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DEVELOPMENT AND EVALUATION OF THE LOCATION-AWARE PLATFORM

MAIN CHARACTERISTICS IN ADAPTABLE LOCATION-AWARE SYSTEMS
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Main characteristics in adaptable location-aware systems

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Abstract

The development of mobile and ubiquitous computing has recently been rapid. One of the most promising research and development fields has been location-aware services. These services are challenging as they require a lot of resources for generating maps from spatial data and for visualizing temporary data gathered from the environment. Applying location-awareness and ubiquitous computing in the industry is currently under intensive research and development activities especially because of signs of promising new business opportunities.

This thesis studies the development and evaluation of a location-aware system platform called Locawe designed for indoor and outdoor conditions. This decentralized middleware-based platform has been developed at CENTRIA Research and Development, Ylivieska. The main objectives of this research have been primarily to study and develop new ubiquitous features for the Locawe platform with various software and hardware combinations. In addition, during these studies gathered experiences have been used in order to design new versions of the Locawe architecture. These ubiquitous features, covering the use of GPS, RFID and WSAN technologies, have been tested in five field experiments, one laboratory experiment and several industrial pilots. In these evaluations, the author has considered what software and hardware alternatives are feasible and appropriate for improving the newly developed features in the Locawe platform. These features have been evaluated from usability, visualization and communication techniques perspective.

As a result the author presents in this thesis main characteristics in location-aware system development from system layers, ubiquitous computing, mobility, and restrictions perspective. The author also suggests that the architecture presented in this thesis enables location-aware system development in indoor and outdoor conditions. With respect of state-of-the-art platforms, the Locawe platform is, at the moment, in some sense unique, although only as a research prototype. This platform combines two approaches, namely research on location platforms, and research on geosensor networks or smart environments. In addition, this platform gives one answer how RFID or WSAN technologies could be integrated under one framework together with mobile devices. Finally, the author also proposes that the research and development approach presented in this thesis can be applied successfully in research and development organizations specialized in applied research.

**Keywords:** location-aware platform, mobile computing, ubiquitous computing, usability
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Tiivistelmä


Asiasanat: käytettävyys, mobiili tietotekniikka, paikkatietoaine ohjelmistoalusta, sulautettu tietotekniikka
Preface

Writing this book has been a coincidence. I dreamt of being a musician but I graduated as a teacher in mathematics. I have always hoped to experience this world from different perspectives, and now I’m grateful I have definitely experienced something. I have learnt from people who have worked next to me. I have also learnt from the people who have lived next to me. Here I wish to express my gratitude to all of you.

I have been lucky to work in an innovative organization which has given me the opportunities and conditions to realize my objectives as a researcher. Especially I wish to thank Vice-President Keijo Nivala and Research and Development managers Antti Lauhikari and Hannu Leppälä: you have trusted me and given me a chance to do this research. I have also had a chance to work in a research laboratory in which colleagues supported me all the time. I feel fortunate and grateful to have been supervised by Professor Kari Kuutti and Dr. Jouni Markkula who have understood my motivations and objectives in this wide research field. I appreciate your expertise and endless support during these past years in helping me finalize this thesis. I also want to express my gratitude to Dr. Timo Partala who opened the door and led me to the academic world. During those years we worked together we made an efficient team with successful results. The other members of this team consisted of professional and skilled researchers: Kirsti Sääskilahti, Taina Lehtimäki, and Outi Sippola. I want to thank you all for your part in the successful results we achieved together. I also wish to thank my developers Ossi Saukko, Pertti Verronen, Ville Autio, Juha Alaspää, Juha Yli-Hemminki, Ville Rahja, and all the others (too many to mention). I owe my success to you. You have worked persistently towards our goals and fulfilled all my expectations and much more.

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European Regional Development Fund, the Finnish Funding Agency for Technology and Innovation, and The Employment and Economic Development Centres. They contributed to successful research in co-operation with companies and other research organizations.

During my projects I met a lot of interesting people from all over the world. Discussions with these people have given me a better understanding of my research field. It is impossible to specify all these occasions, but there are a couple of people I would particularly like to thank. My dissertation deals with subjects close to engineering, therefore I was lucky that I met Professor Tapio Seppänen who taught me much about how to do research in the field of engineering. I also want to thank Professor Markku Oivo who introduced me to the field of information processing science. During the years there have been a lot of companies who have believed in me and in my research group. From these I wish to thank especially CEO Pauli Korpi-Tassi from Pohjanmaan PPO Ltd., CEO Matti Myllylä from M-Technology Ltd., and CEO Samuli Vanhala from Tracker Ltd. for giving us a chance to do our research at the very beginning. I also want to mention the role of end users in this work. End users were required in several field experiments and in industrial pilot studies. I want to thank you all for your contribution to this work. I also wish to thank principal lecturers Sakari Pieskä and Veikko Brax, lecturers Olli Peltonen and Joni Jämsä, and development managers Jorma Hintikka and Janne Känsäkoski, and, last but not least, head of research Zach Shelby whom I have followed during these years. You have all inspired me frequently with new and innovative ideas.

Finally, I wish to thank all those who have been close to me during these years. I have to apologize that this process has changed me a bit. I hope you can help me to recover! This work would not have been possible without my loving parents. You have supported me always and you have taken care of my dearest ones when I have not been present. My wife and friend Riitta, you are so special. How can I find the words to express my gratitude to you? You, together with Roosa, Emilia, and Kasperi, have watched this seemingly endless game which has, I hope, not stolen too much time from us. Thank you all for being so wonderful, so understanding and so patient. I promise now that we will spend time together.
Abbreviations

AutoCAD DXF Drawing Interchange Format of Autodesk Inc.
3-D Three dimensional
6LoWPAN IPv6 over Low power WPAN (IEEE 802.15.4)
API Application Programming Interface
B2B Business-to-Business
Bluetooth Short range wireless connectivity standard (IEEE 802.15.1)
CAD Computer-Aided Design
CAM Computer-Aided Manufacturing
DNA Deoxyribonucleic acid
EU The European Union
FP6 The Sixth Framework Programme of the European Union
FP7 The Seventh Framework Programme of the European Union
FPGA Field-Programmable Gate Array
GIF Graphics Interchange Format
GIS Geographic Information System
GML Geographic Markup Language
GMS GeoMobility Server
GSN Geosensor Network
GPRS General Packet Radio Service
GPS Global Positioning System
GSM Global System for Mobile communications
HCI Human-Computer Interaction
HF High Frequency
ICT Information and Communications Technology
IEEE The Institute of Electrical and Electronics Engineers
i-Mode NTT DoCoMo’s mobile content service based on packet data
IP Internet Protocol
IPv6 Internet Protocol version 6
IS Information System
ISO The International Organization for Standardization
ISTAG Information Society Technologies Advisory Group
ITU International Telecommunication Union
JPEG File Interchange Format of the Joint Photographic Experts Group
LTE Long-Term Evolution
MHz Frequency – one million cycles per second
M2M Machine-to-Machine
MIT Massachusetts Institute of Technology
M-GIS Mobile geographic information services
NASA The National Aeronautics and Space Administration
NFC Near Field Communication
O&M Observations & Measurements Schema
OGC Open Geospatial Consortium
OpenLS OpenGIS Location Service
OS Operating System
PC Personal Computer
PNG Portable Network Graphics Format
RFID Radio Frequency Identification
RTLS Real-time Locating System
SAS Sensor Alert Service
SensorML Sensor Model Language
SMS Short Message Service
SOA Service-Oriented Architecture
SOAP Simple Object Access Protocol
SOS Sensor Observations Service
SPS Sensor Planning Service
SWE Sensor Web Enablement
SVG Scalable Vector Graphics
TML Transducer Markup Language
UHF Ultra High Frequency
UI User Interface
ULPBluetooth Ultra Low Power Bluetooth
UWB Ultra-Wideband
Wibree Bluetooth Low Energy Technology
W-CDMA Wideband Code Division Multiple Access
WFS Web Feature Server
WLAN Wireless Local Area Network (IEEE 802.11)
WMS Web Map Server
WNS Web Notification Services
WPAN Wireless Personal Area Network
WSAN Wireless Sensor and Actuator Networks
XML eXtensible Markup Language
ZigBee Low power, low bit rate WPAN technology (IEEE 802.15.4)
List of original articles


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1 Introduction

The challenges related to applying ubiquitous computing in the industry are currently under frequent investigation especially because of signs of promising new business opportunities. That is to say, numerous promising estimations about location-aware system, Radio Frequency Identification (RFID), and Wireless Sensor and Actuator Networks (WSAN) markets are available. For example according to Mattern and Sturm (2003) ubiquitous computing will have dramatic economic effects and therefore improve productivity and profitability. European Galileo project and Nokia’s Navteq investments, in turn, are examples how important geographic information is nowadays. Moreover, networked microprocessors such as WSAN technologies are said to be a key technology for the 21st century. These tiny computers will gather a huge amount of information from the human environment. In consequence, an entire new industry is forecasted to be set up. Location-aware systems will be the ones which will integrate information collected with sensors from the environment and from the users moving in that environment, and which will process information for the users.

What is the reason the needs of the industry and the promises presented above does not meet? Ubiquitous computing and location-aware system development is a multidisciplinary research area in which many kinds of expertise are needed. DeMarco and Lister (1990) have argued that software development is more complex than any other man-made creation. Similarly, location-aware systems consisting of both indoor and outdoor conditions applying ubiquitous computing can be seen as one of the most complex systems in information system research. However, as already mentioned, location-aware systems are currently under intense investigation. The main challenges can be found from the areas of interoperability and usability.

Especially, location-aware systems which are designed for indoor conditions are problematic for researchers. These conditions still require an extra infrastructure for tracking and tracing moving objects. Furthermore, building services without global standards is inhibiting the realization of the visions about invisible technology drawn by Weiser (1991) or later by the Information Society Technologies Advisory Group (ISTAG 2006). In fact, ISTAG has setup four trajectories for the next generation of Information and Communications Technology (ICT). First of all, the next-generation systems and services will be networked, mobile, seamless and scalable which will mean the capability to offer
ideal connections for the users anytime, anywhere and to anything. Another essential feature in the next generation of systems and services is that they will be embedded into the objects of everyday life. These systems and services will be invisible to the users or will be accompanied by new form-fitting solutions. Moreover, ICT systems and services will be more intelligent and customized. In addition, the contents will be visualized with rich end-user experiences together with highly usable features such as multimodal interaction.

Another challenging research area related to location-aware systems can be found from global geosensor networks. Nowadays these networks which monitor phenomena in geographic space are starting to include ubiquitous technologies. Especially, SENSEI’s (2008) review about state-of-the-art technologies in sensor network integration frameworks shows that interoperability is the main challenge to WSAN development as well. After succeeding in the standardization process it is probable that we will frequently see ubiquitous computing applied in mobile devices and in our everyday life.

This thesis studies the development and evaluation of a location-aware system platform called Locawe designed for indoor and outdoor conditions. This decentralized middleware-based platform is being developed at CENTRIA Research and Development, Ylivieska. The main objectives of this research have been primarily to study and develop new ubiquitous features for the Locawe platform with various software and hardware combinations. In addition, during these studies gathered experiences have been used in order to design new versions of the Locawe architecture. To avoid misunderstanding in this thesis ubiquitous computing will be defined based on a taxonomy presented by Satyanarayanan (2001) as a collection of technologies which can be applied, for example, in location-aware services in mobile devices. These ubiquitous features, covering the use of GPS, RFID and WSAN technologies, have been tested in five field experiments, one laboratory experiment and several industrial pilots. In the following text all these experiments are referred to as field experiments.

Furthermore, as a long-term objective this research has also aimed at designing and developing a software platform which is, to some extent, distributed. That is to say this software platform consists of software components which are able to communicate with each other over the Internet. In addition, this platform should also support developers in the user interface design and users with usable user interface functionalities.

The research actions related to this research can be classified as architecture design, human-computer interaction field experiments, and industrial pilots with
considerations of adaptability to various environments, practical applicability to numerous applications, and, recently, accessibility to sensor data. Thus the main research question in this thesis has been formulated as: *What are the main characteristics needed in order to develop adaptable location-aware platforms for varying conditions?* This question has been divided in next sub-questions: 1. *What kind of architecture enables location-aware system development both in indoor and outdoor conditions?* 2. *What are the bottlenecks that can be found in the design of location-aware system platforms?* In addition, as a result of working as a development manager for CENTRIA an additional research question has become evident, namely: *What kind of research approach can cover both technological development and user needs?*

### 1.1 Research scope

The research scope of this thesis is on the architectural considerations based on HCI experiments and industrial pilots. Location-aware systems typically consist of mobile units and tracking servers. Thus, the architectural study has to cover topics from telecommunication channels and Internet protocols to wireless sensor and actuator networks. The Locawe platform has been evaluated during the design process in various field experiments. These experiments have given valuable information not only about Human-Computer interaction (HCI) but also about how Locawe works with newly-developed features from a technological point of view.

During the design process new ubiquitous features in Locawe have been tested in various industrial pilots. These pilots cover application areas such as mobile maintenance, agriculture, mining and digital manufacturing. Thus the main user groups have not been in consumer markets but rather in business-to-business (B2B) markets. The consumer applications are an interesting research area but one which is not considered in this research. In fact, in this sector the challenges are different than in B2B applications. In consumer applications it is difficult for the developers to design both usable, scalable and portable mobile solutions. The main reasons are the diversity of operating systems in mobile devices.

B2B application development with ubiquitous computing is even more challenging. In this case the challenges are more related to back-end systems which were typically developed before ubiquitous computing and its requirements. Moreover, these applications have different kinds of requirement specifications
for mobile devices than consumer applications have. This point of view is essential when developing mobile services with ubiquitous features. Mobile devices designed for B2B applications vary in robustness, number of radios, size and costs. All these considerations are specified by customers and, in consequence, developers are able to design architectures based on specified devices.

When summarizing the research scope, this thesis will seek answers concerning next generation location-aware systems applied in indoor and outdoor conditions. However, this thesis does not cover considerations related to security management, exception management or power consumption. The scope of this research is rather on the development and evaluation of the next generation location-aware architecture for varying conditions in which map-based user Interfaces (UIs) play a key role, and in which standards are tools when trying to find solutions for the interoperability and scalability issues. It has to be noted that in this thesis human computer interaction and user interface design have been at the centre of development and evaluation activities, and this is true also in the case of B2B applications, in which the Locawe platform has been used.

1.2 Structure of the thesis

This thesis consists of 8 published articles (I-VIII). The author has given the main contribution in the research planning for the new features to be implemented from technological perspective. In practice, he has been a project manager in various research projects and has led all development activities related to the map engine and Locawe platform. Furthermore, he has designed the Locawe architecture based on the information gathered from several field experiments and numerous industrial pilots. This platform has been developed in close cooperation with usability experts (Articles I-VI). The results achieved in the experiments have been valuable for the further development of the Locawe platform. In Article VII the Locawe platform is presented as a novel location-aware platform for outdoor and indoor conditions. Finally, in Article VIII an evaluation of the use of geospatial standards with the Locawe platform is reported.

In Table 1 three sequential phases related to this research are presented. The preliminary studies in this table cover the time when the author was working as a researcher for CENTRIA Research and Development, Ylivieska. During 2004–2005 he was studying location-based services and finalizing his Master’s Thesis in this field. The focus of this thesis was on searching for answers about how
spatial data can be used efficiently in mobile devices. As a result CENTRIA’s first prototype version of a map engine was implemented. In this phase the map engine was able to generate maps from spatial data from street registers and position the user on the map based on GPS. In addition, efficient rendering with map generalization tools were also studied.

Table 1. Research phases related to articles in this thesis.

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<th>Research phase</th>
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The preliminary studies were followed by the first research phase in which CENTRIA Map Engine version 1.0 was released based on the first expertise gathered from the field experiments (Articles I, IV, V) and from the industrial pilots. During this phase the first expertise about ubiquitous computing in the field experiments (Articles II, III, VI) and the industrial pilots were also gathered. The author was then working as a development manager for CENTRIA and was leading these development activities. Finally, the phase in which the Locawe platform was specified (Article VII) as an architecture model is in progress. The author is still working for CENTRIA in the same position and based on his specifications CENTRIA mobile research group is currently constructing the first pilots in which the use of global standards is the focus. In Article VIII the research objective is to use the Locawe platform as a part of a global geosensor network (GSN) in national and international research projects.

The structure of this thesis is as follows. In Chapter 2 a review of the state-of-the-art research of the location-aware systems is presented. The chapter covers a short review about the history of computer sciences as a background, state-of-the-art studies in distributed systems, ubiquitous computing, geographic information systems, location platforms, geosensor networks, and mobile digital maps.

