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From being interrupted by mobile devices to CallMeSmart

A context-sensitive communication system for mobile communication in hospitals

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A dissertation for the degree of Philosophiae Doctor

April 2013

Abstract

Wireless communication infrastructure in hospitals represents a core for information sharing between health care workers. Medical staff's work situation is highly mobile, and important information is constantly shared between co-workers to provide high quality services to the patients. To be able to communicate at any place and at any time during shifts, physicians carry mobile communication devices, often several devices according to their role and responsibilities. This leads, in many situations, to a number of problems, especially regarding to unnecessary interruptions from these devices. This mainly happens due to the callers not being aware of the situation of the called person, or ignoring the situation and context of their colleagues. Such situations often lead to severe medical consequences, such as medication errors and mistakes during treatment, and should be solved.

To tackle this problem, we used methods from Computer Supported Cooperative Work and Human Computer Interaction, including an ethnographic and interpretive field research approach, where user requirements were elicited using a scenario-based approach. The intention was to learn about the communication situation, include the users in the design and testing process, thus ensuring that the system is designed and developed according to the user's communication pattern and needs. To develop the CallMeSmart system we used an iterative software engineering approach, denoted Unified Process.

Summarizing, we confirmed that physicians and surgeons are unnecessarily interrupted by mobile communication devices during their daily work, and identified in which situations such interruptions occur. We proved that a context-sensitive system for mobile communication in hospital settings is a suitable solution to manage the balance between a physician's availability and the interruptions they experience from mobile devices. Under this project, we designed and developed an interruption management system into the existing infrastructure at the Context Laboratory, in our case an Ascom UNITE communication platform, which is similar or compatible with the system used at University Hospital of North Norway. Furthermore, by being able to seamlessly integrate smartphones into the existing infrastructure, we enabled the inclusion of the pagers, messages and alarm systems into the developed context-sensitive system.

The resulting system is called CallMeSmart, a context-sensitive communication system for mobile communication suitable for hospital usage. CallMeSmart is based on an Ascom/trixbox platform, and was designed to reduce interruptions due to wireless phones by improving awareness between the users carrying these devices. The system is designed for hospital environments and reduces interruptions using contextual information related to users, such as: location, availability status and personal commitments. CallMeSmart is intended to meet the new communication needs for health care workers.

The main contribution of this thesis is concentrated around the overall research problem targeted by this Ph.D. project, built up by different research questions. The developed system, CallMeSmart, has been tested by real test users, physicians, and in the Context Laboratory

simulating real scenarios. The users gave a positive feedback welcoming the system in their work, so the next step is to test and verify the system in real hospital settings.

Acknowledgements

Foremost, I would like to thank my supervisor, Professor Gunnar Hartvigsen, for being a good supervisor, believing in me, helping me in difficult periods of the project, encouraging me when needed, for suggesting and setting me in contact with the students we supervised during the project and for letting me work the way I prefer. I also would like to thank Jeremiah Scholl, for writing the project funding application, and for helping me in the first part of my Ph.D..

To my employer, the Norwegian Centre for Integrated Care and Telemedicine (NST), University Hospital of North Norway, I would like to thank for giving me the opportunity to undertake my Ph.D. in this project. I gratefully acknowledge to the Norwegian Research Council - VERDIKT, for financing the main project, and the Tromsø Telemedicine Laboratory (TTL) for financing parts of the project.

I would like to thank the students, from different parts of the world: India, Italy, France, Netherland, Germany and a visiting researcher from Czech, which collaborated with me in this project. To Stefano, Ashok, Annelies, Edouard, Bernd and Jonas for being inspiring students and for helping me collecting data and finding solutions. To Lorenzo for being able to program the first version of CallMeSmart during his master thesis and further when working as a programmer in the project for one and a half year. To Alain, for first doing his internship thesis, his master thesis, and finally working as a programmer during the last year doing an amazing job for the project. To Jan, for the helpful discussions and for sharing his experience with the project. To all of them I am thankful for the amazing times we had together.

I would like to express my gratitude to Pradeep Ray for inviting me and giving me the opportunity to a research stay at the University of New South Wales, Sydney Australia, in the Asia-Pacific Ubiquitous Health Care Research Centre. I would like to thank, Amir for the interesting collaboration, experiments and publications we did together.

At NST I have the best colleges ever and I would like to thank them all for being inspiring and helpful. I specially thank to Tore and Øystein, at the IT department, for helping with anything regarding hardware and networking. To Trine, Berit-Stine and Bente, from the administration, for helping me with administrative stuff like travel invoices and employing programmers. To Elisabeth, Randi, Jarl-Stian and Espen, at the media department, for pushing CallMeSmart to the media. Lone and Sture, at TTL, for helping and supporting the project. I would like to thank my office mates, Monica and Rune, for inspiration, nice discussions, helping with frustrations and for making the office a fun place to work. To Rune, for being my best friend. To Kari, Line, Eli, all my friends at work and the Ph.D. students at TTL. And to Ná, for being an amazing friend, inspiring me and helping me through the end of my PhD and for reading through this thesis correcting my language.

But to whom I am most grateful to is to my girls. My daughters Erica and Aurora, who have bared with their dad working this much, at any time, not always being mentally there, not always caring and understanding when needed, not always having time to help either for school or other things. To Cathrin who supported me in the decision to start this Ph.D., who has always been there for me, helping me, taking care of the girls when I was working or traveling, bearing with me during my frustrations and intensive work periods, for inspiring and believing in me, for coming to Sydney with me, for taking care of the family and for being my friend.

At the end I would like to thank my mother and my family.

Abbreviations

AGI	Asterisk Gateway Interface
APuHC	Asia-Pacific Ubiquitous Health Care Research Centre
CSCW	Computer Supported Cooperate Work
DECT	Digital Enhanced Cordless Telecommunication
ELISE	Embedded Linux Server
EPR	Electronic Patient Record
ESS	Enhanced System Services
FICS	Function, Interactions, Content, and Structure
FOP	Flash operator Panel
GUI	Graphical User Interface
HCI	Human Computer Interaction
IMS	Integrated Message Server
IP	Internet Protocol
IS	Information Systems
OAJ	Open Access Java server
OJS	Open Java Server
PACT	Person, Activity, Context, and Technology
PAM	Policy-based Awareness Management
PBX	Public Branch eXchange
PDA	Personal Digital Assistant
RSSI	Radio Signal Strength Indicator
SIP	Session Initiation Protocol
TTL	Tromsø Telemedicine Laboratory
UI	User Interface
UML	Unified Modeling Language
UNN	University Hospital of North Norway
UNSW	University of New South Wales
VoIP	Voice over IP
WAP	Wireless Application Protocols
WiFi	Wireless fidelity

Table of Contents

List of Figures

List of tables:

PART 1: SUMMARY OF THE PHD DISSERTATION

1 INTRODUCTION

1.1 Background for the research

1.1.1 Mobile communication in hospitals

In hospitals, physicians' work situation often relies on their ability to be mobile. They often have to move frequently between inpatient, outpatient and emergency ward, operating theatres, etc., and seldom stay for long at the same location. In these situations, the physician needs a mobile communication system to be able to communicate with colleagues, at any time and place, to avoid any delay between the decision made and action taken. Delays which could result in medical errors [1], where mobile communication systems have been suggested as a solution to improve the communication situation in hospitals [2]. Before deploying such systems, it will be a challenge to handle the balance between increased availability and interruptions [3].

Most hospitals rely on a mobile communication infrastructure where pagers appear as the most dominant mobile communication device used for communication between colleagues. Pagers provide a cheap and reliable way for contacting staff. Some hospital staff members carry several pagers simultaneously to cover the various work roles they have been assigned. Pagers suffer from a number of problems due to their simplicity. The most obvious limitation is that they require the staff to locate a phone in order to respond to a page. Either they have to find a wired phone or borrow a wireless from a colleague. Pagers also create a lot of unnecessary interruptions [4, 5] and communication overhead. For example, the person that sends the page is not always near the phone anymore when the page is returned [6].

One way of solving this problem is to provide all hospital personnel with wireless phones. One critical issue when providing wireless phones to all hospital personnel is the potential to make people "fatally available" [6]. This issue cannot be overlooked. Healthcare is a knowledge intensive activity where consulting colleagues or senior staff members is a necessity [7]. From the studies in [3, 8, 9] we know that phones can be even more interruptive than pagers. In Scholl et al. [3] a physician states that; "*with a pager you just have to glance down at your coat pocket to see who is paging, while with a phone, you have to pick it up from your pocket to see who is calling. Having done that, it is easier just answering and explaining that you are busy*".

Healthcare workers often exhibit "selfish" and interruptive communication practices [10], where the ease of contacting other staff members, using wireless phones, may result in interruptions for conversations that would not occur without the phone [11]. Thus, there is a clear need for a service able to balance the need for some to get immediate access to important people with authority, with the need of those people to keep from being overloaded by interruptions.

1.1.2 Context-sensitive systems for hospitals

There have been several studies over the years focusing on context-sensitive systems for hospitals. Most of this work focuses on scopes not covered by this project including issues related to accessing clinical data, or on multimedia communication at terminals with fixed locations [12]. Work within context-sensitive mobile communication for hospitals has identified some important elements of context in healthcare work, which includes: location, role, delivery timing and artefact location and state [13]. This model has been applied to an instant messaging system based on PDAs that allows contact based on these contextual elements [13]. This approach, however, requires workers to carry additional mobile devices in order to support voice services and paging since it is not compatible with existing hospital communication infrastructure.

