 2009. WTO | Services: Telecommunication – Glossary of terms. [online] Available at: http://www.wto.org/english/tratop_e/serv_e/telecom_e/tel12_e.htm [Accessed: 4/12 2009].

WWRF, 2001. Book of visions 2001 – Visions of the Wireless World. WWRF – Wireless World Research Forum, Zurich, Switzerland.

ZigBee Alliance, 2008. ZigBee Alliance. [online] Available at: http://www.zigbee.org/en/index.asp [Accessed: 5/27 2008].

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Author(s)
Petteri Alahuhta

Author(s)
Petteri Alahuhta

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Technologies in Mobile Terminals Enabling Ubiquitous Services

Abstract

The vision of ubiquitous computing dates back to the early 1990s. Ubiquitous computing is a model of human-computer interaction in which information processing is seamlessly integrated into everyday objects and environments. During the 2000s the ubiquitous computing vision has extended and blended with wireless mobile communications to become ubiquitous computing and communication. If earlier information processing was done mainly in static office environments, new advances in mobile technologies offer access to the information and services that are relevant to us in this very situation and right now.

In this research an attempt is made to better understand the development of the digital mobile phone as a platform for ubiquitous services. Ubiquitous services are mobile services that are capable of using contextual information and ICT-based resources in proximity to the user of the mobile phone. The hypothesis of the research is that there is a technology trajectory that makes the mobile phone a host, providing gateway and hub functionality to the ubiquitous services.

We introduce a theoretical framework for analyzing the evolution of mobile devices. The framework is based on several theories of innovation. It addresses aspects of the introduction new technology, dominant designs, technology diffusion, and users' needs. According to the analysis of empirical material using our theoretical framework, the mobile phone has the potential to become a gateway to ubiquitous services, largely due to the new technologies integrated with it. New functionalities and technologies, such as local connectivity and sensor-technology in mobile phones play a key role in helping developers implement ubiquitous services utilizing contextual information. Potential challenges for the diffusion of ubiquitous services are privacy and to some extend environmental issues.

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