This chapter is followed by Chapter 3 in which a constructive research approach related to this thesis is described. In the beginning, Hevner’s Information systems research framework (Hevner et al. 2004) is introduced. After the introduction the approach to the framework for this research is explained.
Especially, the process which describes the evaluation of developed artifacts and refinement of used theories in the framework has been the focus of this research. This test-generate process has been used various times for evaluating new features in the Locawe platform and for understanding their feasibility for further development and for industrial use.

After introducing the research approach, the development and evaluation of the Locawe architecture and the Locawe platform are presented in Chapter 4 and Chapter 5. This presentation consists of a description of the research phases already introduced briefly in Table 1, a description of the evaluation process of the Locawe architecture and the Locawe platform, and a comparison to state-of-the-art studies. In Chapter 6 an introduction to original articles and a contribution of the author is included. In addition, the relationships of the original articles to the research phases and to the used research approach are presented. Finally, this chapter is followed by Chapter 7 with a discussion about achievements, significance, validity, unsolved challenges, and limitations related to this thesis.


2 Location-aware systems

In this thesis the location-aware system platform called Locawe has been developed and evaluated. This chapter covers the background of this research field including the main terminology, a literature review of related research and of state-of-the-art platforms.

Location-aware systems can be seen as a specific type of Geographic Information Systems (GIS). In fact, these systems have their historical background in traditional GIS used in desktop environments. Virrantaus et al. (2001) have defined GIS to be an information system that processes geographic data. Corresponding to this definition, GIS can be considered as a system for capturing, storing, checking, manipulating, analysing and displaying data which are spatially referenced to the Earth (Burrough & McDonnell 1998). According to Longley et al. (2005), geographic information consists of location, attributes and, optionally, time. This information is based on data about phenomena and objects that can be associated to location on earth surface. Location on the earth surface is typically expressed using coordinates in a specified geographic coordinate system, even though other reference systems can also be used. One of the most used global coordinate system is WGS-84, which is used in GPS positioning. By positioning with GPS or some other system, the location of the real world objects and phenomena can be defined within the coordinate system.

Later on, due to the advance in technology, especially popularity of GPS positioning, a new type of GIS, namely Mobile GIS (M-GIS), appeared. According to Tang and Selwood (2003), mobile GIS are typically used for tracking and tracing moving items. In these systems it is significant to know when, how and how quickly they are moving together with direction and route information. M-GIS provide tools and services for capturing, formatting, extracting and streaming location information for this purpose (Tang & Selwood 2003). M-GIS can be seen also as a platform for the development of location-based services (Peng & Tsou 2003).

Longley et al. (2005) have defined location-based services as information services in which the used mobile device is able to determine its location and is capable of accessing the information based on this location. In the latter definition, the expression of services with a device capable of determining location means that the device is location-aware. Extending this definition, location-based services have also been divided into position-aware (or location-aware) and location-tracking services (Barkhuus & Dey 2003, Junglas & Watson 2008). In
the latter case, information is not requested by the mobile device user but an external party is using the location information of the user (Barkhuus & Dey 2003, Junglas & Watson 2008).

Traditionally in GIS, the geographic data has been collected and stored on the server side (cf. Virrantaus et al. 2001). Nowadays, when GPS-integrated mobile devices with more extensive computing capabilities are used with client-side software, the data can also be more frequently collected and modified on the client side. When the system allows collection and modification of geographic data based on the location of the mobile device, it can be considered to be location-aware. This collected and modified data can be used for utilizing the location of the user to adapt the service accordingly (cf. Kaasinen 2003). Thus location-aware service can be defined as services which are able to adapt to the current situation, especially to the location, based on geographic information, and which involves both location-based mobile and context data collection and management.

Location-aware and context-aware systems have a close relationship. Context-awareness and context-aware systems can be considered to be evolved from location-awareness by generalization (Schmidt 2002). Schilit et al. (1994) have defined context-aware systems as follows: “Context-aware systems adapt according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time.” It has been noted that location is the most frequently used parameter in context-aware applications (Schmidt et al. 1999; cf. Satoh 2007). According to Katasonov, (2006) in context-aware services location and other attributes such as time, activity of user, the user’s physiological measurements, social situation, and environmental measurements, are seen as parameters of the context in which an application can be run. The challenges related to the use of other contexts in location-aware services can be found from a comment by Jiang and Yao (2006) about context being probably the most difficult part of location-aware services.

The focus in Locawe platform presented in this thesis is, in addition to locating, also on identifying and sensing objects. When location information and measurement of context attributes are utilized in Locawe, it can be called as a location-aware platform. Locawe can be, and has been, used as a platform for building various location-aware services. According to Zündt (2007), location platforms can be classified into device centric, decentralized middleware-based, and centralized location platforms. With respect to this classification, Locawe can be considered as a decentralized middleware-based location-aware platform.
When location-aware systems are considered as specialized GIS and M-GIS seen as platforms for developing location-based services, their characteristics are also, in some extent, suitable for describing the Locawe platform. The Locawe platform can be seen in GIS terms as a map container and a software development platform for location-aware services. However, it cannot be used for solving geographical problems or for analyzing geographical information. Based on this, Locawe platform can be defined as a mobile GIS platform with certain restrictions. To be exact Locawe has only support for geographic data collection and conversions, for geographic data management, and for geographic data presentation but not for geographic data analysis which is one of the main features in GIS (cf. Virrantaus et al. 2001).

2.1 Challenges in location-aware systems

The development of mobile and ubiquitous computing has recently been rapid. One of the most promising research and development fields has been location-aware services as the following estimations and trends will show. In fact, location-based service markets have been estimated to increase in Western Europe from $191 million in 2006 to $1.3 billion in 2011 (Lagorce 2007). Respectively, the US estimations are from $150 million in 2006 to $3.1 billion in 2010 (Reardon 2006).

These services are challenging as they require a lot of resources for generating maps from spatial data and for visualizing temporary data gathered from the environment. Throughout the history of information processing sciences, improvements related to computing resources have been at the centre of the development (cf. Glass 1998). Lessons learned from efficient programming with limited resources can be reapplied not only in embedded software development and in mobile programming, but also in the development of distributed geographic information systems (distributed GIS). Also, usability and standardization are areas in which the best practices are significant and which can be taken into account when developing new innovations.

Leonhardt’s (1998) argument about the lack of platform or infrastructure for building location-aware systems is still valid, at least with certain criteria. The answers to what the challenges and criteria are for location-aware platforms are sought next. Tsalgatidou et al. (2003) have listed requirements for location-based services: user and functional, usability, reliability, privacy, location infrastructure and service interoperability requirements. This list of requirements demonstrates
how many kinds of aspects have to be taken into account in the design process. Location-aware platforms are also technologically complex. Patterson et al. (2003) have stated that the evolution of mobile computing, location sensing, and wireless networking has created a new class of computing, namely location-aware computing. This description continues with four fundamental issues which complicate the design and implementation of location-aware systems. 1) Mobile units are in general resource-poor compared to normal PCs. 2) In telecommunications, security issues are always present but they are even more severe when wireless technologies are used. 3) Wireless connectivity is also highly variable in performance and reliability. 4) Energy consumption has to be taken into account in the development as well. In addition, Patterson et al. gave certain criteria for the application programming interfaces (APIs) of location-aware system platforms. These criteria cover open standards, technology-dependent attributes of the underlying technology, specified accuracy, and capability of handling dynamically combined location information from multiple sources. Timpf (2006) has in turn listed location-aware services which cover way findings, information gathering and presentations of relevant information, reservations, points of interests, and management of daily routine tasks. Finally, a new challenge is to cover indoor conditions as a part of location-aware platform design. Developing location-aware services for indoor conditions always requires extra infrastructure. Therefore, based on the definition of ubiquitous computing as a collection of technologies, which can be applied when developing location-aware services, it can be argued that ubiquitous computing is an important factor in the development of smart environments in the future. In many cases location-aware platforms are part of smart environments.

Cook and Das (2007) have discussed the current state of the development of smart environments. They have found this research area to be multidisciplinary containing, for example, mobile technologies, artificial intelligence, sensor network technologies, robotics, multimedia, computer sciences, and telecommunication technologies. In addition, they have defined a smart environment as one that is able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experiences in that environment. The components of smart environments are classified in their studies into four component types which are decision, information, communication, and physical components. In the first place physical components consist of sensors, actuators, and other wireless technologies. Communication components, in turn, are needed for connecting wireless devices together. These
two components, as an infrastructure, enable information processing between devices and interactions between users and their environment. Information components are needed for storing, delivering, data-mining, and predicting acquired data. Finally, they have stated that the developed ubiquitous system can be smart only if it will contain a software component with rules and decision-making algorithms.

2.2 From distributed systems towards ubiquitous computing

A starting point for this research has been visions about invisible technology and ubiquitous computing (ISTAG 2006, Weiser 1991). In these visions the user’s environment will be equipped with tiny computers. In their state-of-the-art review Mattern and Sturm (2003) have described components needed in ubiquitous computing. In the first place they have argued that the essential techniques of distributed systems will be incorporated into ubiquitous computing. In fact, according to their definition, distributed systems consist of several computers that are able to communicate over a network and are able to coordinate actions and processes. Their review about ubiquitous components also covers interoperability issues such as XML-based communication, and, especially, the use of the simple object access protocol (SOAP). In addition, they have listed scalability challenges in software infrastructures which include hardware systems, operating systems, programming languages, and standards. There are already several middleware and software infrastructures available on the market which provides basic communication facilities for distributed system development. Furthermore, in their review, the trends in distributed application structures contain application servers, peer-to-peer communication, grid computing, mobility, and spontaneous networking.

All of the above aspects are already available for software developers. However, on the way towards ubiquitous computing smart devices which are connected to each other locally or globally over the Internet are the main focus. These smart devices, integrated with ubiquitous technologies, are able to identify and sense objects. In estimates presented by Mattern and Sturm (2003) ubiquitous computing will have dramatic economic effects. New services are able to transform a huge amount of the information gathered by the smart devices into value for the human user. They are forecasting that an entire industry will be set up to establish and run the infrastructure for the new smart and networked information appliances.
As Mattern and Sturm (2003) have stated, we are on the way from distributed systems to ubiquitous computing. In Figure 1, presented by Satyanarayanan (2001), shows the research problems regarding this statement and this multidisciplinary research area. Location-aware systems for indoor and outdoor conditions can be defined based on this figure as distributed systems. On the other hand, all distributed systems are certainly not ubiquitous systems. If a distributed system includes mobile technologies such as wireless networks, positioning sensors with context-aware or energy-aware features then the system embodies smart environments. In addition, according to this classification, a system can be called a ubiquitous system when it contains not only mobile technologies but also invisible technologies, localized scalability and uneven conditioning. In this classification invisibility means, as was presented in Weiser’s (1991) visions, the complete disappearance of ubiquitous computing technology from users’ consciousness. The localized scalability, in turn, in Satyanarayanan’s classification covers bandwidth, energy, and distraction solutions for wireless mobile users. Uneven conditioning is about how to use mobile services in different types of environment.

Based on the review above, it can be realized that ubiquitous computing is an enormous change in the history of computing. In fact, Business Week (1999) has presented networked microprocessors as one of the key technologies in the 21st century. These tiny computers can be placed, for example, in air, water, ground, body, vehicles or buildings. The application areas, in turn, can cover, for example, tracking and tracing human beings or vehicles, directing arms, controlling
restricted areas regions or power plants, and industrial ad hoc sensor networks (Chong & Kumar 2003.)

The main challenges towards ubiquitous computing are definitely in interoperability issues. Tsalgatidou et al. (2003), for instance have described interoperability requirements by stating that interoperability should be assured on all levels of the location-aware system architecture. This aspect will be presented in more detail later in this chapter. However, it should be noted, that the research focus in these studies is not on interoperability but on other challenges related to ubiquitous computing.

2.3 Related research

Challenges in information flow and in computing

In the future the world-wide distributed system will contain sensors which can be used remotely and in real time. One of the main challenges in such systems is information flow. In fact, when these systems produce a lot of data the developers have many kinds of challenges. For example, Youngblood (2005) has designed a system which is able to learn an inhabitant’s behaviour based on user interactions with motion and lighting sensors. In these measurements, an average of 10,310 events per day was collected from motion and lighting sensors. However, this system was measuring just one moving object. On the other hand, a geosensor network, a world-wide distributed system, can provide an amount of data which cannot be collected and analyzed centrally. Therefore, efficient use of the collected data would require entirely new kinds of architectures for information processing. Zbikowski (2004) has found a sophisticated solution from nature. Insects use their limited information processing resources efficiently with a sensor-rich feedback control for flight management. In fact, insects have many sensors with many feedback loops which mean many measurements and much data. Furthermore, they have many simple controllers which are able to use simplified calculation from local data. This is a typical distributed system which is much more efficient than a conventional feedback control with few sensors, few feedback loops and few complex controllers with a lot of calculations. In summary, distributed information processing is a challenge in ubiquitous computing, but also an opportunity for researchers to change practices radically.
Studies related to Radio-Frequency Identification technologies

New solutions in which ubiquitous computing has been applied are seen in mobile phones more generally. In the consumer market the first mobile devices integrated with RFID readers were already released a couple of years ago. In fact, RFID is said to be one of the most successful computing platforms despite challenges related to limited capabilities of the tags, cost-effectiveness, and privacy concerns (Roussos & Kostakos 2009).

RFID markets are currently progressing rapidly. According to the European Commission (2007), in 2006 alone over one billion RFID tags were sold worldwide and by 2016 it might be over 500 times this number. The European markets in these estimations will grow from €500 million to €7 billion by 2016. All this progress will have a positive impact on costs. As a result more RFID integrated mobile devices will be released in the future. One of the main development activities in RFID integrated mobile devices is currently the Pay-Buy-Mobile initiative which is coordinated by the GSM Association (2007). This initiative covers thirty-four of the world’s largest mobile network operators. Their goal is to create and define a global approach for enabling Near Field Communication (NFC) payment services on mobile phones. Several trials around the world have been reported to show early signs of success in mobile NFC payments services.

Currently the most used standards related to RFID integration with mobile devices are ISO 14443A (ISO 2001) and ISO 15693 (ISO 2006) standards which are specified for High Frequency (HF) readers with 13.56MHz radio. Ultra High Frequency (UHF) readers are used mostly in more robust industrial mobile devices. Recently, on the other hand, Nokia revealed the first UHF compatible mobile device E61i which is still in the prototype phase (Savolainen et al. 2009). UHF readers in mobile devices enable longer reading distances. Conversely, a long range reading has consequences such as bigger antennas and power consumption. These limitations have to be taken into account when choosing suitable devices. One of the most challenging issues in the development processes is the readability issue. Particularly when considering the use of mobile devices with RFID readers this is a challenge because of shorter reading distances. Moreover, this is especially problematic with passive RFID tags. However, these tags are already relatively cheap and usable not only in the effective automatic identification of objects, humans, and other species but also locations, and, increasingly, media content and mobile services (Roussos & Kostakos 2009).
As already described above, RFID technologies face a lot of challenges. For instance, challenges when developing smart environments which apply RFID identification are in the area of UI design. This is problematic especially for elderly users who are familiar with neither computers nor mobile devices. However, ubiquitous computing is defined as an invisible technology. Furthermore, innovative use of sensors enables the design of natural user interfaces. For example, Cook and Das (2007) have defined RFID as a sensor which can be used as an essential part of new UIs. Riekki et al. (2006) have in turn studied RFID technology as an extension of normal UI in mobile devices. In their experiments mobile devices were used by physically touching objects in a smart environment. When the user touched smart objects on which tags were attached the system identified the object and provided the desired service.

Due to the challenges related to RFID technologies it is understandable that there are a lot of application areas in which RFID technology is not yet suitable. For example, one of the common applications, in which the use of passive RFID technologies is a challenge, is locating everyday items. In fact, many substitutive technologies are already available on the market if more expensive solutions are not out of the scope. Typically, in these solutions the tracked objects are attached to a radio transmitter. In consequence more expensive technologies such as WLAN, Bluetooth, 6LoWPAN (IPv6 over Low power Wireless Personal Area Network) etc. require power consumption. Loosely defined, all the above mentioned technologies are active RFID technologies. On the other hand, these technologies can be defined as well as WSAN. Frank et al. (2008) have used Bluetooth radio as a sensor for locating everyday objects. In their solution the tracked objects departing from Bluetooth coverage can trigger an alarm. This feature can be used for remembering or for securing tracked objects. Furthermore, a tracked and previously configured known object can also be found when entering Bluetooth coverage.