1.1.3 Interruptions from mobile devices

We know that unnecessary interruptions can cause concentration difficulties and disturb the normal activity [1]. Such interruptions should be prevented in order to avoid distraction that can lead to intolerable actions or decisions. For example; being interrupted during a difficult part of a surgery or during patient examinations where diagnoses are decided. Since we know that healthcare workers often exhibit "selfish" and interruptive communication practices [10], and staff members using wireless phones to contact each other may result in more unnecessary interruptions [11], mobile communication systems for hospitals is an important research area.

1.2 Research problem and questions

The primary research problem targeted in this project is (R) *how can a context-sensitive system for mobile communication in hospitals be designed?* Such a system will support media, such as text, voice and paging services, while maximizing efficiency of communication and effectively manage interruptions. The secondary research problems associated with this primary research problem are listed below.

R1. How do interruptions from mobile devices disturb physicians in their daily work?

R2. How can the balance between availability and interruptions be handled?

R3. How can middleware that integrate interruption management into existing infrastructure be designed and developed?

R4. How can smartphones seamlessly be integrated into existing infrastructure, including integration of alarms and messaging systems?

1.3 Research approach

Research was conducted in three phases, which were constructed in order to ensure that users were involved, as much as possible, in the design and evaluation process of the targeted systems. User participation is a crucial aspect of this project, since over half of medical informatics systems fail because of user and staff resistance [14]. The three phases are observations and interviews, scenarios, and prototyping and evaluations. The phases are used in a complimentary and iterative manner as shown in Figure 1-1. A brief description of the approach used in each phase is given below.

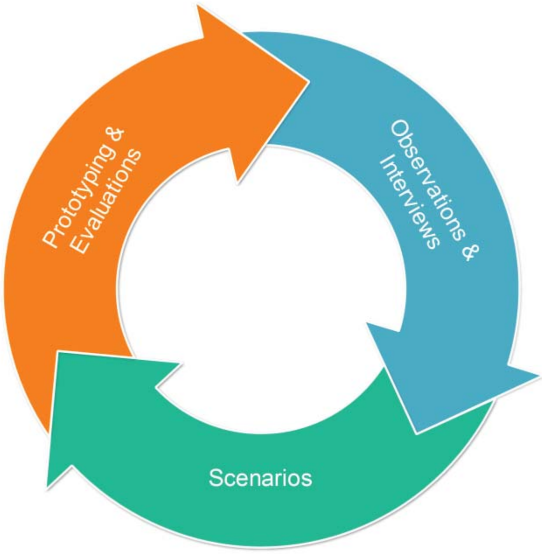

Figure 1-1: The three research phases used in the project

Observation and interviews: Creating technology meant to be used in real work practice requires a thorough understanding of how technology is used in the workplace [15]. We used techniques from Computer Supported Cooperate Work (CSCW), and Human Computer Interaction (HCI) including observations of actual activities, conducting interviews with users, [16-20] and performing workplace studies. This methodology has recently been advocated for improving medical informatics research [21] and will be used in the project in order to construct preliminary scenarios, and also to investigate qualitative aspects of prototype systems during use.

Scenarios: A scenario driven approach to research revolves around analysing specific scenarios and use cases [22] and, subsequently, building technologies in order to serve those use cases. Scenarios [23, 24] emphasize both technical and non-technical aspects of systems design. This is especially important when dealing with technologies requiring changes in large and complex organizations such as hospitals.

Observations and interviews with workers, while using prototypes, may reveal information that can be used to define new scenarios worth investigating.

Prototyping: Prototype systems are developed and evaluated in laboratory settings using observed scenarios. Prototypes are used in order to demonstrate the feasibility of proposed technical systems, test the system in laboratory settings and thereby make it ready to be deployed in real work practice.

Evaluation: Studies evaluating the effects of technology on users and how the users used the technology, that are consistent with practices in HCI and Information Systems (IS), is also conducted in laboratory settings. Alternative user-interface designs were evaluated using metrics such as completion time and error-rates for specific tasks.

The work consisted of the following activities, but not necessarily following this order:
I. Initial observations and interviews. The focus in this initial phase was:

- How communication and cooperation currently works in the selected organisation;
- Are improvements needed, and what is the motivation for improvements;
- Situations where presence and availability of information may be needed;
- How could presence/availability be indicated? What type of presence?;
- Publication of results.

II. Scenarios. The focus in this initial phase was:

- Construct scenarios based on observations and interviews;
- Present scenarios to users for input to the prototype design;
- Publication of results.

III. Prototyping and evaluation. The focus in this initial phase was:

- Design and develop a prototype;
- Evaluate prototype in laboratory settings;
- Improve prototype based on feedback from evaluation of laboratory version;
- Concluding interviews after prototype testing;
- Publication of results.

1.4 Research context

The research in this PhD project is based on an initial study, *Managing communication availability and interruptions: A Study of Mobile Communication in an Oncology Department* [3], done at the Oncology Department at the University Hospital of North Norway (UNN). In 2007, under the project: *Context sensitive systems for mobile communication in hospitals,* we started out by doing further investigations at UNN, but this time at the Gastro Surgical Department. To compare the results gathered from UNN with another hospital that uses wireless phones, in 2009, I contacted St. Olavs Hospital, Trondheim University Hospital, and conducted further investigations there.

The rest of the research was carried out at the Tromsø Telemedicine Laboratory (TTL), at the Norwegian Centre for Integrated Care and Telemedicine (NST), my employer, in the Context Laboratory, which is further explained in chapter 3. I also had a research stay at the University of New South Wales (UNSW) at the Australian School of Business in the Asia-Pacific Ubiquitous Health Care Research Centre (APuHC), from August 2010 – January 2011, where I did some theoretical experiments together with one of the PhD candidates there.

When developing the CallMeSmart system, several students (3 master students and 6 internship and capstone students) participated in the project and did the programming in accordance with the agreed design and then in the evaluation and testing processes of the system.

1.5 Claimed contribution and included papers

1.5.1 Contribution of thesis

A context sensitive mobile communication system for hospital use, focusing on physicians work situation, called CallMeSmart, has been designed and developed. CallMeSmart is an interruption management system which uses context to control the wireless communication, and, thereby, also the interruptions from mobile devices. The system works on top of an existing hospital infrastructure from Ascom [25], where we have integrated Android based smartphones which seamlessly communicate with the Ascom devices, the pagers, messaging, and alarm systems. The system has been tested and evaluated during different stages of the prototype by real users, physicians, in lab settings using scenarios created according to the observations from real settings. The messaging system on the smartphones includes a feature where acknowledgement of received and then opened messages is offered.

Table 1 presents a list of key findings addressed in which paper and what research question answered.

Table 1: Key findings, where all findings are related to the primary research problem: *how to design a context-sensitive system for mobile communication in hospitals*

#	Findings	Addressed in paper(s)	Research question
F1	Unnecessary interruptions from mobile devices are a problem for physicians and surgeons and a solution is wanted and needed	P1, P2, P3,	R1
F2	In which situations physicians are disturbed by interruptions from mobile devices in their daily work	P2, P3	R1
F3	A solution to handle the balance between availability and interruptions using context information	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11	R2
F4	A solution to integrate interruption management into existing infrastructure	P5, P6, P9, P11	R3
F5	A solution to integrate smartphones seamlessly into existing infrastructure using an Ascom/trixbox solution integrating messages and alarms	P10	R4

1.5.2 Included papers

There are eleven papers included in this thesis, as presented in Table 2:

Table 2: List of included papers

#	Paper title and forum
P1	Context-aware systems for mobile communication in healthcare - A user oriented approach. WSEAS International Conference on Applied Informatics & Communications (Botsis, T., Solvoll, T., Scholl, J., Hasvold, P. E., and Hartvigsen, G.)
P2	Strategies to reduce interruptions from mobile communication systems in surgical wards. Journal of Telemedicine and Telecare (Solvoll, T. and Scholl, j.)
P3	Physicians Interrupted by Mobile Devices in Hospitals: Understanding the Interaction Between Devices, Roles, and Duties. Journal of Medical Internet Research (Solvoll, T., Scholl, J., and Hartvigsen, G.)
P4	Mobile Communication in Hospitals: What is the Problem?, Book chapter in Integrated Information and Computing Systems for Natural, Spatial, and Social Sciences (Solvoll, T.,)
P5	Evaluation of an Ascom/trixbox system for context sensitive communication in hospitals. Scandinavian Conference on Health Informatics (Solvoll T, Fasani S, Ravuri

	AB, Tiemersma A, and Hartvigsen G.)
P6	Context-sensitive Communication in Hospitals: A User Interface Evaluation and Redesign of Ascom Wireless IP-DECT Phones. eTELEMED 2011 (Solvoll T, Tiemersma A, Kerbage E, Fasani S, Ravuri AB, and Hartvigsen G.)
P7	Policy-based Awareness Management (PAM): Case study of a wireless communication system at a hospital. Journal of Systems and Software. (Talaei-Khoei A, Solvoll T, Ray P, and Parameshwaran N.)
P8	Maintaining awareness using policies; Enabling agents to identify relevance of information. Journal of computer and system sciences (Talaei-Khoei A, Solvoll T, Ray P, and Parameshwaran N.)
P9	CallMeSmart: An Ascom/trixbox based prototype for context controlled mobile communication in hospitals. Accepted April 26th for publication in ICISA 2013 proceedings (Solvoll T, Gironi L, and Hartvigsen G.)
P10	CallMeSmart: A VoIP Softphone on Android Based Mobile Devices Using SIP. eTELEMED 2013 (Solvoll T, Gironi L, Giordanengo A, and Hartvigsen G.)
P11	Interruption management for hospital communication systems: A user requirements specification. Submitted to AMIA 2013 (Talsma, B. G., Solvoll T, and Hartvigsen G.)

The relevance to this thesis and my contribution to each paper are described below.

P1: Botsis, T., **Solvoll, T.**, Scholl, J., Hasvold, P. E., and Hartvigsen, G.: Context-aware systems for mobile communication in healthcare - A user oriented approach. In the proceedings of the 7th WSEAS International Conference on Applied Informatics & Communications (Vol. 1, pp. 69-74): World Scientific and Engineering Academy and Society.

Relevance to this thesis: This paper is based on an initial study that took place at the Oncology department at the University Hospital of North Norway before the context-aware project has started. The objective of the paper was to provide a theoretical system architecture based on a user-oriented approach, for a reliable mobile context-aware communication system designed for hospital use. The system aims to help healthcare workers in their daily practice to accomplish their main tasks easier and with more success without getting interrupted by mobile devices.

My contribution: I wrote the user oriented approach and system architecture sections and participated in the discussion and conclusions in this paper. I also took a major part in the in the rest of the paper with useful comments and input. The paper was presented in Athens, at the WSEAS International Conference on Applied Informatics & Communications, by the first author, in 2007.

P2: **Solvoll, T**. and Scholl, J.: Strategies to reduce interruptions from mobile communication systems in surgical wards. Journal of Telemedicine and Telecare, 2008. 14(7): p. 389-392.

Relevance to this thesis: This paper is based on the ideas in P1 together with interviews and discussions with surgeons at the Gastro Surgical Department, at the University hospital of North Norway. The purpose of the study was to investigate how and where surgeons were unnecessarily interrupted by phones or pagers, and suggest a theoretical framework, followed by a system architecture based on existing infrastructure, to handle such interruptions.

My contribution: The second author and I did the presentation, discussions and interviews together at the hospital. I wrote the paper, suggested the framework and system architecture with useful comments and discussions from the second author.

P3: **Solvoll, T.**, Scholl, J., and Hartvigsen, G.: Physicians Interrupted by Mobile Devices in Hospitals: Understanding the Interaction Between Devices, Roles, and Duties. Journal of Medical Internet Research, 2013. 15(3): p. e56.

Relevance to this thesis: The objective of this paper was to characterize how interruptions from mobile devices disturb physicians in their daily work. The study adheres to an ethnographic and interpretive field research approach, were participant observations, non-structured and mostly ad hoc interviews, and open-ended discussions with a selected group of physicians were performed. The gathered knowledge was combined with results from earlier studies and has been used as input for the design and development of our context-sensitive mobile communication system suitable for hospitals, CallMeSmart.

My contribution: I did the data gathering, observations, interviews and discussions at St. Olavs Hospital. I also did the data analyses, and wrote the paper with useful input and discussions from the co-authors.

P4: **Solvoll, T.**, Mobile Communication in Hospitals: What is the Problem?, in Integrated Information and Computing Systems for Natural, Spatial, and Social Sciences. 2013, IGI Global. p. 287-301

Relevance to this thesis: This book chapter presents solutions based on context-aware communication systems aiming to reduce interruptions presented in literature. It includes state-of-the-art and relevant research done within the field of context-sensitive communication, and it is the main contributor to the background chapter of this thesis.

My contribution: This book chapter is based on literature searches included from the beginning of the project, supplemented with newer searches to include new relevant literature and research that this project relies on. I did the searches and wrote the book chapter.

P5: **Solvoll T**, Fasani S, Ravuri AB, Tiemersma A, and Hartvigsen G,: Evaluation of an Ascom/trixbox system for context sensitive communication in hospitals. 8th Scandinavian Conference on Health Informatics; August 23-24, 2010, p. 49-53. Tapir Academic Press, Trondheim.

Relevance to this thesis: This article investigates the possibility to accomplish enhanced quality of patient care by making communication among healthcare professionals more efficient and effective by using an Ascom/trixbox system. This was done by conducting an evaluation of the system by analysing two crucial factors: the data transfer performance and the design opportunities offered to develop context sensitive applications. These are critical aspects affecting the use of the equipment in the real scenarios, and if not effective, the user's resistance can be hard to overcome. If the context sensitive design capabilities offered are limited, it is not possible to develop adequate applications.

My contribution: I wrote the paper and designed the tests that the paper is based on, in close collaboration with the second author. The software was implemented by the second author with helpful inputs mainly from me, but also from the other co-authors. At the time of the conference, I was on my way to Sydney, for my stay abroad, so the paper was presented by Gunnar Hartvigsen at the Scandinavian Conference on Health Informatics in August 2010.

P6: **Solvoll T**, Tiemersma A, Kerbage E, Fasani S, Ravuri AB, and Hartvigsen G.: Context-sensitive Communication in Hospitals: A User Interface Evaluation and Redesign of Ascom Wireless IP-DECT Phones. eTELEMED 2011, The Third International Conference on eHealth, Telemedicine, and Social Medicine; February 23, 2011; Gosier, Guadeloupe, France: IARIA, 2011; 2011. p. 37-46.

Relevance to this thesis: This paper presents an investigation on the role of user interface design for mobile communication devices used within health care. This was done in order to improve the user interface, and to include support for context-sensitive communication. The user interface of two Ascom IP-DECT phones was evaluated by test users. A prototype of suggested improvements was developed and tested by the same test users, and were considered as an improvement compared to the old user interfaces. These improvements include support for context-sensitive communication in hospital environments.

My contribution: I wrote the paper and helped in designing the tests performed by the test users. The prototypes were developed by the second and third authors in close collaboration with me. I contacted the test users and organized the tests. I presented the paper at eTELEMED 2011.

P7: Talaei-Khoei A, **Solvoll T**, Ray P, and Parameshwaran N.: Policy-based Awareness Management (PAM): Case study of a wireless communication system at a hospital. Journal of Systems and Software. 2011;84(10):1791-805.

Relevance to this thesis: This paper presents an evaluation on the use of software agents to identify relevance of information using awareness. The evaluation is based on existing policies and scenarios of wireless communication at St. Olavs Hospital. The study addresses the lack of literature for experimental studies on a method to employ software agents for awareness identification. The method used is called

Policy-based Awareness Management (PAM), which allows agents to use policies as a source to identify awareness and, thus, change their behaviours accordingly. The process is evaluated via its application to identify the relevance of information in wireless communication scenarios at the hospital. The study conducts observations, interviews and discussions on the wireless communication system at the hospital, to identify the different scenarios happening in the system. The paper presents a set of simulations on these scenarios.

My contribution: This paper was written during my stay at the University of New South Wales during the fall/winter of 2010/2011. It is based on a method that the group I worked with used in their research projects about awareness. We tested some scenarios from my observation study at St. Olavs Hospital with this method and did some simulation using a simulator made by the first author. I wrote parts of second part of the paper, mostly the ones regarding the observation study and the scenarios, and collaborated closely together with the first author in the experiments and in the process of writing the rest of the paper.

P8: Talaei-Khoei A, **Solvoll T**, Ray P, and Parameshwaran N. Maintaining awareness using policies: Enabling agents to identify relevance of information. Journal of computer and system sciences. 2012;78(1):370-91.

Relevance to this thesis: This paper proposes and evaluates a formalized structure, PAM, to address the problem of awareness identification. PAM extends the logic of general awareness in order to identify relevance of information. PAM formalizes existing policies into Directory Enabled Networks-next generation structure and uses them as a source for awareness identification. The paper argues that efficacy and cost-efficiency of the logic of general awareness will be increased by PAM. This is evaluated by simulation of hypothetical scenarios as well as scenarios from a case study at St. Olavs hospital.

My contribution: This paper was also written during my stay at the University of New South Wales, using the same method as in P7. This paper evaluates cost efficiency and efficacy of PAM in a triangulation of two simulation studies, where the second is my contribution with scenarios found in the case study of wireless communication systems at St. Olavs Hospital.

P9: **Solvoll T**, Gironi L, and Hartvigsen G.: CallMeSmart: An Ascom/trixbox based prototype for context controlled mobile communication in hospitals. Accepted for publication in IEEE-ICISA 2013 proceedings, April 26th 2013.

Relevance to this thesis: This paper presents the first version of the prototype, CallMeSmart. The prototype was evaluated by real users, testing different scenarios from real settings in the context laboratory, resulting in suggestions of several improvements to the system.

My contribution: This paper was written based on the results in Lorenzo Gironi's master thesis, a part of the context project, and was defined and supervised by me. I wrote the paper.

P10: **Solvoll T**, Gironi L, Giordanengo A, and Hartvigsen G. CallMeSmart: A VoIP Softphone on Android Based Mobile Devices Using SIP. eTELEMED 2013, The Fifth International Conference on eHealth, Telemedicine, and Social Medicine: International Academy, Research and Industry Association (IARIA); 2013. p. 198-203.

Relevance to this thesis: This paper presents the first version of the prototype, CallMeSmart – VoIP Softphone. The CallMeSmart system; a communication infrastructure based on collection, analysis and dissemination of context-sensitive information through a communication system based on smartphones and DECT devices, to improve the current communication backbones, and to reduce interruptions from mobile devices in hospital settings. The paper deals with our choices regarding: optimizing the battery usage of the software, computational power vs. audio quality, user interfaces and features of the software, roaming within Wi-Fi networks, and tracking of the devices.