The above described study can also be seen as an example of Machine-to-Machine (M2M) interaction which can be defined as ubiquitous, pervasive or sentient computing (Hopper 2000). The use of the term M2M interaction does not mean that human activities are not in the research scope. Despite using this kind of interaction the user is able to cause events in the ubiquitous systems based on real-life activities. In addition, these events can provide for the user services as virtual extensions related to the current location or context.
Studies related to Wireless Sensor and Actuator Networks technologies

Wireless sensor and actuator network technologies are following the same trends found in RFID markets. For example, Nokia (2007) has visions of using mobile devices with smart objects based on Ultra Low Power Bluetooth (ULPBluetooth, formerly known as Wibree) technology. Based on this technology mobile devices can be used together with sensors in application areas such as in sports, wellness, healthcare, automotive, entertainment and toys. Business Week (1999) has in turn predicted that in the 21st century, planet earth will have an electronic skin. However, before WSAN technologies can come into widespread use many challenges have to be solved. These challenges are covering, for example, service discovery, scalability, proactivity, mobility, privacy, security, and reliability (Satyanarayanan 2001).

The challenges listed above are all still acute research problems if we look at the state-of-the-art review of WSAN reported by the SENSEI (2008) project. In fact, just recently in this project eleven sensor network integration frameworks have been analyzed. These frameworks were IrisNet, Hourglass, Janus, JWebDust, Sensor Web Enablement, SenseWeb, Global Sensor Networks, e-SENSE, Urban Sensing, Ubiquitous Sensor Networks, and CoBIs. For this thesis the results from these analyses are essential, especially from the perspective of information related to standards, data representation, geo-support, and mobility support. The results show that none of these frameworks fulfilled SENSEI’s needs. Three of frameworks do not have geo-support, only five of them were supporting XML-based data representation. Furthermore, four of the frameworks supported mobility, and in the end only a suite of standards called Sensor Web Enablement (SWE) specified by Open Geospatial Consortium (OGC) was named as a promising standardized framework in this review.

Next, before focusing on this suite of standards dedicated to GSNs, these frameworks are introduced shortly. The first framework called CoBIs (Collaborative Business Items) does not, according to SENSEI, have any geo-support. CoBIS is already an ended EU FP6 project. In this project researchers have focused on ubiquitous computing from a business item perspective. These items are defined as product items, containers, shelves, vehicles, pieces of machinery, and buildings as well as human beings. As a result of this project it has been stated that these business items will bring a lot of benefits in the industries of, for example, monitoring storage regulations for hazardous chemicals with WSAN, managing supplies within retail stores with RFID as a
smart shelf concept, demonstrating smart signs in emergency situations with WSAN, and managing heat, ventilation and conditions in buildings with WSAN. CoBIIS has produced a comparison of hardware alternatives as a table in which RFID and WSAN technologies are compared based on costs, reliability, life-span, responsiveness, infrastructure dependence, sensing capabilities, and scalability. Condensing the results into a few words, basic RFID tags are a cost-effective solution but without sensing capabilities (CoBIIs 2007.)

Hourglass (Shneidman et al. 2004) in turn is an Internet-based infrastructure which is able to gather data from multiple, heterogeneous sensor networks. It has been designed especially for emergency and health care situations. However, according to SENSEI (2008), this infrastructure is a distributed system but it is not yet realized. In IrisNet (Gibbons et al. 2003) the research focus has been on worldwide sensor webs which utilize both geo-support and web cameras. IrisNet has been used, for example, in parking space finding, in collecting sensor data from hundreds of sensor nodes located in five continents (IrisLog), and in coastal imaging services for monitoring phenomena such as sandbar formations etc. According to SENSEI (2008) this distributed, two-tiered framework structure is one of the first attempts to develop globally distributed sensor networks over the Internet. This framework has geo-support and XML-based data representation. On the other hand, SENSEI has reported IrisNet to not have any discovery mechanisms for application developers. That is to say, this framework does not allow sensor networks and their capabilities to be automatically discovered. In addition, IrisNet has redundant databases which have not been shared with other applications.

Kansal et al. (2007) from Microsoft Research have designed an open system architecture called SenseWeb. The main objective of this research has been on shared sensing features which are used, for example, in social webs. However, they have stated that these social webs with shared sensing features do not offer development tools for new applications. In this architecture web services have been used for improving the reuse of shared sensing information with an interoperable communication both between sensor gateways and servers, and between clients and servers. SENSEI (2008) has reported this framework to not be scalable for many applications and many sensor networks due to its centralized broker nature.

Ubiquitous Sensor Networks (ITU 2008a) is in turn a framework which is focused on smart buildings in which lights have been monitored and safe conducts established. In this research International Telecommunication Union
(ITU) has created an architecture in which schematic layers of a ubiquitous sensor
network are presented. In this architecture a service layer consists of application
areas such as logistics, health monitoring, disaster surveillance, military field etc.
In their infrastructure both mobile and fixed RFID readers and satellites together
with various sensor networks are described. In addition, ITU has listed
standardization activities related to their Ubiquitous Sensor Networks framework.
This list covers IEEE 1451 smart transducers (IEEE 2007), IEEE 802.15 Working
Group for WPAN (IEEE 2006), ZigBee Alliance (ZigBee 2008), IETF 6LoWPAN
(Kushalnagar et al. 2007), and ITU-T Study Group which all work on standards
for next generation networks (ITU 2008b). SENSEI (2008) has emphasized the
use of Sensor Mode Language (SensorML) in this Ubiquitous Sensor Networks
framework to be an especially important feature. SensorML defined by OGC is a
language that unifies the heterogeneous sensors and actuators definition (OGC
2007b). On the other hand, in SENSEI’s analysis Ubiquitous Sensor Networks
framework has made just the first step in this direction and there is a lot of work
left to be carried out in the areas of security and decentralized services. Finally,
the Wireless Urban Sensing (Srivastava et al. 2006) framework is designed for
spatiotemporal and physical contexts. According to SENSEI (2008), it’s currently
only a conceptual model and no implementations are yet available.

Summarizing the SENSEI (2008) review about state-of-the-art in sensor
network integration frameworks, a couple of requirements are emerging. First of
all interoperability is emphasized in their report. The proposed solutions for the
better interoperability in global WSAN are Service-Oriented Architectures (SOA)
including SOAP, web service, and XML-based approaches. The main reason for
the use of SOA in SENSEI’s requirements is a need for decentralized and
distributed sensor network integration frameworks. Secondly, OGC’s sensor
network integration framework, called SWE, is highlighted in the review. Also,
problems with security and mobility have been addressed. One of the promising
technologies in this area seems to be low-power wireless networks, such as IEEE
802.15.4 (IEEE 2003) supported WSAN technologies with ZigBee (ZigBee 2008)
and 6LoWPAN (Kushalnagar et al. 2007) specifications. Especially, the use of
web services in WSAN is a possible solution for achieving better interoperability
in global WSAN. One of the first commercial embedded web service solutions is
Sensinode’s NanoSOAP which allows SOAP to be used end-to-end from wireless
6LoWPAN sensor nodes to the core Internet (Sensinode 2008b).
Studies related to location platforms and geosensor networks

As in Figure 1 (Satyanarayanan 2001) is shown location information is an important part of mobile and ubiquitous computing. At the same time location information is in the centre of various distributed systems. One type of these distributed systems is called a geosensor network (GSN). Nittel et al. (2004) have defined GSN as a sensor network that monitors phenomena in geographic space. This geographic space can range in scale from confined indoor conditions to highly complex outdoor environments.

These GSNs are maybe one of the most challenging research areas in information system research (cf. SENSEI 2008, cf. Sherwood & Chien 2007). According to Zündt (2007), location platforms can be classified into device centric, decentralized middleware-based, and centralized location platforms. In this thesis the focus is on decentralized middleware-based platforms. These platforms are at the centre when a geographic space covers both indoor and outdoor environments. This research area has a lot of challenges. Indoor conditions typically need an extra infrastructure such as the use of wireless sensors for positioning. So far there are no standards for indoor positioning. In addition, as Zündt has stated, communication between sensors is not yet standardized.

Ubiquitous computing will certainly cause new challenges for development processes and indoor positioning is here a proper example. Because GPS type global standardized positioning technologies are not available for indoor conditions, existing implementations are not scalable and interoperable with each other (cf. Zündt 2007). Sometimes it is reasonable to investigate other alternative technologies. For instance, MIT’s Kidsroom reported by Bobick et al. (1999) is an example of a smart environment which uses overhead cameras and microphones for tracking kids playing in the smart environment. As a result this system has been stated to demonstrate that non-encumbering sensors can be used efficiently for the measurement and recognition of individual and group action with relatively simply perceptual routines in interactive spaces.

Gradually these platforms have been developed into real-time platforms which are able to produce spatio-temporal data autonomously or when requested. Recently, geosensor networks have been evolving into wireless, mobile, and multi-hop networks with ad hoc arrangements. The next step in this development process will be semantic interoperability. In theory, at this stage all kinds of sensor sources can be added to the network. (Schade & Walkowski 2005.)
The challenges discussed above related to the development of location platforms and geosensor networks are two research directions which still have unsolved challenges. In this thesis it is discussed about interoperability but semantics has been excluded. Major reason for that is that semantics in mobile environments is not yet well matured as a research field (Veijalainen et al. 2006). This research area covers both indoor and outdoor conditions. These conditions are challenging for technology and for interoperability. For example, the use of wireless technologies causes problems related to power consumption and security issues. The use of mobile devices and embedded systems in turn are limited by computing resources.

Another challenge related to interoperability issues has already been addressed by SENSEI (2008). Especially, the SensorML specification and the SWE suite of standards for geo-support seem to be a reasonable research direction in the development of sensor network integration frameworks. This is in line with the findings of Peng and Tsou (2003). In fact, they have setup criteria for GIS web services. They have underlined the use of web services. In fact, with web services it is possible to use interoperable, self-contained, self-describing, module components that can communicate with each other over the web service’s platform. Thus, in the definition presented by Peng and Tsou, GIS web services enable future applications to be assembled from multiple services which are networked and supported with geoprocessing and location services.

Next an overview of OGC’s SWE suite of standards (OGC 2008) is introduced together with a couple of state-of-the-art implementations. OGC has been founded in 1994 and it has members from both the industry and academia. The organization has proposed a comprehensive software framework called OpenGIS specification for distributed access to geodata and geoprocessing resources. OGC focuses on both the abstract definitions of OpenGIS frameworks and the technical-oriented implementations of data models and services (Peng and Tsou 2003).

According to OGC (2007a), their OpenGIS Interface Standard defines OpenLS Core Services, which form the Services Framework for the GeoMobility Server (GMS). These services cover Directory Service, Gateway Service, Location Utility Service, Presentation Service, and Route Service. GMS as a location services platform hosts not only these services but also Location Content Databases accessed through OGC Interfaces such as Web Map Server (WMS) and Web Feature Server (WFS). WMS produces maps of spatially referenced data dynamically from geographic information in a raster graphic format such as PNG,
GIF or JPEG, or in a vector graphic format, for example in SVG (Scalable Vector Graphics) format. Moreover, WMS generates a map when requested from spatial data stored in GML (Geographic Markup Language) format which is an XML grammar for expressing geographical features (Kangasharju & Tarkoma 2007).

For geosensor networks the main part of OGC’s work is made under SWE which is a suite of specifications related to sensors, sensor data models, and sensor web services. The goal of the SWE is to enable sensors to be accessible and controllable via the Internet (Sheth et al. 2008). The SWE consists of Observations & Measurements Schema (O&M), Sensor Model Language (SensorML), Transducer Markup Language (TML), Sensor Observations Service (SOS), Sensor Planning Service (SPS), Sensor Alert Service (SAS), and Web Notification Services (WNS). XML is a key part of this infrastructure and all the services and content models are specified in XML schemas (Botts et al. 2006.)

SWE has been successfully piloted in various academic experiments all over the world. The main actors in this research field have been OGC’s research network and The National Aeronautics and Space Administration (NASA). Chu and Buyya (2007) have demonstrated an abstract vision of the sensor web as a combination of SOA, grid computing and WSAN. They have reported a number of successfully developed and deployed sensor network applications around the world. However, they have stated these applications are not designed from an interoperability perspective. In their experiments interoperability challenges have been at the centre and they have found OGC’s SWE specifications to be useful in the development of their OSWA architecture. This architecture consists of application, service, sensor, and physical layers. Furthermore, this service oriented sensor web architecture is evaluated by applying a middleware to a simple temperature monitoring sensor application. The communication has been XML-based between the application and service layers. They have realized some performance challenges and in the future they are aiming to move the heavy workload of queries from the sensor network itself onto the host machine instead. This is a typical example which shows the challenges in the use of standardized XML-based communication methods in sensor networks.

Another example of sensor web implementations based on SWE specifications has been designed to enhance the tempo of disaster response in South Africa. A satellite-based system for regional vegetation fire detection has been evolved into a sensor web application (Terhorst et al. 2006). Also, NASA has used SWE specifications in their geosensor networks and sensor web applications. Their EO-1 sensor web architecture is currently being updated to
support an interface developed by the SWE group. This Earth Observing-1 Mission has been operating an autonomous, integrated sensor web linking dozens of sensor nodes in 24/7 operations since 2004. The use of sensor web technologies was reported to have been successful with a number of cost effective impacts in the maintenance. These sensor web technologies have been used in National Snow and Ice Data Center, and in Cascade Volcano Observatory. In the first case these technologies were applied to track both ice formation and melting and then the use of this information in EO-1 analysis. In the latter case the goal was to acquire high resolution infrared data from Mt. St. Helens. (Chien et al. 2007.)

2.4 Commercial location platforms and ubiquitous integration frameworks

Introducing state-of-the-art location platforms in industry is challenging because the Locawe platform designed in this thesis has features not only of location platforms (including map engines and GPS positioning) but also features of indoor positioning, RFID integration frameworks, and sensor network integration frameworks.

In this commercial location platform review the focus is on B2B solutions. The VTT Technical Research Centre of Finland (2007) has collected, in their report called Mobile Enterprise Market and Business Landscape, a list of wireless technology solutions from sectors of industry, transportation, construction and services. In this report a wide range of technology providers, system integrators, and end users have been included. This report also shows how wide business area wireless technology solutions are even given that the focus in this report has been on mobile business solutions. For example, Dudley (Sybase 2009) has described this business area covering telecommunication network business, cross-operator solutions, and service integrations and evolutions.

As an example of this wide business area Logica Ltd. is examined, which is an IT and business services company employing 40000 people (Logica 2009a). This company has, for example, mobile and GIS services which have been developed in cooperation with ERP manufacturers such as SAP or Microsoft’s Business Solutions (SAP 2009, Logica 2009b), and with GIS manufacturers such as ESRI (ESRI 2008). Logica has applied RFID identification in mobile ERP solutions designed for cleaners and in the container shipping industry together with ZigBee technology (Logica 2009c). They also have a wide range of services
in which map-based user interfaces are at the center of development. For example, their Merlot solution for medical care and emergency services combines positioning techniques, GIS, and wireless communications (Logica 2009d).

Logica’s example shows that the business area of location platforms is relatively large. On the other hand, this example also illustrates how big companies such as Microsoft, SAP or ESRI can be categorized in this business. That is to say Logica’s role here is to integrate software and hardware combinations as solutions which can be applied in different business areas. In many cases, ERP, together with GIS form a back-end system in which information will be provided from positioning, identification and wireless sensor network technologies.

**Location platforms**

Several commercial location platforms can be found in the market. Traditional GIS manufacturers such as ESRI and MapInfo have their mobile extensions ArcPad, and MapX. For example, ESRI’s ArcPad has been used successfully for many years in large mobile GIS applications such as in fire fighting, storm water monitoring, asset management, and health care (ESRI 2007). Also the telecommunication industry has shown their interest in location platforms. Nokia, for instance, acquired the digital-map provider Navteq in 2007 for a price of approximately €5.7 billion (Lagorce 2007). After this investment Nokia has concentrated on mobile map content such as Ovi services. Nokia has released, in September 2009, software development tools for map and navigation players as a part of Ovi. These tools offer 2D and 3D vector-based maps for service providers (Nokia 2009). Furthermore, Nokia has been active in studying mobile and ubiquitous computing architectures together with the VTT Technical Research Centre of Finland. In their studies they have envisaged how Ovi will be linked to Internet solutions and services for the users and how so-called M3 smart space fusion will combine in the physical and information worlds (Soininen & Lappeteläinen 2009). Based on Wibree, or later on Ultra low-power Bluetooth, Nokia also aims to connect mobile phones with sensors in things such as watches, wireless keyboards, gaming and sports sensors (Nokia 2007). As this technology is not yet in use, Nokia is actively seeking new innovations for combining mobile services and sensor networks such as Sensing the World with Mobile Devices (Nokia 2008). Also, companies such as Google and Microsoft have their location platforms called Google Earth and Virtual Earth. These platforms are mainly
designed for consumer markets. However, for example Google Geospatial APIs provide tools for developing mapping applications also in B2B markets (cf. Marks et al. 2009).

*Indoor positioning*

For indoor positioning there are manufacturers such as Ekahau (Ekahau 2008) and Cisco in the market, which are using WLAN communication as a key technology. On the other hand, WLAN positioning has limitations in accuracy. More precise indoor positioning can be achieved based on Ultra-Wideband (UWB) positioning. This technology is still expensive and thus has not yet achieved high popularity in the market. The first manufacturers in UWB positioning have been companies such as Parco, Multispectral and Ubisense. One of the main challenges related to these technologies is the fact that they are not globally interoperable with other positioning technologies. The above mentioned technologies are developed and used mainly because the use of GPS signals in indoor conditions is still challenging. For example, in Japan the Quasi-Zenith Satellite System (QZSS) program has developed an indoor positioning system called IMES (Indoor Messaging System). However, like other indoor positioning systems IMES also needs extra infrastructure to be installed (Dempster 2009).

In many cases accurate indoor positioning has to be solved with more than one technology. As an example of these hybrid solutions, Infineon Technologies has installed a real-time localization solution to its wafer fabrication facility in Villach. This installation included 100 controller devices and more than 1000 so-called DisTags, which were a combination of ultrasound sensors and active RFID transponders. This system provided about 3 billion measurements daily for positioning wafers cassettes with an accuracy of 30 cm (Thiesse et al. 2006).

*RFID integration frameworks*

RFID technology has already been applied successfully for years in many application areas. References can be found, for example, in ticketing, such as in the London underground (Konomi & Roussos 2007). In retail, in turn, RFID has also been used successfully especially in areas of supply chain management. However, benefits for the consumers as added value services are still in the piloting phase. As an example, RFID has been piloted successfully in smart carts (Kourouthanassis & Roussos 2003). Large-scale implementations can already be
found in logistics or in maintenance work. The port of Kaohsiung, which has been ranked in the top 6 ports in the world, has decided to start using RFID on a large scale after tests of 7 months with 10 companies and with 4200 containers (APEC 2009). According to Legner and Thiesse (2006), in Frankfurt airport RFID has been used for years in maintenance work. In the first phase all 22000 fire shutters were attached with to RFID tags. All maintenance information can now be archived automatically in digital format instead of 88000 paper documents. However the use of sensors as a complementary technology has been reported to have even bigger effects on the nature of maintenance services.

Like the examples above show, RFID as an identification technology is already a feasible technology with a wide range of manufacturers from LF, HF, UHF, and active-RFID sectors. In fact, this diversity of technologies makes the use of RFID in location platforms challenging. In the market there are already integrators who are creating middleware for improving hardware and software management with different kinds of combinations. For example, Sybase’s iAnywhere (Business Solutions 2008) has a device support for devices such as passive RFIDs, handheld RFIDs, forklift RFIDs, Active RFIDs, and RTLSs (Real-time locating systems). Respectively, Fujitsu-Siemens has created an Automatic Identification Technology (AIT) which has the same kinds of goals for creating an interoperable module for RFID APIs (Ung & Hoang 2008). Also SAP has been active in RFID related business development. They have designed the so-called Auto-ID infrastructure for RFID applications such as pick, pack and ship operations. This infrastructure has been specified mainly based on UHF RFID readers. However, WSAN technologies are also described in their vision (Kubach 2005). Up to now SAP has had a wide range of references as to how RFID has been applied in large-scale applications in chain management, manufacturing, asset management and maintenance, and environmental health and safety (Botero 2008). On the other hand, another ERP manufacturer, Oracle, has stayed away from RFID middleware (Baudin & Rao 2005).

**WSAN integration frameworks**

WSAN can also be used for indoor positioning. However, this has not yet achieved success in the market. On the other hand, these networks were originally developed for sensor monitoring. Thus, the first priority is and will be in this area. In the future these networks are also a promising alternative for the above mentioned indoor positioning technologies. WSAN are becoming more
widespread in industry. For example, Intel Research (IrisNet), and Microsoft Research (SenseWeb) have been active in research areas of sensor network integration frameworks. In addition, NASA (EO-1) has been working closely with the SWE standardization group. Especially the interoperability and standardization activities are ongoing processes which are currently hindering the business.

Intel has also been active in trying to combine the benefits of RFID and WSAN technologies by specifying the so-called WISP (Wireless Identification and Sensing Platform), which is a battery-free platform for sensing and computation. WISP tags are powered and read by standard-compliant UHF RFID readers (Yeager et al. 2008). Cisco, in turn, has focused (in cooperation with Dust Networks) on applying WSAN technologies in the HART (Highway Addressable Remote Transducer) communication protocol in control system networks. So far, according to Cisco Systems (2007), more than 1000 wireless sensor network nodes can already operate in the same radio space.

2.5 Using digital maps in mobile devices

Location-aware systems combine geographic information and telecommunication solutions. Traditionally, in geography analyses related to spatial databases are executed with special GIS software which is developed for desktop computers with powerful computing resources. Nowadays instead of desktop computers a part of these analyses are executed in the field in more challenging conditions with mobile devices and with limited computing resources (Jagoe 2003).

Criteria for map-based user interfaces

As a starting point for a discussion about criteria for map-based UIs, spatial data is said to be critical in emergency systems like those presented in the final report of the Coordination Group on Access to Location Information for Emergency Services (CGALIES 2002). This project funded by the European Union has provided requirements related to emergency services for GIS and spatial data. CGALIES has also recommended the use of vector graphics mainly based on usability issues. According to CGALIES, the used spatial databases in emergency services shall be accurate up to 10 meters. Furthermore, GIS has to support a number of standard global and also local coordinate formats. In addition, Brenner and Sester (2005) have stated spatial data to be essential information in location-
based services and in car navigation. In order to enable spatial data visualization for the user in different scales, the system has to be designed with features for zooming in and out. This is possible if spatial data is available in different levels of detail.

Map-based applications are regularly a part of location-aware services. In order to illustrate for the user information related to the current location it is natural to use a user interface with a map. The GiMoDig project (Nissen et al. 2003), in turn, has defined recommendations for developing services with map-based UIs. In their preconditions an application with a map-based UI should at least include functionalities for zooming and panning. Furthermore, this kind of UI should also cover information about the users, waypoints and destinations. They also recommend the use of SVG format for generating digital maps because it is a specification developed for general graphic presentation based on GML and they are expecting SVG to be supported by all major vendors on the market.

Lehto (2002) has predicted that mobile devices will be able to process vector images based on GML and SVG specifications. However, he has doubted that these maps will be transformed into a form of raster images when using vector maps in mobile devices with sparse resources. The current trend in standardized mobile map architectures seems to be in the use of GML-based data encoding (cf. Botts et al. 2006) and SVG-supported web browsers (cf. Mikkonen & Taivalsaari 2008, cf. Yan-tao & Jiang-guo 2008). The main benefits of the use of these standardized mobile map architectures can be found in the maintainability and scalability of these web information systems.

Due to the popularity of car navigation, the behaviour of map-based UIs in mobile roadmaps has been researched intensively during the last years. For instance, Bennett et al. (2006) have implemented a location-aware system which has been designed for supporting egocentric rotation of the map. Using their system, the users can physically point at objects and automatically look at them on the digital map in relation to where they are. Pointing is implemented in this study with a magnetic compass and an accelerometer. The magnetic compass and accelerometer in location-aware systems have been studied also in Baus et al. (2002) and in Arhippainen et al. (2005). Hornbæk et al. (2002) have in turn found their subjects to prefer a zoomable map system with an overview because it supported navigation and helped keep track of their position on the map. On the other hand, display size creates challenges with these kinds of enhancements in mobile devices.
Using spatial data with sparse resources

One of the research tools for using digital maps in mobile devices with sparse resources is map generalization. Butz et al. (2001) have studied incremental transmission of vector graphics. In their implementation floor plans have been generated for the UI in several steps. In addition, in their algorithm of incremental transmission, for example a route depicted as an arrow, is shown in the beginning. This has been followed by the longest lines, and finally all more detailed information of the floor plan has been also shown. This kind of technique is beneficial especially in low-rate networks. As a result information can rapidly be visualized in these circumstances for the user. Thus, the user can perceive his or her location on a map which will be generated with more details incrementally. In incremental transmission it is reasonable to store spatial data in layers in a database. For instance, less detailed layers could contain a major road network with main streets and roads, and more detailed layers a minor road network. Furthermore, it is possible to design a location-aware service so that a downloading process with incremental transmission can be interrupted whenever the map has sufficient details for the user. (Bertolotto & Egenhofer 2001.)

There are circumstances where incremental transmission does not work properly. For example, filtering small streets and roads out of a presentation does not improve the efficiency of map rendering with limited computing resources in mobile devices. In this case filtered information can be generalized far more efficiently by rendering beforehand. Bard and Mustière (2001) have defined a map generalization process as a simplified way to present a geographic space, according to the scale and objectives of the map to be realized. This goal can be achieved by deleting less important and emphasizing more important information. Traditionally, this has been handwork but nowadays researchers are automating this process. Bard and Mustière have underlined that the map generalization is a highly complex process to automate, but it can significantly reduce both time and cost of production.

One of the most efficient map generalization algorithms is called the Douglas-Peucker algorithm (Mustafa et al. 2001, Douglas & Peucker 1973). Chong and Su (2008) have compared their own map generalization algorithm to this classical polygonal simplification algorithm. The results in this relatively new study still show that the Douglas-Peucker algorithm is an efficient generalization method which can be used as a part of larger generalization processes with better results. In any case, when comparing the results with the rendering times, it has to
be noted that the Douglas-Peucker algorithm was reported by Chong and Su to still be almost twenty times faster.

**Map-based user interface studies**

Reichenbacher (2003) has found adaptive map rendering to be an answer for the requirements discussed above related to map-based UIs. Users are mobile and demand immediately available services. Thus functionalities both in map-based UIs and in location-aware services have to be nimble and easy to use for supporting the user’s decision making.

![Figure 2. Process of adaptive map rendering (Reichenbacher 2001).](image)

Figure 2 presents the process of adaptive map rendering suggested by Reichenbacher (2001). According to this research, the use of spatial data and digital maps offers new possibilities for visualization such as adaptability, user focus, dynamism, and context awareness. Furthermore, in adaptive map rendering the digital map is adapted to a specific user with a current context. In consequence, different visualizations can be generated for different users in exactly the same location. Therefore, for the same user map visualization can be changed according to changes in contexts. Principally, the context-aware systems use context to provide relevant information and services to the user where relevancy is dependent on the current tasks (Dey 2001).

Adaptive maps are an example of the needs for dynamically generated maps based on spatial databases. Above, the research focus was on an efficient use of spatial data. Another aspect in adaptability is location or context sensitivity. This can be achieved with ubiquitous computing. In the next chapters it will be shown
how these techniques related to map-based UIs are applied with ubiquitous computing.

2.6 Summary for literature review

A couple of aspects are clearly emerging in location-aware system development. First of all, computer scientists have worked intensively with interoperability and standardization issues. As a result, software developers have tools for achieving better interoperability with SOA including SOAP, web service, and XML-based approaches. However, XML-based communication is still a challenge in low-rate networks. Therefore, more research work is needed for improving interoperability in networks such as WSAN and GSN. The SWE suite of standards designed by OGC is a promising solution but it still has challenges related to low-rate communication. In fact, OGC has made the first steps in this direction with their BXML best practices specification.

Another essential aspect for this thesis is the lack of location-aware platforms. Researchers in this field have worked toward improving digital map rendering in mobile devices. The specifications such as SVG and GML are examples of successful research results. These tools are solutions for interoperable location-based services. However, they are not designed for the efficient use of ubiquitous computing. That is to say, location-aware services demand client side software which has APIs available for localizing, identifying, and sensing objects nearby the device. Moreover, this kind of client side software is a solution for better usability with an efficient map rendering together with numerous services provided by servers. Thus the research area as a combination of map-based user interfaces and ubiquitous computing seems to be worth studying.

The third aspect to be noted as an important research topic for this thesis is location-awareness covering both indoor and outdoor conditions. Currently many kinds of indoor positioning technologies are available such as WLAN or ZigBee/6LoWPAN positioning. These technologies are useful for many application areas in which the criteria for accuracy is not in centimeters but rather in meters. In addition, better accuracy can be achieved, for example, based on more expensive UWB positioning technology. On the other hand, the main challenge to indoor positioning is a lack of global standards. Therefore, location-aware platforms with features for indoor positioning are not yet interoperable with each other. Typically, the ideal indoor positioning can be achieved by combining different kinds of ubiquitous technologies.
A research direction which is a combination of standardized and decentralized location-aware system development with interfaces to other location-aware systems seems to be promising. For instance, Cuff et al. (2008) have stated that the widespread use of mobile devices, availability of GIS-related technologies, growth of Web 2.0 together with advances in sensor technologies have unleashed so-called urban sensing. They believe that in 15 years mobile devices can be used for detecting other aspects of the environment such as pollution. On the other hand, these technologies, with certain limitations, are already available for creating the first pilots. In the next chapters, the author presents the research results achieved in evaluating and developing the Locawe platform. In this thesis, the research focus has been on studying a decentralized location-aware solution which has been widely tested in several field experiments and industrial pilots. The research has covered considerations related to issues such as interoperability, usability, cost-effectiveness, and the technological development of WSAN with mobile devices.

Table 2. Related research.

<table>
<thead>
<tr>
<th>Location platforms</th>
<th>Indoor positioning</th>
<th>RFID</th>
<th>WSAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bennett et al. (2006)</td>
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<tr>
<td>Hornbæk et al. (2002)</td>
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<tr>
<td>Reichenbacher (2003)</td>
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<tr>
<td>Isomursu et al. (2005)</td>
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<tr>
<td>Zündt (2007)</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Nielsen &amp; Goodrich (2006)</td>
<td>X</td>
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<tr>
<td>Frank et al. (2008)</td>
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<tr>
<td>Thiesse (2006)</td>
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<td>X</td>
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<tr>
<td>Alisto (2003)</td>
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<td>Riekki et al. (2006)</td>
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<tr>
<td>Korhonen et al. (2006)</td>
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<tr>
<td>Chu &amp; Buyya (2007)</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>Chien et al. (2007)</td>
<td>X</td>
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<tr>
<td>Arhippainen et al. (2005)</td>
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<tr>
<td>Baus et al. (2002)</td>
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<tr>
<td>Kulyukin &amp; Gharpure (2006)</td>
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<td>Rogers et al. (2005)</td>
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<td>Bruce (2003)</td>
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<tr>
<td>Botts et al. (2006)</td>
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</table>
As a summary, it is positive that the scientific community has clearly identified the main challenges. Standardization organizations are actively seeking solutions for interoperable communication even in complex GSN. On the other hand, based on the literature review, the lack of location platforms seems to be evident (Table 2 above and Table 3 below). That is to say, location platforms are not yet reliable or interoperable, which are basic requirements for location-aware services. Moreover, location platforms are not yet able to manage our daily routine tasks in assisting in decision making and information sharing or handle dynamically combined location information from multiple sources (cf. Tsalgaditou et al. 2003, Patterson et al. 2003, Cook & Das 2007). The standardization process is unfinished in indoor positioning, and in WSAN communication. In addition, location-aware systems still have unsolved challenges in user interface design. Thus, it can be argued that a research on a location-aware system platform for different kinds of conditions is relevant.

### Table 3. State-of-the-art related to this thesis.

<table>
<thead>
<tr>
<th>Location platforms</th>
<th>Indoor positioning</th>
<th>RFID integr. frameworks</th>
<th>WSAN integr. frameworks</th>
<th>ERP</th>
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<tbody>
<tr>
<td>ESRI</td>
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<td>Mapinfo</td>
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<td>Ubisense</td>
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<td>Infineon Tech's</td>
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<tr>
<td>Sybase</td>
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<tr>
<td>Fujitsu-Siemens</td>
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<td>SAP</td>
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<td>Intel</td>
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<tr>
<td>Cisco</td>
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</tbody>
</table>

In addition, as Table 2 and Table 3 show, an appropriate platform for developing location-aware services does not yet exist. That is to say, a platform which is able to support software development activities related to mobile and ubiquitous computing, related to servers with interoperable and standardized communication methods, and related to various combinations of hardware for creating an additional infrastructure in the environment itself especially in the case of indoor conditions.
3 Research methods

For developing location-aware services a wide range of technologies is available. In consequence, the use of mobile and ubiquitous computing can cause problems with usability issues. That is to say, applying these technologies is challenging in a UI design. Cook and Das (2007) have stated that desktop metaphor that is generally employed for computer applications to be inappropriate for services in smart environments. This is caused by software development tools which are designed for computer applications and not for new kinds of devices and usage contexts.