My contribution: This paper was written based on the results from the design choices done when extending CallMeSmart, to include a Voice over IP (VoIP) softphone for Android based mobile devices, using Session Initiation Protocol (SIP). The design and tests were done by Lorenzo Gironi and me and the implementation was done by Lorenzo Gironi. I wrote the paper.

P11: Talsma, B. G., **Solvoll T**, and Hartvigsen G.: Interruption management for hospital communication systems: A user requirements specification. Submitted for AMIA 2013 in March 2013.

Relevance to this thesis: In this paper we used scenarios to elicit user requirements. The resulting requirements match with the broader literature of interruption management and with the ones previously identified. The results present insights into user requirements for an interruption management system for hospitals. Hospital workflow protocols were identified as a major source of interruptions. We have shown that even though the hospital is an exceptionally demanding environment, the user requirements for interruption management concur with earlier findings in the broader fields of context-aware interruption management and computer supported cooperative work.

My contribution: This paper was written by Bernd Talsma, an internship student in the context project, which I supervised, as a part of his thesis. He worked on user requirements using scenarios and user stories in close collaboration with me. I contacted the users we tested our cases with. I worked close with Bernd when writing this paper.

1.6 Thesis structure

The reminder of this thesis consists of two parts.

PART 1 - Summary of the research process

Table 3: Thesis structure

Chapter	Content
2 - Background	This section introduces the problem area and focus of my research. Technological concepts and current state of the art is presented here
3 – Materials and research method	In this section I present the materials and methods used in this thesis
4 – Results	This section will present the research results according to the three phases the research were carried out: observations and interviews, scenarios, prototyping and evaluation
5 – Discussion	In this section I will discuss the results according to the research questions and suggests future work
6 – Conclusion	Concludes the work based on the results and discussion of the research questions

PART 2 – Included papers

P1: Botsis, T., Solvoll, T., Scholl, J., Hasvold, P. E., and Hartvigsen, G.: Context-aware systems for mobile communication in healthcare - A user oriented approach. In the proceedings of the 7th WSEAS International Conference on Applied Informatics & Communications (Vol. 1, pp. 69-74): World Scientific and Engineering Academy and Society.

P2: Solvoll, T. and Scholl, J.: Strategies to reduce interruptions from mobile communication systems in surgical wards. Journal of Telemedicine and Telecare, 2008. 14(7): p. 389-392.

P3: Solvoll, T., Scholl, J., and Hartvigsen, G.: Physicians Interrupted by Mobile Devices in Hospitals: Understanding the Interaction Between Devices, Roles, and Duties. Journal of Medical Internet Research, 2013. 15(3): p. e56.

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2 BACKGROUND

The background and the problem area, technological concepts and current state of the art, of my research were published by me in the book chapter, P4: Mobile Communication in Hospitals: What is the Problem? in the book: Integrated Information and Computing Systems for Natural, Spatial, and Social Sciences [26]. Therefore, this section of the thesis will be based on the book chapter [26], presenting a similar short version amended with a sub-section where some additional research within the field is presented.

2.1 Mobile communication and interruptions in hospitals

Unnecessary interruptions are unwanted and can cause concentration difficulties and disturb the activity performed [1]. This kind of interruptions should be minimized in order to avoid distractions that can lead to intolerable actions or decisions, especially during surgery or while examining patients. This is a problem in today's hospital settings, and a solution to reduce such unnecessary interruptions from mobile devices is needed and wanted [3, 9, 27]. A lot of work has been done in the area, but we cannot see that the situation has changed for the better.

Physicians' working conditions rely on mobility. They move frequently between inpatient, outpatient and emergency wards, operating theatres, etc., and often do not stay more than a few minutes at the same location. This kind of mobility requires mobile communication systems which make it possible for physicians to communicate with colleges, at any time and place, to avoid any delay between the decision made and the action taken. Such delays could result in medical errors [1], and mobile communication systems have been suggested as a solution to improve communication in hospitals [10]. The challenge when deploying such systems is to handle the balance between the increased availability and interruptions [3, 8, 9].

Most hospitals rely on a mobile communication infrastructure with dedicated devices for each role, where pagers are the dominant device. Pagers provide a cheap and reliable way for contacting staff and are so ubiquitous that many members of the hospital staff carry several pagers with them, each related to one of the various work roles they have been assigned. Pagers suffer from a number of problems due to their simplicity. The most obvious limitation is that it requires the staff to locate a telephone (landline or wireless) in order to respond to a page, which often causes unnecessary delays and communication overhead, since the person placing the page is not always near the phone when the page is returned [6]. They also create a large amount of unnecessary interruptions [4, 5], which are unpleasant and can lead to medical errors [1].

The most intuitive solution to improve the communication situation in hospitals is to provide physicians with wireless phones. But these devices can be more interruptive than pagers [3, 8, 9]. In [3] a physician states that: "*with a pager you just have to glance down at your coat pocket to see who is paging, while with a phone, you have to pick it up from your pocket to see who is calling. Having done that, it is easier just answering and explaining that you are busy*". Nevertheless, some preliminary studies have shown a variety of potential benefits from wireless phones in hospital settings, using both mobile text and voice services [6, 28-30]. These studies, however, also revealed limitations of the technologies, which can partly explain the trouble of gaining acceptance. Since text-chat is a less obtrusive medium than other forms of workplace communication [31], it is unlikely that mobile text-messaging has the same potential for creating interruptions as mobile voice services. Improved asynchronous communication systems have also been recommended for improving hospital communication practices [10], which means that, in addition to mobile synchronous communication systems, mobile text-messaging systems are also an interesting medium to explore in hospitals settings. However, the current generation of mobile text-messaging systems seems ill suited for hospital environments. Studies on mobile text-messaging during hospital use have revealed, for example, difficulties related to small screen size [29] and problems related to forcing doctors to carrying an additional device [28]. Of course these studies are not recent, and a lot has been done to improve displays and keyboards since these studies were published. Another problem is that the sender, in many situations, needs an acknowledgement that an asynchronous message has been read [10], which could be solved by just force a feedback when a message has been opened. Also, automatic suggestions for replies may ease the difficulties with text-messages, and it has been reported that predefined messages can meet up to 90% of the mobile text-messaging needs for some hospital workers [32].

Mobile communication systems for hospitals, is an important research field since hospitals are noted to suffer from poor communication practices. The fact that hospital workers prefer interruptive communication methods before non-interruptive methods [4, 5, 10], and often exhibit "selfish" interruptive communication practices, could result in making it so easy to contact other staff members via wireless phones that it may result in unnecessary interruptions for conversations that otherwise would not occur [11]. This amplifies the risk of overloading limited resources with special knowledge, experience and the power of making decisions. The balance between getting immediate access to resources and overloading or causing interruptions, in moments where it is not appropriate, has similarities with classical problems regarding collaboration and sharing of resources, such as of disparity in work and benefit, "prisoner's dilemma" and "the tragedy of the commons" [33]. A critical issue for voice services is, thereby, the potential of make people "fatally available" [6], which cannot be overlooked since healthcare is a knowledge intensive activity, where consulting colleagues or senior staff members is a necessity in many situations [7].

One way of tackling this problem is to provide the caller with context information from the receiver's situation. Context information could be any kind of information which helps to decide if the receiver is available or not, such as, location, activity, surrounding noise and role. In a study by Avrahami et al. [34], was revealed that if the caller is provided with context information about the receiver's situation, it reduces the mismatch between the caller's decision and the receiver's desires.

2.2 Context-sensitive communication systems

To identify context-sensitive communication systems we first need to define context-sensitive/aware systems, where each word is equally important. Hereafter I will use context-sensitive when referring to both context-aware and context-sensitive, as their underlying meaning is the same.

2.2.1 Identifying context-sensitive systems

To define context, we had to investigate some of the definitions given by the research community [35-37] over the years, and concluded that the most suitable definition for our research is [38]:

> *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant for the interaction between a user and an application, including the user and applications themselves."*

This definition shows the importance of which information is relevant or not in a context-sensitive system. A context-sensitive system could, therefore, be defined as a system allowing interactions between multiple entities using relevant information. In [38] they state that: "*A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task".* This definition shows that a context-sensitive system can change its behaviour and send some relevant information according to the context, which reflects our view. So, what is relevant information? What are the most common types of contextual information used by context-sensitive applications? Mizzaro, Nazzi and Vassena [39] identified some common types of information:

- Spatial;
- Temporal;
- Social situation;
- Resources that are nearby;
- Physiological measurements;
- Schedules and agendas;
- Activities;
- Identity.

Only a small number of these information types are used by the existing applications. Such applications only use the information that satisfies the targeted requirements, technology available and environmental constraints. Despite this, the trend has been to push as much information as possible to the users, in order to provide more sophisticated and useful services while, at the same time, making users more available. During a preliminary research study on the Aware Media system [40], they suggested a classification that splits the above listed information along three main axes:

- Social awareness: `where a person is', `activity in which a person is engaged on', `self-reported status';
- Spatial awareness: 'what kind of operation is taking place in a ward', 'level of activity', 'status of operation and people present in the room';
- Temporal awareness: 'past activities', 'present and future activities' that is significant for a person.

This classification describes social aspects regarding knowledge about a person, spatial aspects regarding information about a specific place, and temporal aspects describing information about history and future plans of a subject.

The adoption of context-sensitive services based on these definitions is growing in a variety of domains such as, smart homes, airports, travel/entertainment/shopping, museum, and offices, as mentioned in [41].