In this research the above mentioned challenges have been addressed by using a research approach which has been constructive and in which new further developed features in the Locawe platform have been evaluated in field experiments with quantitative research methods from usability, visualization, and communication techniques perspectives. In this chapter the research questions are presented in the beginning. These questions are followed by a short literature review about the research methods applied in this research. After this review the used research approach is introduced.

3.1 Research questions

This research has been a mixture of architecture design, human-computer interaction with field experiments, and industrial pilots with considerations of adaptability to various conditions including indoor and outdoor environments. The Locawe platform has been evaluated from a practical applicability perspective for numerous applications, and just recently from an accessibility perspective for sensor data.

Thus, the main research question in this thesis can be formulated as: What are the main characteristics needed in order to develop adaptable location-aware platforms for varying conditions? This main question can be divided in the following sub-questions: 1. What kind of architecture enables location-aware system development both in indoor and outdoor conditions? 2. What are the bottlenecks that can be found in the design of location-aware system platforms? As a result of working as a development manager for CENTRIA an additional research question became evident, namely: What kind of research approach can cover both technological development and user needs?
The answer to the main research question will be found from several test-generate cycles which have lasted for years. The research approach used, including test-generate cycles, will be presented in this chapter. These test-generate cycles have consisted of several field experiments and industrial pilots. Based on gathered information the answer will consist of the main characteristics needed for a successful location-aware system development.

The answers to the first sub-question will be presented in details in Article VII. Furthermore, the phases of architectural design and evaluation during the research of the last 2 to 3 years will be described in Chapter 4 and Chapter 5. In addition, reasons for the answers to sub-questions will be analyzed in Chapter 7 based on the literature review and related research presented in Chapter 2.

### 3.2 Challenges in information system research

As a starting point for a discussion about challenges in IS research a comparison of differences between disciplines is presented. Basili (1996) has contrasted software engineering to physics. Similar differences described below can be found also in information system research. These relatively new research areas differ from physics in many ways. For instance, researchers cannot rely solely on observation followed by logical thought as in physics. However, experimental research is an essential part of research activities in both of the disciplines and the research objectives are the same. Computer scientists are experimenting with new phenomena to understand functionalities, limitations and possibilities for improvements. One of the differences between physics and computer sciences is in their characteristics. In fact, a lack of native theory is a basic challenge in computer sciences (DeGrace & Stahl 1990). Another difference is related to research objects. Unlike in physics, in computer sciences most of the research questions are related to human-computer interaction. In consequence, the same experiment can provide different results depending on the people involved (Basili 1996).

It has to be highlighted that software systems are among the most complex things ever created and the use of empirical methods, especially when cooperating with the industry, is essential (Sjöberg et al. 2007). However, in computer sciences empirical studies have not had the same success as in other sciences. Perry et al. (2000) have found a lot of articles in which it is reported that the biggest barriers to using empirical studies lie in the details of conducting them.
Basili et al. (1999) in turn have stated experimentations to be complex and time-consuming.

### 3.3 Constructive research approaches

This research field can be defined as one of the applied sciences. Järvinen (2004) has defined basic research as a research which is to find out what is a part of reality. In turn, applied research is applying the knowledge of the basic research. A part of applied research can be called constructive research. Hevner et al. (2004) have distinguished a difference between system building efforts and constructive research. The latter focuses on system building but combined with the underlying formalism concerning research evaluation, contributions, and rigor.

One society which has strong traditions in constructive research and in applied sciences is Japanese society. Evaluating their success as one of the leading high technology societies, efficient use of the technology transfer between academia and the industry has to be highlighted. In innovative systems the technology transfer with all three factors, namely research, development and practice, has important roles. In fact, in Japanese society new technology innovations are emphasized and they have mechanisms to provide prototypes from academia to industrial pilots. In consequence, constructive research with prototypes has not only academic significance but also importance in the execution of the technology transfer (cf. Glass 1991.)

The Department of Defense (1987) has published recommendations for software development. For example the 23rd recommendation advised the iterative setting of specifications, the rapid prototyping of specified systems, and incremental development. Glass (1991) has interpreted these recommendations and as a result argued prototyping to be beneficial especially in massive software systems. The use of prototyping has decreased the risks related to business opportunities according to his findings. At the same time the efficiency of setting up the requirement specifications has increased. Furthermore, better interaction between users and designers has also been reported to have been more active when using prototyping instead of waterfall models. Another aspect of the use of prototyping is cost-effectiveness. For example, DeGrace and Stahl (1990) have noticed prototyping to be a cost-effective method in the case of massive software systems. This is in line with findings reported by Boehm and Basili (2001).

Prototyping and agile methods have many common factors. In fact, agile methods usually emphasize involving the product users in the prototyping, and
encourage a rapid user-to-developer feedback cycle (Song et al. 2005). In this thesis, users have been at the center of the research. However, principles of agile methods have not been applied.

Prototyping has been reported to have positive impacts on functionalities in software systems. Both Boehm et al. (1984) and Alavi (1984) have found prototyping to have better results compared to waterfall models in the following areas. Users commented software systems to be more usable, and their reports to be more accurate and useful. From the software development perspective the constructed software systems were reported to be simpler and the software development processes to be less time-consuming. It is not clear if good products will emerge from good prototypes (Glass 1991). Nunamaker and Chen (1990) have given the aircraft design area as an example of successful prototyping. In fact, the Wright brothers built the first airplane before the aerodynamics field was created. Nowadays the situation is contrary; the aircraft industry uses Computer-Aided Design and Computer-Aided Manufacturing (CAD and CAM) tools for designing next generation airplanes.

As in aircraft design, systems development and empirical research methodologies are also complementary to each other. A pattern of this kind of research progress can be formulated as follows. In the first phase the prototype system is built. This phase will be followed by the development of theories and principles based on observing behavior. Finally, the next innovations can be created more sophisticatedly by encoding expertise in software tools for easy access (Nunamaker & Chen 1990.)

3.4 Research approach in this thesis

The research approach has many characteristics which can be found from the information system research framework presented by Hevner et al. (2004). In general, this framework (Figure 3) has been formulated to inform IS researchers and practitioners on how to conduct, evaluate, and present constructive research.
Fig. 3. IS research framework (Hevner et al. 2004).

This framework has been published with seven guidelines for constructive research. This chapter focuses on the centre part of this framework and on those seven guidelines. IS research is described in this framework as in the middle of the business environment and the research knowledge base. Influences on the environment and the achieved results as additions to the knowledge base will be reported later in the conclusions.

Hevner et al. (2004) have presented guidelines for constructive research containing guidance for artifact designs, problem relevance, design evaluations, research contributions, research rigor, search process designs, and research communication. Next is a description of how these principles are applied in this thesis (Figure 4).
The challenges related to information system research and ubiquitous computing described earlier in this chapter have been a motivation for this research. Moreover, the research as a combination of challenges related to ubiquitous systems and prototyping seems to be reasonable. Finally, as a result from the literature review, the information system research framework with seven guidelines presented by Hevner et al. (2004) emerged to be a suitable background for the research approach used in this thesis.

To underline the close cooperation with the industry, the description of the used research approach, the research objectives, and the motivation for this
research are presented. First of all, the research objectives have been gathered from the field. That is to say, the author together with his research group has worked for years in close cooperation with the industry. Therefore, the research objectives have changed over time based on necessity and technological development. In these discussions the technological development has been described with demonstrations for the industrial partners. Some of these discussions have led to research projects in which industrial pilots have been developed. These development activities describe the business needs in the IS research framework introduced above.

These discussions have also had another role in this research process. In fact, some of the discussions have not led to research projects but they have had an important impact on the field experiments conducted. Thus the selected research objectives have been relevant based on frequent communication with industrial partners. Both field experiments and industrial pilots have been a test-generate cycle. In many cases the search for the optimal design is often intractable and the optimal design can be found from several test-generate cycles (Hevner et al. 2004). As a note, in this thesis the test-generate cycles have an additional meaning to those presented by Simon (1996) or Hevner et al. (2004). In fact, the test-generate cycles have followed each other in this research over the years. Instead of generating new alternatives from the original research object, the research objects have also been changed between the cycles. Therefore, in one cycle new features developed in the Locawe platform have been evaluated with field experiments and industrial pilots. The cycle was followed by a new test-generate cycle with newly developed and evaluated features.

The data gathered from the experiments has been analyzed with appropriate metrics. These metrics, mostly quantitative, have been used for evaluating the new features from a usability, visualization or communication techniques perspectives. Parametric methods have been analyzed with ANOVAs and paired t-tests. Non-parametric methods in turn have been analyzed with Friedman’s rank tests and Wilcoxon’s matched pairs signed ranks tests. As already mentioned, the field experiments and industrial pilots have followed each other over many years. These evaluations together with industrial pilots have been an iterative and incremental design process in which essential feedback has been gathered and analyzed for the next construction phases. In the construction phase it has been essential to find solutions which are in one way important for the industry and in another way globally standardized. Thus, as a result of various test-generate cycles, the Locawe architecture has been designed in a manner in which both
academic and industrial considerations have been taken into account. These test-generate cycles have also been used in designing the Locawe platform.

Between these test-generate cycles the results have been presented at scientific conferences and industrial seminars. For an academic audience the results have been reported in detail for enabling a repeated construction of test procedure. In addition, for an industrial audience the results have been reported with sufficient details for evaluating gained extra profitability in production etc.

The results of these cycles are discussed next in detail in Chapter 4 and Chapter 5. These test-generate cycles have been used for seeking alternative solutions with different kinds of requirements.
4  Development of Locawe platform

In this chapter the research phases related to the development of the Locawe platform are described. The research process covered three consecutive research phases which are presented below in Figure 5. A source for the further development of the Locawe platform has already been discovered in the first research phase. On the other hand, the research focus has been on conceptualization of the location-aware system platform just in the second research phase.

![Fig. 5. Three consecutive research phases related to the development and evaluation of Locawe platform](image)

### Preliminary Studies (2004-2005)
- Location-Aware Pilots:
  - Mobile Service for Fire Inspectors
  - Tracking Units in Fire Operation
- WSN Pilot:
  - Direct Seeding Machine

### Phase 1: Map Engine with Ubiquitous Features (2006-2008)
- Releasing the First Version of CENTRIA’s Map Engine:
  - Field Experiments (Articles I, V)
  - Industrial Pilots
- RFID and WSN-Related Studies:
  - Field Experiments (Articles II, III, IV, VI)
  - Industrial Pilots

### Phase 2: Locawe Platform (2008- )
- Locawe Architecture:
  - Conceptualization of Locawe Platform (Article VII)
  - Use of Global Standards
- Embedded Software Development:
  - Integration of RFID and WSN Devices
  - Global Standards in WSN (Article VIII)

4.1  Preliminary studies

First of all, the preliminary studies cover the author’s Master’s Thesis on presenting vector-based maps in mobile devices (Luimula 2005). During this phase in 2004–2005 the first prototype version of the map engine was developed together with the first industrial pilots. The prototype version of the map engine was presented in the Master’s Thesis. This prototype was able to generate a digital map from a street register and position the user on the map based on GPS.
In addition, the research covered map generalization methods. The street register that was used contained only polylines and these objects were generated from local data storage in a location-aware prototype. This prototype contained basic zooming and panning tools together with GPS positioning provided by a Bluetooth receiver. The main focus of this research was on efficient rendering related to the digital map in a mobile device. One of the main results in this thesis was the use of the Douglas Peucker algorithm. This algorithm has been designed for real-time map generalization in PC environments. As a result this algorithm was later used in CENTRIA’s location-aware pilots for generalizing complicated objects such as polygons (for example water areas) beforehand for improving the map rendering process in mobile devices.

The preliminary studies also contained the first expertise about industrial pilots (Figure 6). The know-how achieved related to the use of spatial databases together with GPS positioning in mobile devices with sparse resources and the use of efficient map generalization methods led CENTRIA Mobile research group to cooperation with a local fire department (Jokilaaksojen pelastuslaitos) and with a software company called M-Technology Ltd. In this pilot the main challenge was the use of spatial data encompassing twenty-one municipalities. In fact, the
most critical factor for the successful implementation was the use of homogeneous spatial databases. Thus, the spatial data used contained Finnish topographic maps (Maastotietokanta) from the National Land Survey of Finland, and a part of the Finnish Resident register related to buildings and apartments (Rakennus- ja huoneistorekisteri) from the Finnish Population Register Centre. The goal of this pilot was to implement a mobile location-aware service for fire inspectors. The author’s role here was to lead the development activities related to the location-aware module and to work in close cooperation with M-Technology. In this pilot the results from the previous studies were used successfully and a source for the further development of the CENTRIA Map Engine was produced. At the same time the author was involved with his research group in another development case. In fact, the fire department was also interested in the state-of-the-art technology for tracking units in fire operations. For this test the research group implemented, in cooperation with Tracker Ltd., a prototype in which units were tracked in outdoor conditions with GPS positioning and Finnish topographic maps. For the further research the main achievement of this prototype was the use of floor plans when arriving at a fire operation area. This was implemented by using vector graphic data in the form of AutoCAD DXF (Drawing Interchange Format of Autodesk Inc). Thus, for the further development of the map engine indoor support was now available as well. After these experiments the knowledge gained about location-aware services was used in the development of the first version of the mobile learning platform. In fact, this platform was used later in several field experiments and has been a foundation for the development of the Locawe platform.

In this phase CENTRIA’s wireless sensor technologies researchers were involved in a development case concerning control systems for direct seeding drills. This implementation is also essential to note because the pilot was the first location-aware pilot related to WSAN technologies in CENTRIA. Thus it was a significant pilot and these results were later applied in the development of the Locawe platform. The results concerning this WSAN pilot have been published in Tervonen et al. (2006).

4.2 The first research phase

During the first research phase, from 2006 to 2008, the CENTRIA Map Engine was designed and the first prototypes, which applied ubiquitous computing, were developed. In those years the CENTRIA mobile research group together with
Oulu Southern Institute published several articles in international conferences and journals. The majority of the articles were written from an HCI perspective in which new features were evaluated with quantitative research methods. These results have been an important input for the further development of both the map engine and the Locawe platform. From a constructive research perspective this has been a long-term test-generate process which is still continuing intensively.

In the beginning, the development processes concentrated on the design of the map engine. The goal was to design the engine as software components which could be used in the following prototypes and pilots efficiently. Version 1.0 was designed in 2007 and the pilots later implemented were utilized by using these components. The pilots included e.g. a maintenance service of telephone poles for the telecommunications operator Pohjanmaan PPO Ltd., a mobile learning platform for students (Haapala et al. 2007), a location-aware hiking service for elderly people in Peuran Polku hiking trail, and a contractor service pilot for tractor operators in cooperation with Suontieto Ltd. The author led the development of the new features related to the map engine. Thus, the planned and designed features have been constantly tested and generated by the CENTRIA mobile research group according to the author’s management.

Fig. 7. The first version of the Locawe architecture

The research has lasted years and has contained various test-generate cycles (see Chapter 3). The first evaluated feature in this test-generate process was the automatic rotation and zooming feature in mobile roadmaps based on the use of spatial data together with GPS information including location, direction and speed information (Article I). In this phase of development only the prototype version of
the map engine, GPS positioning, and tracking data were introduced in the architecture (Figure 7).

This feature was followed by a suite of selection techniques which were namely physical selection using RFID technology, automatic selection based on GPS coordinates, selection from a mobile map with a stylus, and a textual selection technique involving a virtual keyboard and a selection list (Articles II and III). This was the first time in which ubiquitous computing was applied to the map engine. Thus, this can be considered to be a source for the further development of the Locawe platform. Like the first feature, these selection techniques were also evaluated in field experiments (Article III). For the further development, both of these experiments gave the researchers valuable quantitative information, especially about how usable the implemented features were. An updated version including RFID identification of the Locawe architecture was introduced in this phase (Figure 8).

**Fig. 8. The second version of the Locawe architecture**

In all, this research phase covered six field experiments and several industrial pilots (presented in Figure 9). In Figures 9 and 11, the test-generate cycles, which were related to the evaluation of the map engine with new features are described. The third field experiment was a parallel learning evaluation in which the Locawe platform was gaining a form and was extended with location-aware communicational techniques such as route tracking, chat messaging, photo transmission, information points, and a drawing tool (Article IV). The application area utilized as selected from the field of education. Although these results are
valid in education the results can also be applied in the industry in the future. Based on the previous pilots with the industry, such as the mobile solution for fire inspectors, location-aware communication is an important part of working routines. So based on the results, together with the expertise gained from the industrial pilots, the tested communicational techniques can be applied, for example, in maintenance work in the future. The next field experiment, explained later in this chapter, concentrated on indoor conditions.

The fourth field experiment, in which the map engine was evaluated, was route visualization for mobile devices. The central part of the Locawe platform, namely the map engine, was extended with a new visualization technique with three route history parameters: speed, direction, and location (Article V).
As previously mentioned version 1.0 of the map engine was already designed in 2007. This component was attached to the Locawe architecture together with features needed especially in the parallel learning experiment. The results of these additions are presented above in Figure 10.