2.2.2 Context-sensitive communication systems to control interruptions

One approach for generalizing context-sensitive communication systems that aim to reduce interruptions, is to divide them into two categories, as presented by Khalil and Connelly [42]. The first category includes systems where the phone automatically changes configuration [43-46]. This includes quiet calls where the receiver could negotiate with the caller through text or pre-recorded audio messages [44], which will not reduce personal interruptions since the user is expected to act upon the received call. SenSay [46] is an interesting context-sensitive mobile phone that adapts to dynamically changing environmental and physiological states. It combines information from several different sensors to catch the user’s context and, thereby, change the ringer volume, vibration, provide feedback to the callers about the current context of the user's phone, and make call suggestion to users when they are idle. Contextual information is gathered by using 3-Axis accelerometers, Bluetooth, ambient microphones, and light sensors, mounted on different parts of the body. A central hub mounted on the waist is the central component that receives and distributes data coming from the sensors to the decision logic module. The decision logic module analyses the collected data and changes the state of the phone. The system provides four states: Uninterruptible, Idle, Active and Normal state. A number of settings on the phone are automatically changed within the different states. The uninterruptible state turns off the ringer and turn on the vibration only if the light level is below a certain threshold. This state is enabled when the user is involved in a conversation (recognized by the environmental microphone) or in a meeting (recognized from the phone’s calendar). In this state, all incoming calls are blocked and feedback messages sent to the caller. The caller does have an option to force the call in case of emergency. When high physical activity or high ambient noise level are detected, by the accelerometer or microphones, the active state is entered. This means that the ringer is set to high and the vibration is turned on. When the activity level is low, and the detected sounds of the surroundings are very low, the idle state is entered. In this state the phone reminds the user of pending calls. As the name indicates, the normal state will configure the ringer and vibration to default values. In another system presented by Schmidt, Takaluoma and Mäntyjärvi [45], wireless application protocols (WAP) is used to automatically change the phone’s settings based on the recognized context. Khalil and Connelly [43] combine calendar information with the user’s scheduled activity stored, to automatically configure the phone.

The second category presented by Khalil and Connelly [42], deals with systems that give the caller information about the receivers context and, thereby, helping the caller to make decisions on when it is appropriate to make the call [47-49]. In a study by Avrahami et al. [34], is revealed that if they provided the caller with context information about the receiver’s situation, it reduces the mismatch between the caller’s decision and the receivers desires. In

Milewski and Smith’s study [47], they provide information about the receiver’s presence using the phone book and location, like the “buddy list” in instant messenger services. An interaction web-page that gives caller information about the receivers’ situation and the available communication channels is used in [48], and in [50] they formed a type of members-list combined with a prototype of a wristwatch that captures the user’s context and shares it with the members of the list, which use the information to check the availability before calling.

2.2.3 Context-sensitive communication systems for hospitals

Context-sensitive systems for hospitals are a promising application domain. Hospitals are dependent on a wide and reliable communication infrastructure for exchanging different kinds of data, such as patient reports, lab tests and working shifts, together with text, voice and alarm services. The management of this information is difficult and requires considering a wide variety of problems that should be avoided in order to properly meet the needs of hospital professionals. Context-sensitive applications for mobile communication seem to be a valid solution, which also can be used to move parts of the worker’s activities over to computers.

While the society outside of hospitals has embraced mobile phones (GSM/3G/4G), health care only shows a limited use of the technology. This is mainly due to a possible interference with medical equipment. However, some earlier studies showed that the benefits from this technology could outweigh the risk of interference [51, 52], which has been challenged by [53].

Several other studies have been carried out within hospital settings, aiming at communication improvement and interruption reduction [6, 10, 28-30, 54]. In [10] they recommend a variety of approaches to improve communication, including support and asynchronous communication with acknowledgement. Different kind of text messaging systems for hospitals have also been revealed as having a positive impact [28, 29], but also raised concerns for character limits, small displays, and yet another device to carry. Of course, regarding small displays and keyboards, a lot has been improved within text-messaging systems and mobile devices, since these studies were carried out, which may obliterate these concerns. Other studies have shown positive results when providing nursing teams with wireless phones [6], wearable radio transmitters [30], and wireless hands-free headsets which interface the phone system [54]. The feedback was: quicker updates to patient information; easier to locate nursing staff; and reduced noise levels, but also concerns about being too available.

Personal Digital Assistants (PDA) have been used by [13] in a contextual message exchange system. This solution, developed at IMSS General Hospital in Ensenada Mexico, uses handheld devices that allow users to specify when and where they want to send messages and/or data to other colleagues. Physicians’ can, for example; specify who will be the recipient of a patient's lab test result, and thereby automatically send it when it is ready. Moreover, within this system it is enabled that physicians can send messages without knowing the names of the recipients. This is done by sending the lab tests to any physician in charge for the next shift, or to the first doctor who enters a specified room the next day. In another system [55] they used PDAs for simple text.

PDA's with built in mobile phones, web-browsers, electronic versions of commonly used UK medical reference text books, drug interactions compendium, anatomy atlases, International Classification of Diseases – 10 (ICD-10), guidelines, and medical calculators, have been used by Aziz et al. [56] to enrich communication between health care workers. The purpose of this study, carried out at the Academic Surgical Unit at St. Mary's Hospital (London), was to verify whether PDAs with built-in phones could be an efficient solution to improve communication between hospital workers. This solution was also compared with pagers. During the assessment phase, Palm Tungsten PDAs were given to a surgical team. The information used to evaluate the communication efficiency gained with these devices, was the time clinicians needed to respond to a call. After 6 weeks of tests and questionnaires filled out by the involved participants, the results were encouraging. IT showed a general benefit in replacing pagers with the new advanced PDA devices. In a study described in [57] they used PDA's with access to patent data and with virtual white boards, which allowed health care workers assigned to the same patient know about each other's work progress.

Skov and Høegh [58] evaluated a context-sensitive solution based on mobile phones capable to give nurses patient information. The provided information included the nurse's daily tasks, timing constraints and positions. Moreover, the mobile devices could also be used to insert collected data during the daily work, and to view previously stored patient information in order to monitor changes. After the development, an assessment phase was conducted. The identified problems mainly concerned the complexity of the automatic update mechanism of the devices: Some subjects did not understand how to navigate between the different interfaces and they felt forced to undergo the information displayed on the phone; others felt confused when the system suddenly changed the interface while they were reading the information displayed; some of the nurses also expressed uncertainties about the validity of the data previously entered into the system, and they were not sure if the information was saved properly when using the device.

Intelligent Hospital, QoS Dream Platform, is an application proposed by Mitchell et al. [12]. It is based on wired touch-sensitive terminals ubiquitously scattered throughout the hospital. These terminals make it possible for clinicians, after an authentication process, to request a video call with a colleague without knowing the location of the person they want to contact. The call is routed to the nearest terminal of the recipient, who can choose to accept the call, or refuse it. The user's location is tracked by an active badge system worn by the clinicians. The application is used for: Remote consultation between doctors (e.g. discussions regarding patients and their treatments); and consultation of patient data enabled by an event notification infrastructure that allows pushing clinical data directly into the terminal's display. The Intelligent Hospital application was built to demonstrate a real application within the QoS Dream middleware platform. This platform supports context-sensitive, event driven applications, and solutions based on multimedia contents where user mobility is a predominant factor. It is based on four main conceptual components: Operating system with resource management and overall control functionality; a dynamic multimedia streaming component based on the DJINN platform used to re-route video streaming contents according to the movement of the participants; an event-based infrastructure based on the HERALD architecture; and a set of APIs for building applications using the technologies within the system.

Other systems like the AwareMedia and the AwarePhone systems, developed at the Centre for Pervasive Healthcare at the University of Aarhus, in Denmark, by Bardram et al. [32, 40], support context-sensitive communication. These systems in combination form a complete communication system for clinicians in a surgical ward. The tracking system tracks clinicians in selected areas, using Bluetooth tags/devices worn by the clinicians. The AwareMedia shows information on a number of large interactive touch screen displays scattered throughout the hospital. The information includes: location from the tracking system along with the clinician's schedule; what kind of operation is currently performed at a specific ward; status of the operation; which physicians are present in the room; actual stage of the operation through dynamic coloured bars; and status of the work schedule (e.g. delays or cancellations) provided by displaying visual signs and text messages. Furthermore, in a dedicated area of the display, the application shows the status on other physicians' activities, their location, status, and future schedules. The AwarePhone system is an application running on a mobile phone (GSM/3G), which allows clinicians to call or send a message to a person in an operating theatre. Messages sent directly to the room, are shown to all people present in that room through the AwareMedia Screen. The feedback from the use of these systems in practice focus on privacy issues, being one of the major drawbacks when deploying a system like this.

2.3 Research directions

The work done on context-sensitive mobile communication within hospital settings has identified some important elements of context, including location, role, delivery timing and artefact location, and user state [13]. As presented in the previous section, this model has been applied to an instant messaging system based on PDAs enabling contact based on these contextual elements. This approach, however, requires workers to carry additional mobile devices in order to support voice and paging services, since it is not compatible with existing hospital communication infrastructure. Another issue, by our knowledge not covered in previous work on role-based contact, is how to design interaction forms that allow users to easily switch work roles.