In the meantime, the author, together with his research group, was also involved with Pohjanmaan PPO Ltd. in the development of three dimensional (3-D) maps in the Ylivieska region. This company owns the 3-D spatial data which was designed by Fontus Ltd. In cooperation with these companies the author led a development process for a 3-D map engine for CENTRIA. As a result, the CENTRIA mobile research group implemented the first version of the 3-D map engine which was used later in the next field experiment. The fifth field experiment evaluated methods developed for 3-D mobile roadmaps which adjust the map view automatically based on the speed of a vehicle. These results are published in a conference paper (Partala et al. 2009) and in a Master’s thesis (Flink 2008).

The first research phase was not only covered the development of location-aware technologies but also technologies related to RFID and WSAN. This part of the research phase is described in more detail next (Figure 11).
The author was working for CENTRIA as a development manager during the period 2006–2008. The author’s role as a development manager was not only working in the area of location-aware system development but also in ubiquitous computing related studies. Moreover, as a project manager of several research projects in which the research focus was in the area of ubiquitous computing, the author had possibilities to enlarge the Locawe platform development to cover both indoor and outdoor conditions. As described above, the first expertise with RFID technology in which the map engine was combined with RFID technology were already achieved. But then, ubiquitous technologies were tested on a larger scale in the fourth field experiment. To prepare for the upcoming fourth field experiment the author and his research group, together with the CENTRIA digital manufacturing research group, designed a prototype in which expertise from robotics, wireless telecommunication technologies, ubiquitous computing, and geographic information systems were applied. In the beginning, additional components of ubiquitous technologies such as RFID reader with antennas, ZigBee nodes, and active RFID tags were attached to a mobile robot (Evolution...
Robotics ER-1) (Luimula et al. 2007b). Furthermore, the architecture developed in the previous projects (Sallinen et al. 2006) was applied in the development of the mobile robot’s remote control system. The test-generate cycle in this stage covered new experimental techniques which were implemented in the Locawe platform. The techniques evaluated displayed for the user the position of the robot on an indoor floor plan augmented with 1) a video view from a camera attached to the robot, 2) a display of nearby obstacles (identified using RFID technology) on the floor plan, and 3) both features (Article VI and Luimula et al. 2007a).

During the period 2007 and 2008, CENTRIA mobile research group invested a lot in ubiquitous computing. The invested RFID technology covered adapters for mobile devices, handheld readers, UHF and active RFID readers for longer range reading. Another part of this investment was in WSAN technologies which were also under intense development during those years. The pilots were made in the beginning based on ZigBee (ZigBee 2004) specifications and later based on 6LoWPAN (Kushalnagar et al. 2007) specifications by the CENTRIA test system development research group in close cooperation with the Oulu Southern Institute. Both of these WSAN technologies are specified based on IEEE 802.15.4 standard (IEEE 2006).

As a result of investigating suitable RFID readers and WSAN solutions in laboratory conditions initially, the author, as a project manager, led several industrial pilots related to ubiquitous computing in 2007 and 2008 (Luimula et al. 2009, Pieskä et al. 2009, Tervonen et al. 2009, Pieskä et al. 2007, Tervonen et al. 2006). Industrial pilots where RFID technology was in the main role covered, for example, installations in a wheel loader (E.T. Listat Ltd.) and in a forklift truck (J. Kärkkäinen Ltd.). These examples show that the results achieved in the remote control of mobile robot can be applied as a part of industrial pilots (Figure 9). The research group recognized a lot of demand in the industry for tracking or tracing moving objects such as vehicles in storage areas both in indoor and outdoor conditions. In outdoor conditions, for example, a wheel loader can localize pallets based on GPS positioning and can individualize them based on RFID identification. In addition, this information can be visualized for the user in map-based UI.
On the other hand, in indoor conditions the challenges are more complicated and different kinds of wireless technologies have to be tested and combined to achieve a convenient solution. If the environment contains wireless technologies such as WLAN, a suitable indoor positioning technology can be WLAN positioning (cf. Ekahau 2008). However, it has to be noted that the remote control of a mobile robot was not initially possible based on either WLAN or ZigBee positioning. Thus, this indoor positioning technology can be used only in pilots where accuracy is not a critical factor. That is to say WLAN positioning can be applied if the requirements for the positioning are not in centimeters but rather in meters.

One of the most promising technologies for better accuracy seems to be UWB positioning technology. On the other hand, this technology also has challenges related to reflections from metal surfaces and the line-of-sight criteria (Schwarz et al. 2005). As a result of our remote controlling experiments one alternative for relatively expensive UWB positioning can also be considered to be RFID-based positioning. RFID tags can be attached to the floor as in our experiments or to the roof in the same manner. The results show (Articles VI) that the achieved accuracy was about 15 centimeters when the tags were attached to the floor and the floor antenna was attached under the robot at a distance of about 5 centimeters from the floor.

As already mentioned, indoor positioning within centimeters is a challenge. However, WLAN and ZigBee positioning with modest accuracy has been recognized to be feasible in many application areas. The author has been a project manager in a couple of pilots in which the achieved accuracy was reported to be convenient for these conditions. Both WLAN (Ekahau 2008) and ZigBee (Chipcon 2006) positioning have been tested in Pyhäsalmi mine (Inmet Mining)
and in a cowhouse (Haapajärvi vocational school). In both cases the accuracy was around 5–8 meters and satisfied the criteria in these circumstances.

As a conclusion, the field experiments have given valuable information for the industrial pilots and vice versa. The examples discussed above have in many cases consisted of a map-based UI together with critical information about the tracked objects or local environment. The maps used in indoor conditions or in factory areas have not been generated from national spatial databases. Rather, spatial data has been replaced with floor plans or factory areas in DXF format. In this case positioning has been relative.

### 4.3 The second research phase

As already mentioned at the beginning of this chapter a source for the further development of the Locawe platform has already been discovered in the first research phase. However, just in the second research phase has the research focus been on conceptualization of the location-aware system platform.

![Fig. 13. The final version of the Locawe architecture.](image)

The field experiments and the industrial pilots shown in Figures 9 and 11 have been in this process iterative test-generate cycles. These various academic and
industrial test cases have given the author valuable information covering both users’ needs and alternative software and hardware solutions. As a result of this conceptualization process the author has constructed the Locawe architecture presented in Article VII in which remote monitoring, indoor positioning, and WSAN related in-situ measurements have also been taken into account (Figure 13 above).

Software architecture, in turn, is described in Figure 14 above. In this thesis, IEEE 1471 standard (2000) has been adopted. In this standard, architecture is defined as “the fundamental organization of a system embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution”. Because this development has been made in several test-generate cycles software components have evolved from the first field experiments. All the software components have been programmed with C++. However, the software development tools have been varied from eMbedded
Visual C++ 4.0 (eVC) to Visual Studio 2008 (VS2008) and to Borland C++ Builder 6.0. The recent versions of Locawe client and server applications have been developed in VS2008.

The central facility in the creation of new location-aware services is the map engine component. This component handles spatial data management and renders maps. The use of the Locawe map engine has been reported in Article VII. The core service component of Locawe client applications, in turn, is responsible of information processes between sensors and servers. The features of Locawe client applications related to field experiments, such as rotations and zooming of the map engine, selection and communicational techniques, route visualizations, and displaying of positioning and movements, have been reported in Articles I-VI. Evaluation of ubiquitous technologies has required the use of APIs such as RFID, positioning, WSAN, and robot APIs from the core service component. In the experiments related to spatial standards in low-rate networks, mobile device has also been used as a server for requesting sensor information from 6LoWPAN nodes.

Also map generator in the server side is another central facility in the creation of new location-aware services. This component can be used or adjust for different kind of data structures. In addition, it has features for optimizing maps. Research focus has mostly been in mobile client side in the field experiments (Articles I-VI) because of research questions related to usability and visualization of mobile map-based UIs. However, in Articles IV and VI the client-server architecture has been at the center of research. In these experiments, data transmission between clients and server has been made with HTTP communication over ASP services and Internet Sockets. The first one has been used for communication between users and mobile robot, positioning robot, obstacle identification, photo transmission, chat messaging. Positioning users, route tracking, information points, and drawing, in turn, has been implemented based on HTTP communication over ASP. In Article VI, the video information was transmitted over Skype communication. Web services have only been used in industrial pilots. Protocol stacks used in the Locawe architecture have been presented in Appendix 1.
The main focus of the further development of the Locawe platform is currently on WSAN solutions and global standards (Figure 15). WSAN solutions are at this stage of the development the area from which it has been reasonable to gather more research results. The use of WSAN in mobile devices is still uncommon. On the other hand, the use of WSAN in the Locawe platform is one of the main objectives in this research phase. Because of this contradiction, embedded software development has become a part of the Locawe platform development activities. In fact, the use of WSAN together with mobile devices is now possible. In this development the CENTRIA test system development research group has had a key role. In the first place this objective was achieved with a Bluetooth node. This node as a Bluetooth gateway extended the use of mobile devices as a part of WSAN in the Locawe platform. As a result, Locawe now supports data gathering directly from wireless sensors to mobile devices (Article VIII, Luimula et al 2010, Jämsä et al. 2009). Recently, CENTRIA has also managed to integrate 6LoWPAN and RFID radios in a Kitwrx 456 handheld device (Sensinode 2008a).

Due to the challenges related to WSAN supported mobile devices, WSAN technologies have not yet been tested in field experiments. The WSAN pilots
already implemented have concentrated on positioning or on ad hoc measurements. Further development is needed both in automatic and remote sensing. That is to say using WSAN both automatically and in situ with mobile devices are research areas worth studying. The latter, especially, will be at the centre of the further development of the Locawe platform. In fact, in recent studies the author has focused on these challenges (cf. Luimula et al. 2010, Jämsä et al. 2009).

Concerning these studies, the use of OGC’s SWE standards (OGC 2008) in particular seems to be suitable for the creation of standardized GSN (Article VIII). This research direction as a combination of GSN and embedded software development in which different radio transmitters such as 6LoWPAN, GPRS, and RFID will be integrated in one Printed Circuit Board (PCB) seems to be promising. Concerning future progress, for example, innovative use of Field Programmable Gate Array (FPGA) together with 6LoWPAN and RFID would mean that miniaturized objects in a smart environment could enable autonomous decision-making (cf. Roy et al. 2006).
5 Evaluation of Locawe architecture

This chapter covers evaluation of the Locawe architecture and the Locawe platform. Before reporting outputs of this architectural evaluation an overview for the evaluation process is introduced (Figure 16). In this process methods presented by Clements et al. (2008), and Barbacci et al. (2003) related to hybrid evaluation techniques of software architectures have been applied. In addition, these hybrid techniques are related to the IS research framework presented by Hevner et al. (2004).

Fig. 16. An architectural evaluation process used in this thesis.

In the first place, it has to be noted that the evaluation process used here has not included formal workshops as the evaluation methods presented by Clements et al. (2008) did, but instead has used discussions with end users. In this research the objectives have not been particularly about quality attributes, but rather they are based on new characteristics of the Locawe architecture. Evaluation discussions have typically generated new ideas which have led both to architectural design and development activities. Developed pilots have been analyzed based on new implemented characteristics. That is to say, architecture has been validated by implementing new characteristics and analyzed based on relevant quality attributes for successful experiments. Functionality visible to users has been evaluated from the usability perspective. Based on evaluations, the Locawe
architecture has been updated several times. These updates have been used next in the following field experiments and industrial pilots with end users.

5.1 Evaluating characteristics of the Locawe architecture

In Chapter 4 evolution of the Locawe architecture was presented. In this chapter it was shown how this architecture has evolved from map engine design and from GPS positioning to an architecture which consists of a wide range of ubiquitous computing characteristics, and in which mobility has been taken into account from different perspectives.

The Locawe architecture has been evaluated based on Figure 16 presented above. New characteristics have been implemented based on information gathered from literature and from end users. These characteristics have been developed and evaluated from the human-computer interaction perspective. On the other hand, in human-computer interaction evaluations, such as in usability evaluations, the research focus is largely on functions of the user interface.

In this evaluation the focus is on new characteristics designed for the Locawe architecture. These new characteristics have included research challenges in areas of ubiquitous computing and mobility. In these evaluations, ubiquitous computing has consisted of positioning, identification, sensing, and communication technologies. Mobility, in turn, has involved research areas such as map-based UIs, mobile devices, and infrastructure.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS positioning</td>
<td>I, II, III, IV, V, VIII</td>
</tr>
<tr>
<td>Indoor positioning</td>
<td>VI</td>
</tr>
<tr>
<td>RFID</td>
<td>II, III, VI</td>
</tr>
<tr>
<td>WSAN</td>
<td>VI, VIII</td>
</tr>
<tr>
<td>Communication</td>
<td>IV, VI, VIII</td>
</tr>
<tr>
<td>Map engine</td>
<td>I, II, III, IV, V, VI</td>
</tr>
<tr>
<td>Mobile devices</td>
<td>I, II, III, IV, V, VI, VIII</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>VI, VIII</td>
</tr>
</tbody>
</table>

In Table 4 above, the characteristics of ubiquitous computing and mobility used in the original articles has been introduced. This table shows how GPS positioning, indoor positioning, RFID identification, WSAN, communication, map engine, mobile devices and infrastructure have been used successfully in field experiments.
reported in those original articles. In these field experiments mobile devices have been mainly PDAs but also, for example, laptops in mobile robots, and TabletPCs. Infrastructure, in turn, has consisted of WLAN base stations, ZigBee/6LoWPAN nodes, and RFID readers and tags.

In addition, the use of these characteristics in industrial pilots has been reported in many industry-oriented conference papers (Luimula et al. 2009, Pieskä et al. 2009, Tervonen et al. 2009, Pieskä et al. 2007, Tervonen et al. 2006). Some of characteristics, such as the use of mobile devices with geosensor network nodes and the use of 3D graphics, have recently been reported in conference papers (Luimula et al. 2010, Jämsä et al. 2009, Partala et al. 2009).

During the development and evaluation of the Locawe architecture, a couple of serious restrictions have become evident. Especially interoperability, usability, and application contexts have been discovered to be the main challenges when designing location-aware services. Usability has been at the center of research in Articles I-VI. In Article VIII, in turn, the Locawe architecture has been evaluated from an interoperability perspective. As a result the Locawe architecture has been designed based on the OGC’s standards. However, interoperability is still a challenge in the case of indoor positioning because of a lack of global standards. Especially in industrial pilots but to some extent in field experiments the application context has also been one of the evaluated characteristics of the designed architecture. In fact, one of the main reasons for the experiment of the remote monitoring of the mobile robot was a motivation to expand the use of the Locawe architecture to indoor application contexts. In industrial pilots the application context has varied from the metal industry to mines, from agriculture to warehouse management, and from fire department to maintenance work (Luimula et al. 2009, Pieskä et al. 2009, Tervonen et al. 2009, Pieskä et al. 2007, Tervonen et al. 2006). These pilots have given the author a better understanding about how mobile and ubiquitous computing can be arranged with various software and hardware combinations in the Locawe architecture. In addition, these pilots have not only forced suitable mobile devices with RFID readers, and GPS receivers to be sought out, but have also demanded compromise in which the key priorities have had to be in robustness (Figure 17), and in usability, and in which other features such as RFID readers, WLAN or GPRS communication, and operating systems have therefore been more or less important features.
5.2 Evaluating quality attributes of the Locawe architecture

The main focus in this thesis has been on evaluating characteristics of the Locawe architecture. However, like Figure 16 above showed this process has also included evaluations related to some quality attributes, usability and interoperability have been evaluated many times. Changes in usability have been reported in detail in Articles I-VI. Interoperability, in turn, has been at the center of the research, especially in Article VIII.

Other quality attributes, namely performance, reliability, adaptability, portability, and functionality, have been evaluated by achieving a satisfying level for the purposes of experiments. The research and development prototypes have been evaluated, and not products. Although some components, such as the map engine, have actually evolved to a stability and performance level comparable to that of products, no exact metrics have been used for measuring, for example, performance. On the other hand, performance or efficiency as quality attributes have links to the function of the user interface and also to other areas of the evaluated system (cf. Nielsen 1993). Furthermore, reliability also has links both in user interface and system design (cf. Katasanov 2006, Tsalgatidou et al. 2003).

Performance and reliability of the Locawe architecture have been measured in several field experiments (Articles I-VI, Partala et al. 2009) and industrial pilots (Luimula et al. 2009, Pieskä et al. 2009, Tervonen et al. 2009, Pieskä et al. 2007, Tervonen et al. 2007). These evaluations have given information, for
example, about how efficient and how reliable GPS positioning and RFID identification have been when implemented. Information has been gathered not only in the form of interviews but also as log files. Industrial pilots, in turn, with long-term testing periods, have provided information about performance and reliability criteria in industrial environments. In this case back-end systems and limitations of harsh environments have also to be taken into account.