A variety of models for detecting interruptibility have been created for stationary [59-61] and mobile settings [46, 62, 63]. In general, these models focused on office workers and social settings, and used information, such as a user's calendar, interactions with computing devices, switches to determine if doors are open, accelerometers, microphones and motion sensors. Accuracy rates of approximately 80 to 90 % have been reported for directly predicting interruptibility and user state, such as "standing" or "walking", and social context, such as "lecture" or "conversation". None of these models, to my knowledge, has been explored in health care settings, and there are several factors which suggest that new health care relevant models need to be developed. First; studies on context-sensitive communication for hospitals suggest that information not included in these interruptibility models, such as work role, is critical for detecting proper context in health care settings [13]. Second; another issue is that elements, such as location and social relationships, are inherently different within health care and need to be accounted for in health care appropriate models. For example, scenarios such as “visiting patients” and “in surgery”, need to be considered in combination with the work roles of the person initializing the contact and the contacted person.

In addition, appropriate forms for user-interaction with these interruptibility models also need to be investigated. It has been reported that users tend to use the information provided about a person’s availability for communication, as a presence indicator instead of using it to control interruptions. This suggests that automatic configuration of devices may be the most appropriate approach [64]. As previous presented, the “SenSay” context-sensitive mobile phone [46] uses a hybrid approach that automatically blocks calls, and also generates text messages notifying the callers that their call have been blocked. Then they are allowed to override the blocking by calling back within a predetermined number of minutes from the same phone number. This problem needs to be reinvestigated in health care settings, since there are some situations where certain calls should not be blocked (such as those for a specific role), whereas other calls may need to be restricted. Thus, the context of both the caller and person being called will need to be considered.

The use of semi-structured messages has shown to be particularly useful for work coordination [65]. Preliminary studies have estimated that up to 90 % of mobile text-messages used by hospital workers, could be met by the use of such messages [32]. However, we have not been able to find any published work on the style and function of such messages, or any studies that demonstrate if they would actually be adopted, or if they would have any effect during real work practice. The possibility to create automatic replies, and suggestions for replies, is also an advantage when using predefined messages, but the appropriate replies have not been studied in the context of mobile-text messaging. This could be particularly useful within health care settings, since such replies actually offer acknowledgement that a message has been read [10].

2.4 Additional research

Some interesting work within patient signals and nurse calls has been done by a research group at Norwegian University of Science and Technology (NTNU). This group studied the combined nurse call system recently implemented at St. Olavs Hospital, which comprises fixed and wireless devices. Following this study, context, coordination and communication technology is now being investigated in the scope of a new project in health informatics.

In a study published by Kristiansen [66], she describes in detail how the nurse call system at NTNU is intended to work, compared with how it actually works in practice. The focus was on the contextual decisions taken by the nurses, and how ICT systems may support them through awareness or raise issues through unwanted interrupts. She concludes by proposing improvements to the existing system, considering the role of function and data redundancy [66].

In another study by Karlsen et al. [67], they compare communication patterns and use of communication technology in a geriatric and an emergency department. In this study the authors used three dimensions to analyse the structuring of cooperative work - spatial, organizational, and social. In this study is explained the difference in the use of communication technology according to the different degrees of overlap, in both departments, between the notion of physical space and the wider notion of place [67]. They suggest that the notion of space and place, and their three structuring dimensions, should be included in the requirement elicitation process of intra-hospital communication technology [67].

3 MATERIALS AND RESEARCH METHOD

3.1 Materials used in the research

This section will introduce the overall working framework and materials used when developing the context-sensitive system for mobile communication for hospitals, CallMeSmart. The system is based on the Ascom Unite System, trixbox, Zimbra exchange server and Smartphones, which will be explained further in the following sub-sections.

3.1.1 Ascom IP DECT

Digital Enhanced Cordless Telecommunication (DECT) standard provides general radio access technology for wireless telecommunication[68]. DECT is designed to provide any telecommunication network a variety of applications and services. A DECT system consists of a DECT fixed part, one or more base stations, and one or more DECT portable devices. There is no restriction on how many base stations each network can include. Each DECT system supports traffic for up to 100000 users [68]. This technology is used all over world and is a worldwide standard within telecommunication[69]. Ascom IP DECT is a DECT system connected through an IP backbone within the Ascom UNITE system.

The Ascom UNITE system

Ascom UNITE system is build up by modules connected over an IP backbone. All the available modules are tightly integrated and exchange data using the proprietary UNITE protocol using TCP/IP. Each module runs on an hardware platform called ELISE (Embedded Linux Server) and comprises: a host router which handles all the internal communications and between the modules, a UNITE Name Server used to translate call IDs into internal addresses, a Web Server for module configuration, a Linux based operating system and a Host Attendant which handles the basic configuration and supervision of the installed software. All modules communicate as one system by using the UNITE protocol as a common platform. The main functionalities of the system include:

- Remote management;
- Number planning and advanced message routing;
- Group handling;
- System supervision and advance fault handling;
- Activity logger;
- User administration.

Ascom Enhanced System Services (ESS)

The ESS is the central unit of the UNITE system. It is based on ELISE hardware to manage portable devices and provide different services:

- Number planning and message routing;
- System supervision, logging and fault handling;
- Message routing based on alarm functionalities.

It can be connected to different carriers: System 900, DECT and VoWiFi systems, and manages the number planning, the creation of user groups and configuration of individual users. The ESS is replaced by the context-aware system, CallMeSmart, and the PBX in order to override the standard call management.

Ascom Integrated Message Server (IMS)
The IMS is a middleware between the IP-DECT base stations and all the other modules within the Ascom UNITE system. It manages data directed to and from the phones, and supports the following services:

- Message distribution;
- Central phonebook;
- IMS messaging tool.

Ascom Open Java Server (OJS)
The OJS is part of the Ascom IP messaging platform. It is a programming server, which makes it possible to implement customized features not covered by the standard Ascom UNITE System, and it is directly interfaced with the IMS. Using OJS it is possible to make a Java application communicate with the Ascom messaging system, and also establish communication with external systems like CallMeSmart. The communication between OJS and IMS is illustrated in Figure 3-1 and the communication with external systems is illustrated in Figure 3-2.

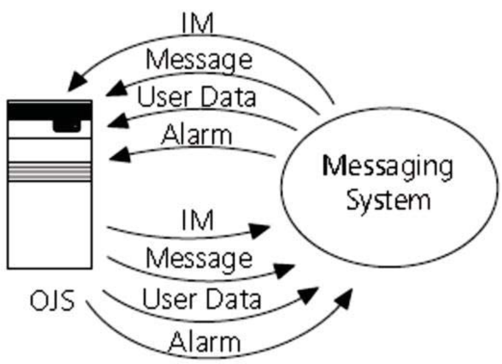

Figure 3-1: OJS communication with the IMS [28]

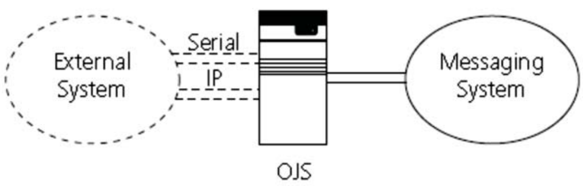

Figure 3-2: OJS communicating with external systems [28]

The OJS provides a Java interface called the Open Access Java server (OAJ). The OAJ is an API containing specific libraries that can be used to manage all the information listed in Figure 3-1 and it includes an application development kit, used for development of customer specific applications.

Ascom IP-DECT Base Station

The Ascom IP-DECT base station, shown in Figure 3-3, uses the DECT standard to enable full access to messaging and voice functions between the base station and the wireless handsets. It works as a bridge for data exchange between the Ascom wireless phones and the Ascom UNITE network. Its main characteristics are the following:

- DECT GAP/CAP radio interface;
- Supports H.323 or SIP protocol over IP;
- On-air synchronization;
- Web interface for configuration and software upgrade;
- Roaming and handover.

Figure 3-3: Ascom IP-DECT base station

Ascom handsets

We had two different types of handsets from Ascom available in the Context lab: 9d24 MkII and d62, shown in Figure 3-4 and Figure 3-5. The d62 differs from the 9d24 MKII by being more intuitive and with a coloured display not available on the 9d24 MkII.

Figure 3-4: Ascom 9d24 MkII

The d62 is a new generation of handsets from Ascom. Ascom d62 provides easy interaction with colleagues and systems, with smooth administration by application of smart solutions, such as Centralized Management. Both models provide advanced messaging functions, up to 10 profile modes with customizable settings, and 3 programmable soft keys for each profile, which can be used to push data to the Ascom UNITE system.

Figure 3-5: Ascom d62

The Ascom Location Device

The DECT location devices are based on the DECT standard. The 9dLD location devices pick up and locate wireless DECT devices and store location information when the device changes its location. The 9dLD location device only works with the DECT devices in which the location feature has enabled.

The 9dLD devices continually transmit location information and RSSI (Radio Signal Strength Indicator) value to the base station. The wireless device that picks up the signal compares the radio signal from the 9dLD device with received RSSI value. Based on if the radio signal is equal or stronger than the RSSI value, the location is considered as being valid and stored by the wireless handset. Two location codes are stored in order to get information about direction of movement. When an alarm is sent, the two last stored location codes and the time elapsed since they were received, are transmitted to the alarm server. This can be used to locate the last position of the wireless device.

IP-PBX
Public Branch eXchange (PBX) server, also known as public Business Exchange server, is a telephone exchange system. The PBX is the internal phone server which enables the connection between a public phone line and the phone extensions within the office or, in this case, the hospital. The main functionalities of the PBX system include: management of phone extensions, voice mail, call routing based on user phone status and call parking.

The Ascom IP-DECT system is connected to the IP-PBX, in this case trixbox.

3.1.2 trixbox

trixbox PBX manages the call functionally for the Ascom UNITE system within the Context lab. All components in trixbox come with pre-installed components, which include:

- CentOS 5.2: The core operating system, a community supported version of the Red Hat Enterprise Linux distribution;
- Asterisk 1.4: The PBX engine which include full customization capabilities;
- Free PBX 2.5: Graphical User Interface (GUI) which includes easy management of the Asterisk configuration files;
- Flash operator Panel (FOP): GUI designed for call management, which include users to check the status of all the extensions subscribed in the system and manage them if necessary;
- trixbox CE Dashboard: trixbox GUI.

The Asterisk's dial plan defines how to handle inbound and outbound calls, and is one of the most important parts of Asterisk. The dial plan is a list of commands and instructions, which is executed during a call directed to a number identified to a particular phone.

Asterisk Gateway Interface (AGI) enables third party applications to dynamically change the dial plan when a call is introduced. It is a programming interface for Perl, PHP, C and Pascal.

FastAGI is a Java implementation of the AGI communicating with Asterisk over TCP/IP using TCP sockets. FastAGI API makes it possible to remotely control the dial plan and thereby the call's behaviour.

3.1.3 Zimbra exchange server

Zimbra Collaboration Suite is an enterprise open source email server. It offers services through its SOAP interface [70]. SOAP requests over a TCP-IP connection makes it possible to extract user data stored on the servers. CallMeSmart uses Zimbra to extract appointments for the users. It runs on Linux Ubuntu Server 64 bit.

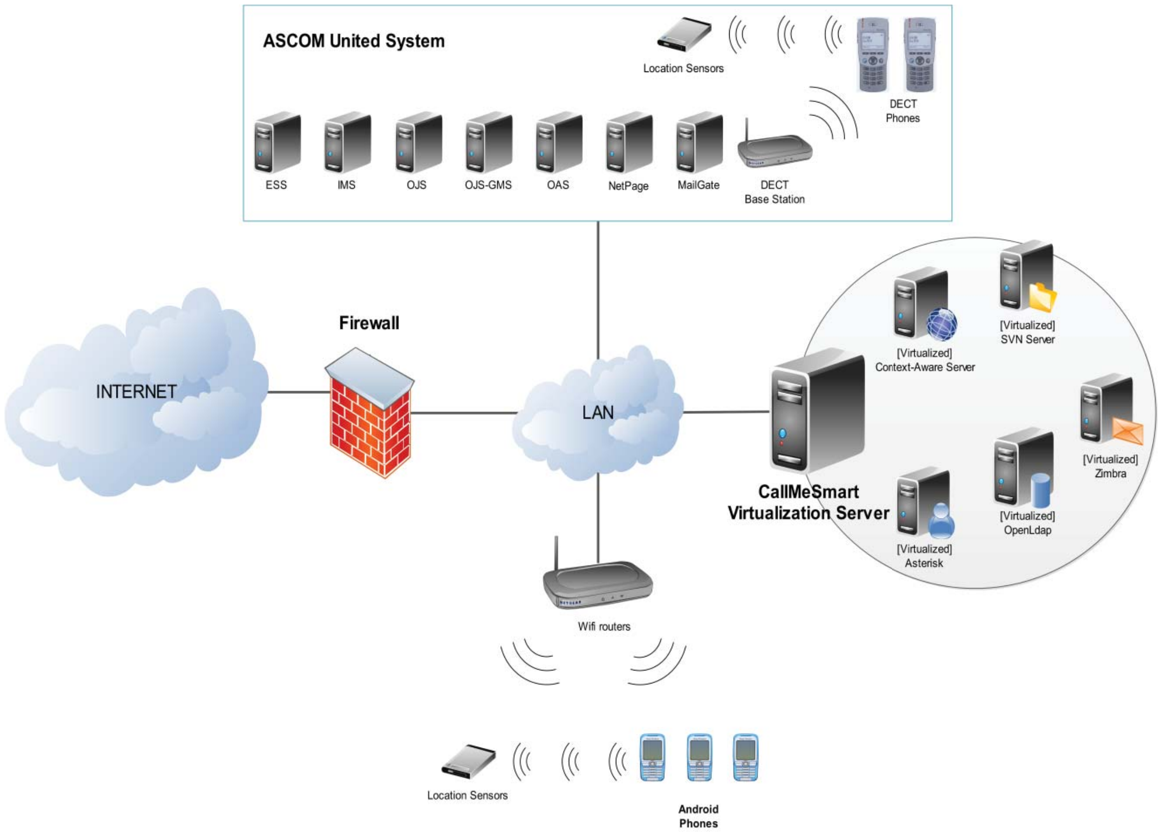

Figure 3-6: Context laboratory framework architecture

3.1.4 Work framework

The Context laboratory is illustrated in Figure 3-6 and consists of:

The Ascom Unite system, previously described.

The CallMeSmart Virtualization Server: Windows Server 2012 which runs VMWare Workstation 8 to virtualize all machines needed by the CallMeSmart system.

> **Context-Aware Server:** Set of software solutions installed on Microsoft Windows Server 2008 R2, to provide context-aware services by intercepting, analysing and managing calls and messages. It is composed by:

- **The Context-Aware Application:** application that permits the interception of all information circulating in the network to provide additional services (i.e. if a caller tries to call a busy person, the caller will hear a pre-recorded vocal message). In fact, this device performs all context services. A GUI was made to allow the visualization of the status of each user of the system. This is a self-made Java 6 application.
- **Openfire server 3.7.1:** A real-time collaboration server using the XMPP protocol [71] for instant messaging. This server is used by the Context-Aware Application and by the Android smartphones to share messages and data using XML format.

- **Administration Panel:** Application which permits administrators to manage groups, users and the configuration of the global CallMeSmart System (Ldap [72], Context-aware database etc.). It is a self-made Java EE program, running on Glassfish v3.1.2 [73].
- **Context-Aware database:** A set of databases running on PostgreSql 9.2 to store all data used by the CallMeSmart system (configuration, logs of services provided, accounts etc.)

SVN Server: This is a subversion server (a software versioning and revision control) running on Ubuntu Server 12.04. The source code of every self-made application is available here (Android Softphone, OJS Client, Context-Aware Application, Administration Panel, Location Application)

OpenLdap: Running on Debian 6, this server implements the LDAP protocol for accessing and maintaining distributed directory information services over a hierarchical structure. This server implements a self-made ldap schema in order to provide a centralized authentication system for the CallMeSmart system (e.g. Asterisk and Openfire). OpenLdap was chosen because it is platform independent software and under a BSD license. Any LDAP server could be used in the CallMeSmart System as long as the self-made schema is installed.

Asterisk(1.8): A software implementation of a PBX under GPL running, in our case, on a Debian 6. Until October 2012 we used trixbox Community Edition system, a free PBX based on Asterisk with graphical and command-line tools on top of it, as explained previously. Since October 2012, this version is no longer supported or updated and only a proprietary version called trixbox Pro is available. Due to license restrictions, CallMeSmart will use only Asterisk. This Software permits to intercept calls and customize them through the Context-Aware Application over the AGI API.

Android based Smartphones

- Samsung Galaxy ace: Android 2.3.3 and TouchWIZ User Interface (UI).
- Samsung Galaxy SII: Android 2.3.5 and TouchWIZ UI installed, updated to Samsung original Android 4.0.3.
- Samsung Galaxy Tab 7”: Tablet set up with Android 3.2 and TouchWIZ UI installed.
- Samsung Galaxy SIII: Android 4.0.4 and TouchWIZ UI installed.
- HTC Desire: Android 2.1 and Sense UI installed, updated to HTC original Android 2.2 and 2.3.3. It was also tested with a rooted Android 4.0.4.
- HTC Sensation XE: Android 2.3.4 and Sense UI installed.

Location devices for Android phones

The Bluetooth location sensors we use are Windows based laptops running Microsoft Windows XP with self-made software developed in C# called Location App. Every minute, this software tries to establish a connection with all Bluetooth devices in the range of the Bluetooth station. Every time the software connects to a device stored in the CallMeSmart system, it forwards this information to the Context-Aware Application through Web Sockets.

The hardware and software versions, on which the Context laboratory is built on, are listed below:

- Ascom UNITE platform hardware: IP-DECT Base Station v3.1.23, Handsets models: 9d24 MKII v3.71 and d62 v2.8.22, IMS2 v2.36, OJS v3.0
- Machine running the application: Primergy TX100 S1 server, dual processor Intel Xeon CPU X3220 @ 2.40 Ghz, 2.39 Ghz, 8 GB RAM. Operating System: Microsoft Windows Server 2012 Standard provided with VMWare-Workstation 8.
- Ubuntu Server 12.10 64 bit
- Debian 6 64 bits
- Zimbra Collaboration Suite version 7.0.0 installed on Ubuntu Server
- Android 2.3 (Minimum)
- WiFi Routers: TP-LINK TL-WA730RE

3.2 Research method

The research methods used during this PhD project will be presented according to the different phases of the research: observations and interviews; scenarios; prototyping and evaluation. For more details I refer to the papers where the methods are explained according to the collected data.

3.2.1 Observations and interviews

For the observations and interviews, we used an ethnographic and interpretive field research approach [74-77]. Ethnography and participant observations are representing a uniquely humanistic interpretive approach [77]. Interpretive research has the potential to explain the human thought and action in a social and organizational context [75]. I have also considered principles from trusted pervasive health [78, 79].

How people describe their activities often differ from what occurs in practice. This is one of the main rationales for doing observations. "*There can be several reasons for this phenomenon, such as the limitation of the human memory, people are not always aware of their actual behavior, people may be concerned with their image and thereby smarten up the story, and also the complexity of the social life could do that different people report differently.*" [9].