Because it has been possible to repeatedly expand the architecture with new characteristics, the Locawe architecture has been shown to be adaptable. Adaptability has also been evaluated based on implementations. For example, the latest new characteristics, namely a satisfying implementation of a 3D map engine (Partala et al. 2009) and an interoperable WSAN implementation (Luimula et al. 2010), show that the Locawe architecture is adaptable for new characteristics.

Functionality as a quality attribute also has links to usability. In the original articles (Articles I-VI) mainly just functionalities of the user interface have been evaluated, such as rotations and zooming of the map engine, selection and communicational techniques, route visualizations, and displaying of positioning and movements. On the other hand, these functionalities also give output information about how new software and hardware components have worked. In addition, new functionalities have also been evaluated based on information gathered from log files and based on long-term testing periods in industry.

As a summary, evaluation of the Locawe architecture has been carried out for research and development prototypes not for products. Therefore, the objectives have been to achieve a satisfying level which is relevant for successful experiments.

5.3 Comparison to the state-of-the-art platforms

In the state-of-the-art review in Chapter 2 location platforms, indoor positioning, RFID integration frameworks, and WSAN integration frameworks were found to be central issues. Many types of location platform already exist in the market and some of these already support ubiquitous computing. However, as shown in the review in Chapter 2 (especially Table 3), this business area is relatively wide in which both technology providers and system integrators are needed to satisfy end users’ needs. None of the technology providers or the system integrators currently has solutions, which could cover all the features listed in Figure 18 below. The Locawe as a decentralized middleware platform is not designed to compete with
car navigation systems, GIS software, or ERP systems. A summary of this comparison to state-of-the-art platforms is also illustrated in Figure 18.

Fig. 18. A comparison to state-of-the-art platforms.

With respect of state-of-the-art platforms, the Locawe platform is, at the moment, in some sense unique, although only as a research prototype (Articles I-VI). First of all, the literature review showed that research on location platforms has been extensive during the last few years. On the other hand, these studies have rarely focused on challenges of geosensor networks or smart environments. The Locawe platform combines these two approaches.

Secondly, the importance of combining the two approaches can be found from the visions presented by the companies reviewed earlier in Chapter 2. For example, Nokia is planning to combine Ovi services together with the M3 platform (cf. Article VII) and Nokia has envisioned using sensors with mobile devices (Nokia 2008, Nokia 2007, Soininen & Lappeteläinen 2009).

Thirdly, these are still visions and do not give concrete answers as to how RFID or WSAN technologies could be integrated under one framework. The literature review showed that a couple of RFID integration frameworks already exist in the market. However, these integration frameworks have mainly been designed for industrial environments with challenges of indoor conditions.
(BusinessSolutions 2008, Ung & Hoang 2008, Botero 2008). So it is understandable that map-based UIs have not been at the center of these frameworks. It is more likely that these frameworks will move towards WSAN field. In the Locawe platform, one concrete answer has been given to the integration problem (Articles VII-VIII).

Fourthly, in the literature review in Chapter 2, it showed the success of ubiquitous computing where there is an evident need to integrate mobile devices and WSAN. This far, WSAN are typically used for remote monitoring, although increasing capabilities of mobile devices would make in-situ measurements possible and useful. The Locawe platform is also a concrete solution for this integration problem (Article VIII, Luimula et al. 2010, Jämsä et al. 2009).

From a business point of view it is perhaps useful to show the difference between large-scale applications and the needs of small or medium-sized companies. For example, system integrators such as Logica are already using RFID and WSAN technologies, at least on some level. Logica, together with technology providers and GIS companies, can create a combination which can produce support for wide range of ubiquitous technologies with map-based user interfaces. As a consequence, these companies will provide services only for large-scale applications. On the other hand, the Locawe platform has another focus. It has been designed in a manner which is cost-effective and which can also be used in small or medium-sized companies. Another business aspect is that WSAN as a technology is not yet feasible enough for critical solutions: Cisco’s and Smart Networks’ examples show that the technology is promising but not yet applied in many use cases. A review of OGC’s SWE shows that geosensor networks are still in the phase in which first business models have been designed globally. Therefore, the Locawe platform appears to have features which are not yet to be found in commercial markets.
6  Summary of the original articles

In this chapter an overview is presented of the results of this dissertation and the original articles. Table 5 summarizes these contributions and results which form the basis of this dissertation.

Table 5. Summary of contributions and results in this thesis.

<table>
<thead>
<tr>
<th>Research phase</th>
<th>Description of the research phases, results, and significance to industrial pilots</th>
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<tbody>
<tr>
<td>Preliminary studies</td>
<td>The studies contribute to the understanding of an efficient use of spatial data in mobile devices with sparse resources</td>
</tr>
<tr>
<td></td>
<td>First prototypes of the map engine</td>
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<tr>
<td></td>
<td>An efficient use of spatial data and GPS positioning in mobile devices</td>
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<td></td>
<td>Algorithms both for zooming, panning, and rotating digital maps, and for map generalization</td>
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<tr>
<td>Phase 1</td>
<td>Map engine with ubiquitous features</td>
</tr>
<tr>
<td>Contributions of the studies:</td>
<td>The studies contribute to the knowledge of location-aware services evaluation and to the understanding of location-aware platform design</td>
</tr>
<tr>
<td>Results</td>
<td>Automatic rotation and zooming can enhance navigation</td>
</tr>
<tr>
<td>Article I</td>
<td>Map engine was extended with new visualization techniques</td>
</tr>
<tr>
<td></td>
<td>These evaluated features are valid for the further development of map engine and for industrial use</td>
</tr>
<tr>
<td></td>
<td>These results have been used for example in m-learning services</td>
</tr>
<tr>
<td>Articles II and III</td>
<td>Location selection techniques were tested in real mobile applications and all four implemented techniques were evaluated as highly usable</td>
</tr>
<tr>
<td></td>
<td>Ubiquitous computing was applied for the first time with map engine</td>
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<td></td>
<td>The idea for Locawe platform was born</td>
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<td></td>
<td>These evaluated features are valid for the further development of Locawe platform and for industrial use</td>
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<td></td>
<td>RFID identification with mobile devices was applied for example in maintenance, and in animal identification</td>
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<tr>
<td>Article IV</td>
<td>Location-based communication techniques supported the students’ interaction and learning well, and these techniques were highly usable</td>
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<td>Locawe platform was extended with location-aware communicational techniques</td>
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<td>These evaluated features are valid for the further development of Locawe platform and for industrial use</td>
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<td>Communicational techniques are an essential part of mobile maintenance services</td>
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<tr>
<td>Research phase</td>
<td>Description of the research phases, results, and significance to industrial pilots</td>
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<tr>
<td>Article V</td>
<td>Route history visualization is an improvement over currently used visualizations</td>
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<td>Map engine was extended with a route visualization technique</td>
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<td>These evaluated features are valid for the further development of the map engine</td>
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<td>and for industrial use</td>
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<td></td>
<td>Route visualization has been used in a hiking service for elderly people</td>
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<tr>
<td>Article VI</td>
<td>Techniques for displaying information about the position and movements of a</td>
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<td>remote robot were successful</td>
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<td>Ubiquitous technologies were tested on a larger scale</td>
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<td>Locawe platform development was enlarged to cover both indoor and outdoor</td>
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<td>These evaluated features are valid for the further development of Locawe</td>
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<td>platform and for industrial use</td>
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<td></td>
<td>RFID identification and positioning technologies together with a map-based user</td>
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<td>interface have been tested for example with a wheel loader</td>
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In the following sections each paper is introduced with the addressed research problems, descriptions, and results. The articles are introduced in this chapter in logical order (see Table 4). Their relationship to the research phases are presented in Chapter 4.

6.1 **Article I: “Automatic rotation and zooming in mobile roadmaps”**

Research problem, description, and results

The aim of this research was to explore the navigational effects of two common features in current mobile roadmap systems: automatic rotation based on the vehicle’s direction of movement and speed dependent automatic zooming. This study covered a field experiment in which 12 subjects tried four different visualization techniques for a mobile map in real traffic. The visualization techniques were 1) no rotation/constant zooming, 2) no rotation/automatic zooming, 3) automatic rotation/constant zooming, and 4) automatic rotation/automatic zooming. The subjects rated the techniques on four scales: position knowledge support, direction knowledge support, identification of real-world objects based on map objects and an overall score. The results showed that conditions involving automatic rotation and/or zooming got systematically more positive ratings on all scales than the conditions without those features. The implementation of automatic zooming created for this experiment was rated as very close to optimal. These results suggest that both automatic rotation and automatic zooming can enhance navigation when implemented to a mobile roadmap.

6.2 Article II: “Techniques for location selection on a mobile device”


Research problem, description, and results

In this research the objectives were the implementation of techniques for selecting one’s current location in mobile location-aware systems. CENTRIA’s location-aware system platform called Locawe is presented with four alternative location selection techniques. These techniques covered 1) physical selection using RFID technology, 2) automatic selection based on GPS coordinates, 3) selection from a mobile map with a stylus, and 4) a textual selection technique involving a virtual keyboard and a selection list. As a result these techniques have been tested in real mobile applications.
6.3 Article III: “A field comparison of techniques for location selection on a mobile device”


Research problem, description, and results

This article presents the results of a field comparison of techniques for selecting one’s current location in mobile location-based systems. Four location selection techniques implemented in CENTRIA’s Locawe platform are described, which are 1) physical selection using RFID technology, 2) automatic selection based on GPS coordinates, 3) selection from a mobile map with a stylus, and 4) a textual selection technique involving a virtual keyboard and a selection list. These techniques were compared in a field experiment with 12 test subjects. The results showed that all four implemented techniques were evaluated as highly usable. Physical selection with RFID and selection from a mobile map with a stylus were the preferred location selection techniques by the test users.

6.4 Article IV: “Location-based communication techniques in parallel learning between the classroom and the field”


Research problem, description, and results

The aim of this research was to study parallel collaborative learning between students in the classroom using a desktop computer and students in the field using a mobile device. The experimental setup was built on CENTRIA’s Locawe platform with new location-aware communication techniques features including route tracking, chat messaging, photo transmission, information points, and a drawing tool. The experimental system was evaluated by 12 students, who participated both in the classroom and in the field. The students rated the
communication support, learning support, and usability of the developed techniques. The results showed that the techniques supported the students’ interaction and learning well, and were highly usable. The results also suggest that the students’ theoretical knowledge provided by classroom teaching can be extended by facilitating practical understanding with parallel learning using mobile communications. The results also suggest that the current approach is a fruitful combination of many contemporary learning paradigms such as collaborative learning, situated learning, and problem-based learning.

6.5 Article V: “LocaweRoute: an advanced route history visualization for mobile devices”


Research problem, description, and results

In this article, the research problem was in visualizing route histories on a mobile device. The solution combined the visualization of three route history parameters and was built on the CENTRIA Map Engine. The route history parameters in this LocaweRoute software were 1) speed, 2) direction, and 3) location. The visualization was tested in a laboratory evaluation with 12 subjects. The results showed that by using the visualization the subjects were able to estimate actual driving speeds accurately. The subjects also evaluated that the visualization supported their knowledge of the speed, location, and direction quite well. The results suggest that the presented visualization is an improvement over currently used route history visualizations.

6.6 Article VI: “Remote navigation of a mobile robot in a RFID-augmented environment”

Research problem, description, and results

This article addresses the problem of constructing RFID-augmented environments for mobile robots and the issues related to creating UIs for efficient remote navigation with a mobile robot in such environments. First, the article describes a RFID-based positioning and obstacle identification solution based on CENTRIA's Locawe platform for remotely controlled mobile robots in indoor environments. In the robot system an architecture specifically developed by the authors for remotely controlled robotic systems was tested in practice. Second, using this system, three techniques were compared for displaying information about the position and movements of a remote robot to the user. The experimental visualization techniques displayed the position of the robot on an indoor floor plan augmented with 1) a video view from a camera attached to the robot, 2) a display of nearby obstacles (identified using RFID technology) on the floor plan, and 3) both features. In the experiment the test subjects controlled the mobile robot through predetermined routes as quickly as possible avoiding collisions. The results suggest that the developed RFID-based environment and the remote control system can be used for efficient control of mobile robots. The results from the comparison of the visualization techniques showed that the technique without a camera view was the fastest, and number of steering motions made was smallest using this technique, but it also had the highest need for physical human interventions. The technique with both additional features was subjectively preferred by the users. The similarities and differences between the current results and those found in the literature are discussed.

6.7 Article VII: “Locawe: A novel platform for location-aware multimedia services”


Research problem, description, and results

This article presents a suggestion for a next generation mobile GIS architecture. The proposed architecture enables the use of GIS data in mobile devices and in handling information received from local sensors. The architecture has been used
to design CENTRIA’s Locawe platform, which has been tested in several field experiments. This platform has been used in various industrial pilots and prototypes which have proven that the Locawe platform can be used efficiently in developing location-aware services for both outdoor as well as indoor environments.

6.8 Article VIII: “Developing geosensor network support for Locawe platform - application of standards in low-rate communication context”


Research problem, description, and results

Wireless sensor and actuator networks (WSAN) are a combination of embedded, wireless and positioning technologies. Existing geospatial standards used in location-aware systems can be applied in building these networks, but they present challenges due to the characters of the geosensor networks. In this paper, we present a study of geospatial standards related to a location-aware system platform for improving its interoperability. The location-aware system platform used here is Locawe. Locawe has been developed in CENTRIA and tested with wireless sensor and actuator network technologies in various industrial pilots including precision agriculture. This paper includes an experimental part, where we focus on geospatial standards in WSAN. In this field, geospatial standards are still under specification. Our first results show that geospatial standards can be applied also in WSAN, with certain limitations. These limitations are mainly related to low-rate data transmission and limited computing resources. We also propose further directions in standardization, which would be needed for geosensor networks and wireless applications for machines and systems.

6.9 About joint publications

This introductory part of the thesis was written solely by the author. In Articles II, III, VI, VII, and VIII the author was the principal author. Articles I, IV, and V
were written together with other authors in close cooperation. The author has
given the main contribution in the research planning for the new features to be
implemented from technological perspective. In practice, he has been a project
manager in various research projects and has led all development activities related
to the map engine and the Locawe platform. Furthermore, he has designed the
Locawe architecture based on the information gathered from several field
experiments and numerous industrial pilots.

Table 6. Original articles and contribution of the author

<table>
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<tr>
<th>Contribution of the author</th>
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<tr>
<td>Writing the article as a principal author</td>
<td>II, III, VI, VII, VIII</td>
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<tr>
<td>Writing the article as one of the co-authors</td>
<td>I, IV, V</td>
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<td>Leading the research plans related to the new features of the map engine and/or Locawe platform</td>
<td>I, II, III, IV, V, VI</td>
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<tr>
<td>Participating in the research plans related to the new HCI and/or visualization techniques</td>
<td>II, III, VI</td>
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<tr>
<td>Leading the development of the map engine and/or Locawe platform</td>
<td>I, II, III, IV, V, VI</td>
</tr>
<tr>
<td>Designing Locawe architecture</td>
<td>VI, VII</td>
</tr>
<tr>
<td>Coordinating the development of WSAN as a part of Locawe platform</td>
<td>VIII</td>
</tr>
<tr>
<td>Designing the use of OGC and BXML in Locawe</td>
<td>VIII</td>
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The author has also been involved in WSAN related development activities. Under his coordination a pilot has been implemented in which mobile devices have been able to be used as part of WSAN. In these software and hardware development activities, expertise has been needed both from his mobile research group but also from another research group (test system development research group). From an information system research perspective the research objectives related to the use of WSAN have been related to interoperability issues. Therefore, the author has also designed an interoperability test in which the Locawe platform was used with OGC’s specifications. In Table 6, above, presents the original articles and the contribution of the author.

Next, the co-authors’ role in relation to the articles is described shortly. The major collaborator in this research has been Dr. Timo Partala. All field experiments have been made in his usability research group. That is to say, Dr. Partala has been responsible for all field experiments about HCI research plans with rigorous research methods. Under his guidance and involvement usability researchers Mrs. Kirsti Sääskilahti, Mrs. Outi Sippola, and Mrs. Taina Lehtimäki
have executed field experiments, analyzed and reported the results. Mr. Sakari Pieskä has in turn been responsible for technical arrangements related to the ER-1 mobile robot system. Furthermore, Professor Kari Kuutti, Dr. Jouni Markkula, and Dr. Jouni Tervonen have written and commented on articles as well as Mr. Zach Shelby and Mr. Petteri Weckström. In addition, Mr. Ossi Saukko, Mr. Pertti Verronen, Mr. Juha Alaspää, and Mr. Juha Yli-Hemmininki have been involved in these studies and articles with numerous software development activities based on the author’s plans.
7 Conclusions

In this chapter the achievements and the significance and validity of the results achieved in this research are discussed. The results achieved in this thesis have been compared to the state-of-the-art research in Chapter 5. The chapter is closed by considering the unsolved challenges.

In this thesis the author has attempted to find out through constructive research approaches what software components are needed in the development of location-aware services. This development process has been evaluated in various test-generate cycles. In these evaluations the author has considered what software and hardware alternatives are feasible and appropriate for improving the newly developed features in the Locawe platform. These features have been evaluated from usability, visualization and communication techniques perspective. In other words, in this research the author has attempted to describe the big picture of location-aware services development (cf. Basili 1996).

These development and evaluation activities have been executed based on Hevner’s et al. (2004) information research framework and seven guidelines. The research phases described in this thesis have taken place in the RFMedia Laboratory which is a collaborative laboratory established with two research organizations. The objectives for the researchers in the RFMedia Laboratory are in observation, in implementations, and in analysis of wireless applications for machines and systems in close cooperation with the industry. Thus, the objectives of the research activities at RFMedia Laboratory are in line with Basili’s (1996) descriptions of industry-based laboratories. The research work in this laboratory is a combination of development and evaluation research activities related to information systems. In this research the research questions are typically related to the improvement of productivity and profitability. The role of the author in this process has been to coordinate and design the development and evaluation activities related to location-aware services.

7.1 Achievements

In order to evaluate the achievements in this thesis the research questions need to be reconsidered. The main question has been formulated as: What are the main characteristics needed in order to develop adaptable location-aware platforms for varying conditions?
The answer to the main research question has been sought for years in several test-generate cycles. The answer is presented in Figure 19 and is explained in the following.

![Diagram of Main characteristics in location-aware system development]

Fig. 19. The answer to the main research question.

This thesis covered six field experiments in which newly developed features related to the map engine, to the Locawe architecture and to the Locawe platform have been evaluated. A portion of these newly developed and evaluated features are only plugged into the map engine. In these experiments the constructive research problems have been in the use of spatial data and in the development of map-based UIs. Another portion of these developed and evaluated features are more linked to the development of the Locawe platform. In this case the constructive research problems have been in the areas of architectural design, positioning, identification, sensing, and communication. In addition, these new features have also been tested in various industrial pilots.

As already mentioned location-aware system development can be seen as one of the most complex man-made creation (cf. DeMarco & Lister 1990). These complex systems generally consist of four components which are originally presented as components of smart environments (Cook & Das 2007). These components, namely physical, communication, information, and decision layers are also needed in the context of geosensor networks. In this research the physical layer consists of numerous hardware alternatives ranging from mobile devices to
RFID readers and 6LoWPAN nodes. In the communication layer communication technologies such as GPRS, Wideband Code Division Multiple Access (W-CDMA), Bluetooth, WLAN, and ZigBee / 6LoWPAN have been used. The information layer in turn covered spatial databases such as topographic maps, street registers, factory areas, and floor plans together with application-specific non-spatial databases. Due to the challenges in the use of WSAN technologies, the decision layer as the top most layer has not yet been the topic of intense research. So far the main algorithms in this layer have been related to positioning, identifying, and sensing actions. Thus, the constructed WSAN infrastructure has been used mainly for sensor and not for actuator purposes. On the other hand, for example, the control system of the direct seeding drill is an example of implementations in which actuators have also played a key role.

Location-aware systems are typically used with mobile devices. In this thesis the development of the map engine has played an essential role. Based on the literature review, map-based UIs seem to have a key role in next generation mobile services. In addition, these services will cover both indoor and outdoor conditions. One of the main challenges in this progress will be how the challenges related to a combination of indoor and outdoor use can be solved. Based on the results and literature review of this research challenge can be overcome with ubiquitous computing. However, the results also show that currently the main challenges are in interoperability issues because no global standards are available.

Therefore the designers have to be aware of the alternatives and the limitations. There is a need for location and context-aware services with positioning, identification, sensing, and communication features which are typically implemented with a wide range of radios. In fact, all these technologies already exist but they are not included in a compact package. That is to say APIs related to different types of ubiquitous technologies are not yet available even though a wide range of technologies based on standards already exist. Thus, knowledge about the available standardized hardware, middleware, and software solutions play an important role in the design phase of location-aware systems.

In this thesis the use of a location-aware system platform called Locawe designed for indoor and outdoor conditions is studied. As a result of these studies the author has gained an understanding of the appropriate hardware, middleware, and software solutions together with several bottlenecks especially in the use of WSAN technologies. Therefore, the main research question of this thesis was divided in questions: 1. What kind of architecture enables location-aware system
development both in indoor and outdoor conditions? 2. What are the bottlenecks that can be found in the design of location-aware system platforms?

The answers to the first question have been reported in detail in Chapter 4, in Chapter 5, and in Article VII with the description of the Locawe architecture. Summarizing briefly, the answers to this question have been sought both from field experiments and from industrial pilots based on the evaluation process presented in Figure 16. The use of spatial data can be solved as a combination of both traditional spatial databases such as topographical databases and floor plans which can be converted into DXF format. In addition, hybrid positioning methods are needed for covering the requirements of both indoor and outdoor positioning. Indoor positioning can be taken into account in the design phase with an extra infrastructure. The design phase covers considerations of how to apply different kinds of ubiquitous technologies to achieve the most suitable solution both in an economical and technological manner. Within certain requirements ubiquitous technologies are more reasonable to attach to the environment than mobile devices.

The answers to the second question have been reported in detail in Article VIII. In Chapter 2 Leonhardt’s (1998) argument about the lack of platform or infrastructure for building location-aware systems was presented. Based on the literature review and the results in this research Leonhardt’s argument is still valid, at least if location-aware services are cover both indoor and outdoor conditions. An appropriate platform for developing location-aware services should give support for software developments related to mobile and ubiquitous computing, related to servers with interoperable and standardized communication methods, and related to various combinations of hardware for creating an additional infrastructure in the environment itself especially in the case of indoor conditions.

During this research another research question became evident, namely: What kind of research approach can cover both technological development and user needs? This research has not only been a learning process for the author about the appropriate research approach but also for CENTRIA. The author suggests that the research approach presented in Chapter 3 can be applied in similar kinds of research organizations as CENTRIA. That is to say, research organizations which are working closely for regional development. The research approach used is beneficial to the research organization itself. As a result the organization is able to develop its excellence in regional development. The academic research activities with field experiments in turn will give the research organization tools for publicity, respect and cooperation possibilities on an international level.
7.2 Significance

Before considering the significance of this thesis the motivations and the reasons for this study should be addressed again. The author has found the lack of location-aware platforms to still be a reality. The main reasons for this are mainly related to the challenges in standardization activities in WSAN and in indoor positioning. Also, the challenges in UI design are addressed to be a relevant research area.

Another aspect when considering the significance is the progress achieved in this thesis. The research objectives were challenging. Geosensor networks are a complex and time-consuming research area with a lot of unsolved challenges. On the other hand, the author suggests that this research has given new information about location-aware system development from a progressive point of view. In the first place, the Locawe architecture designed for indoor and outdoor conditions has got input from various field experiments and industrial pilots. As an output the Locawe platform has been conceptualized with a focus on interoperability issues. The research results did not provide one ideal solution for location-aware system development. On the contrary, the results show that the developed and evaluated platform can be used in various conditions with several different kinds of hardware combinations. In addition, the research has lasted several years and the results achieved from the field experiments have already been applied in the industry. The latest field experiments and articles also prove that this platform can be modified with substitutive new technologies.

Furthermore, this research has been worthwhile as a learning process. In fact, a new research approach has been introduced. This process has given the author, the research organization, and also the research network new information about how to apply ubiquitous computing in location-aware system development.

7.3 Validity

In this thesis a constructive research approach was used. Hypotheses in the field experiments have been evaluated with quantitative research methods. In these analyses statistical differences between experimented alternatives have been found. These field experiments have provided the author with important information, especially about the validity and reliability of the new features as well as applicability for indoor and outdoor conditions. The results achieved in
the industrial pilots in turn have confirmed the applicability of the new features developed and evaluated in the field experiments.

The results have been gained from various test-generate cycles. As an exception to the original test-generate cycles reported in Simon (1996) the tested features have not been the same between the cycles. Thus the used research methods have not been strictly formulated based on Hevner’s et al. (2004) IS research framework. In addition, in the evaluation process of the Locawe architecture, hybrid evaluation techniques have been applied. The evaluation process in this thesis has not included workshops but discussions with end users. Thus the process used here has not been strictly formulated based on evaluation techniques presented by Clements et al. (2008) and Barbacci et al. (2004).

However, the significance and relevance of this research can be evaluated based on the IS framework presented by Hevner et al. (2004). The author, as a project manager, has got a lot of valuable information from discussions with various industrial partners. As the industrial pilots presented in this thesis show, this research has had relevance for the environment (cf. Hevner et al. 2004). Furthermore, a number of these pilots have already evolved to software products such as the mobile fire inspector solution (M-Technology 2008). The research rigour, in turn, in this research can be evaluated based on the additions to the knowledge base in this research field. Concerning the knowledge base, the main additions can be found from the interface between information system research and geoinformatics. In addition, it can be argued that this research has contributed to human-computer interaction research, to ubiquitous architecture design, and to interoperable communication in geosensor networks. The research approach used is also in the line with Basili and Rombach’s (1988) improvement-oriented TAME software process model in which the characterization of current environment, setting goals, executing constructions, analyzing experiments, and packaging the gathered experiences in models and forms are at the centre of the research activities.

### 7.4 Unsolved challenges

The author has focused on the development and evaluation of the Locawe platform in this research. Locawe as a location-aware system platform is neither ready for use in global geosensor networks nor for the use in widely interoperable smart environments. These are objectives with a lot of unsolved challenges. Moreover, these challenges can be solved only with standardized solutions.
Unfortunately, these standards do not yet cover the WSAN part of geosensor networks. As one of the results in Article VIII the further development towards standardized communication in low-rate networks is currently going on with academic and industrial partners. With this cooperation the use of SWE specifications will be realized.

Another area of unsolved challenges is the use of test-generate cycles in WSAN research. Currently the main problems in this research field are related to the limitations of mobile devices which support WSAN. As already mentioned, CENTRIA has been active in this research field and a couple of WSAN supported solutions are now available for upcoming field experiments. The use of WSAN supported mobile devices will open new perspectives for the use of the Locawe architecture. The first experiences have shown promising opportunities to apply WSAN locally. This will open possibilities, for example, to execute GIS analyses directly in the field instead of using remotely measured sensor data with traditional desktop computers.

The main findings in this research are in architectural design, in the identification of a need for more standardizations related to the use of WSAN, and in interoperability issues. The Locawe architecture design is possible to use in both indoor and outdoor conditions with different kinds of hardware combinations. On the other hand, for indoor use additional infrastructure is needed and a wide range of technologies for additional infrastructures already exists. The challenges lie currently in the design and evaluation of the most suitable hardware, middleware and software combinations. In consequence, the design of location-aware systems for indoor and outdoor conditions is a mixture of different kinds of ubiquitous technologies. Efficient use of these technologies as a part of location-aware systems will rely on standards which are needed especially for interoperable communication. A lack of standards is currently a bottleneck in the development of wireless applications for machines and systems. This is resulted by the use of embedded wireless applications for machines and systems.

7.5 Limitations

In this thesis the author has used the constructive research approach introduced in Chapter 3 to evaluate the Locawe platform developed in various test-generate cycles and hybrid techniques introduced in Chapter 5 to evaluate the Locawe architecture. The author has led the development of this platform in CENTRIA Research and Development, Ylivieska. While working for CENTRIA the author
has met some limitations concerning the objectives related to this thesis. The research has been conducted in several research projects in which many kinds of organizations such as municipalities, companies, and research organizations have been involved. Naturally, the objectives of the author have not been the same as the other parties. In other words, the nature of this research would have been different if working alone as a researcher without any other parties and other objectives.

Due to the nature of this research the research approach has been practically oriented. Therefore, it has to be admitted that this thesis has some limitations with architectural design. That is to say, the author has focused mainly on his research work of evaluating and developing new features for the Locawe platform based on the experiences gathered in earlier field experiments and industrial pilots. In consequence, the author has not especially specialized in studying information system architectures.

These limitations can be seen also from another point of view. It is obvious that the research work has been more productive because of many kinds of expertise available to the author. One of the advantages related to this kind of research has also been the opportunity to work in a close cooperation with companies. From an academic perspective the main advantage has been in working closely with the Oulu Southern Institute from Oulu University. The field evaluations conducted together have been used in this thesis as a tool for analyzing the validity and reliability of the newly developed features.

Concerning future progress, the author assumes that further development of SWE-type geospatial standards is currently a research direction with a lot of potential. B2B markets with the need for better productivity and profitability are challenges in which location-aware systems, especially smart environments, will have the potential for improving the situation. Another area with a lot of research challenges is global warming. Location-aware systems, especially geosensor networks, will definitely have contributions in sustainable development and energy efficient solutions.
References


Botero A (2008) SAP real world awareness program: 10 years integrating RFID and auto-
sensing technologies into enterprise business processes. Industrial Focus – The
European Journal of Manufacturing. URI: http://www.industrialfocus.co.uk/

Botts ME, Percivall G, Reed C & Davidson J (2006) OGC Sensor Web Enablement:
Overview and high level architecture. Proc the 2nd International Conference on

Generation Geospatial Information 1(2): 33–42.


Business Solutions (2008) Sybase iAnywhere updates RFID and sensor computing
middleware. Articles. April 2008. URI: http://bsminfo.com/article.mvc/Sybase-
ianywhere-Updates-RFID-Middleware-0001?VNETCOOKIE=NO.

Business Week Online (1999) 21 ideas for the 21st century, Business Week, August 30,

6th International Conference on Intelligent User Interfaces. New Mexico, USA: 25–32.

the ACM 51(3): 24–33.

CGALIES (2002) Coordination Group on Access to Location Information for Emergency
http://www.telematica.de/cgalies/.

Chipcon (2006) System-on-chip for 2.4 GHz ZigBee / IEEE 802.15.4 with location engine.
Chipcon.

Chien S, Tran D, Davies A, Johnston M, Doubleday J, Castano R, Scharenbroich L,
Rabideau G, Cichy B, Kedar S, Mandl D, Frye S, Song W, Kyle P, LaHusen R &
sensorweb. Proc the 7th International Symposium on Reducing the Cost of Spacecraft
Ground Systems and Operations. Moscow, Russia.

Chong C & Kumar S (2003) Sensor networks: Evolution, opportunities, and challenges,

Chong CS & Su Y (2008) Automatic model simplification and reconstruction from
geographic information system data for computer-aided engineering. Proc Computer-


and case studies. SEI Series in Software Engineering. Pearson Education, Addison-
Wesley.

documenting software architectures – views and beyond. SEI Series in Software
Douglas D & Peucker T (1973) Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. The Canadian Cartographer 10(2): 112–122.


Logica (2009b) Logica named as this year’s leading partner within Microsoft’s Business Solutions. URI: http://www.logica.com/logica+named+as+this+year%23s+leading+partner+within+mscotsoft%23s+business+solutions/400007209


Appendix 1

In Locawe platform next protocol stacks has been used (see Figure 1 and Figure 2).

Figure 1. Protocol stacks (A-G) used in the Locawe platform
Figure 2. Protocol stacks (A-G) in the Locawe architecture
Original articles


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Original publications are not included in the electronic version of the dissertation.

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536. Salmi, Tuukka (2009) Very small families generated by bounded and unbounded context-free languages
538. Kangas, Katja (2009) Recreation and tourism induced changes in northern boreal environments
539. Laari-Salmela, Sari (2009) The process of strategy formation in software business: three cases from Kainuu region, Finland
541. Eskelinen, Anu (2009) Plant community dynamics in tundra: propagule availability, biotic and environmental control
544. Saari, Eija (2009) Towards minimizing measurement uncertainty in total petroleum hydrocarbon determination by GC-FID
545. Pihlajaniemi, Henna (2009) Success of micropropagated woody landscape plants under northern growing conditions and changing environment
548. Kemppainen, Jukka (2010) Behaviour of the boundary potentials and boundary integral solution of the time fractional diffusion equation
549. Varga, Sandra (2010) Significance of plant gender and mycorrhizal symbiosis in plant life history traits
550. Räisänen, Teppo (2010) All for one, one for all. Organizational knowledge creation and utilization using a new generation of IT tools

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DEVELOPMENT AND EVALUATION OF THE LOCATION-AWARE PLATFORM

MAIN CHARACTERISTICS IN ADAPTABLE LOCATION-AWARE SYSTEMS