The purpose of observing is to learn and understand, as much as possible, from the work of physicians focusing on interruptions from mobile devices. During observations, I took the role of a first year medical student, dressing and acting like a physician, to blend in as much as possible to get a more realistic picture of the communication situation. This technique is often referred to as "shadowing" [80]. I registered data on a self-constructed form using pen and paper. I decided to use pen and paper instead of a digital device like a PDA, as used in [81-84], since these physicians did not used devices like that. This helped me blend in as much as possible, and avoided unintentional attention.

Interviewing is also an important method within ethnography. Interviews could help to understand the observed situation and the subjects' perspective. I did the interviews during on-going activities during the observations. This way, I connected the observations to the interview and thereby got answers to questions about the observed activity. This helped me understand the situation from the subjects' perspective. Interview guides were not used, but questions were asked relating to the observed situation context. The interviews and discussions focus on the use of wireless mobile communication devices regarding improvement and interruption management.

Data analysis was conducted concurrently with the data collection process using Grounded Theory [85]. I began the initial data analysis by reviewing all the notes and reflecting on some general issues that seemed inherent to the data. This is an adequate approach to understand the communication situation in hospitals. Analysing observed situations, and then compare them with comments and answers from interviews and discussions, is a good way of mapping the communication situation, and also to capture and understand potential changes over time.

3.2.2 Scenarios

After doing observations and interviews, different techniques can be used to define requirements of a system. Regarding HCI, Carroll [86] argues the use of scenarios, and in [87] is proposed a scenario driven process for context-aware service design. A framework for scenario based design within HCI has been proposed by Benyon and Macaulay [88]. This framework consists of two main approaches:

1. The user-centred perspective is characterized by Person, Activity, Context, and Technology (PACT);
2. The designer-centred aspects are characterized by Function, Interactions, Content, and Structure (FICS).

For information systems research, Hevner et al. [89] describes another framework which divides business needs in three categories: People, Organizations and Technology. Benyon and Macaulay [88], seems to reflect this.

Sutcliffe [90] also describes the use of scenarios during the design process. He defines his scenarios within system design as: ‘visioning scenarios’, ‘scenarios of use’ and ‘context and use scenarios’. This also reflects Benyon and Macaulay’s [88] framework for scenarios within the design process.

The use of scenarios in HCI and requirements engineering is also described by Go and Carroll [91]. They also describe the shift of scenario usage from a single user with a single device to CSCW.

Favela’s [92] and Bardram’s [93] projects within context-aware systems, like the CallMeSmart project, also applies to scenario based design. Bardram agrees with Benyon on the dynamic nature of scenarios during the design process. The ‘organizational’ and ‘personal’ oriented records reflect the PACT aspects and the ‘object’ oriented record reflects the FICS aspects. Favela used a less formalized scenario structure.

In this project we have used Benyon and Macaulay’s [88] framework for scenario design and the framework for the actual scenarios. This includes the PACT and parts of the FICS aspects, which is updated with the service aspect presented by Widya et al. [94] and van’t Klooster et al. [95]. The idea of using conceptual scenarios in the design of CallMeSmart is to open up for discussions that eventually deal with the remaining questions on how the system requirements were clearly defined. Then the developers were involved to formulate the concrete scenarios, which were evaluated by users before the initiating the prototyping.

3.2.3 Prototyping & evaluation

Before starting the development of the CallMeSmart prototype, we had to do performance analyses of the Ascom/trixbox system. To do this, we developed a benchmark program which was mounted on the OJS to test the timing of the data transmissions. Denning et al. [96] engineering approach was used in an iterative manner, followed by tests with different amounts of data typical from real scenarios within healthcare. We used Raj Jain's approach [97] to avoid common mistakes on performance evaluation.

A software engineering approach was used to develop the prototype of the context-sensitive communication system, CallMeSmart. We used the Unified Process, based on the ideas of Boehm [98] and Gilb [99], which is an iterative and incremental development methodology, also known as spiral development or evolutionary development. Using this approach we divided the development process into a series of mini-projects or iterations. The purpose was to increasingly enlarge and refine the system during the iterations. This way we gradually approached the requirements of CallMeSmart. In this model they normally do not start with the full specifications of the requirements. Only the most important features are developed and then subsequently improved and adjusted to include missing requirements during the next iterations. Each iteration includes [100]:

- Requirements: Identified, collected and analysed;
- Design: The software solutions were designed using Use Case diagrams to capture the functional requirements. Interaction diagrams were used to define the interactions between the software components. Other graphical Unified Modelling Language (UML) notation models were applied to define the overall architecture of the software;
- Implementation: Implementing the software and improve the system already developed;
- Testing: New developed features were tested in order to verify consistency, stability and bugs free.

A new iteration was started if the requirements were not met after these steps.

The evaluation and tests were carried out by simulating typical scenarios within healthcare settings, where the functionalities of CallMeSmart were tested for quality and stability with several test users, in this case physicians. After each scenario, the users gave feedback on their experience. We also asked them a set of questions regarding their user experience.

For the GUI design of the CallMeSmart system we used ideas from HCI and we made new interfaces that we visualized in a low-fidelity prototype, using Microsoft PowerPoint 2007. This is advanced enough, at this stage, to test a GUI with users [101-103]. The prototype simulates the real phone and makes it possible to interact with the GUI by using the mouse on simulated buttons, and with enough details to get feedback on the usability from the test users.

To evaluate the GUIs we used a method with similarities to heuristic evaluation, where 3-7 usability experts identify challenges of a GUI using their experience and design heuristics [101, 104]. Based on guidelines for interface design [104-107], we made a list of possible usability problems. The context and requirements, for the usage of the system in a healthcare environment, were kept in mind when identifying the problems [108], together with a set of guidelines for the design of context-aware mobile devices [109].

4 RESULTS

In this chapter the results from the research attained in this project will be presented. The research was conducted in three phases, carried out in the order I will present the results.

4.1 Observations and interviews

4.1.1 The initial study

This Ph.D. project is based on the initial study done at the Oncology Department at UNN [3]. The initial study was carried out in three stages. The first stage, denoted participatory observations, included open interviews and informal discussions; the second stage involved semi-structured interviews of a selected group of physicians, at various levels of experience; and the third stage consisted of a second round of participatory observation sessions. The study revealed a general concern among the physicians that wireless phones lead to more frequent and more severe interruptions than pagers. The observed physicians adopted various strategies for obtaining benefits from wireless phones but, at the same time, they avoided interruptions by, for example; using the wireless phones only for outgoing calls and kipping the number unknown to other staff members. Also, some physicians showed a general preference for pagers by avoiding carrying a wireless phone at all.

From this study, we started planning a context-aware communication system to provide physicians with a reliable mobile to use in their daily practice and accomplish their main tasks easier and successfully. We came up with a premature model for what the system was supposed to do according to users and their surroundings. This is illustrated in Figure 4-1 [27], and was published (P1) in Botsis, Solvoll et al. [27], at the 7th WSEAS International Conference on Applied Informatics and Communications, Vouliagmeni, Athens, Greece in 2007.

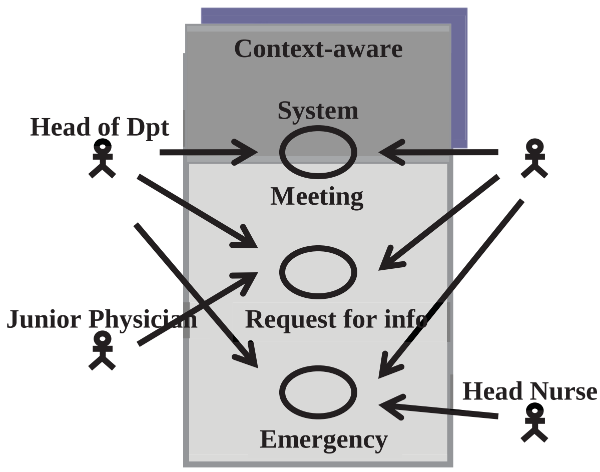

Figure 4-1: Use cases and users [27]

We also proposed a simple system architecture built on top of the existing infrastructure UNN used, where we were supposed to sniff the signals from the existing paging/phone system before they are sent out to the pagers/phones, leaving the existing system intact. The signals were then supposed to be re-routed through our context-aware server, where we decided what would happen with the call/page, as presented in Figure 4-2.

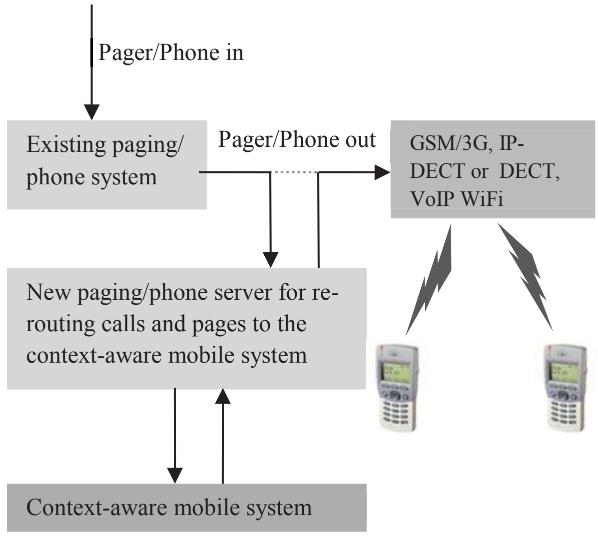

Figure 4-2: Proposed system architecture [27]

4.1.2 Interviews from a surgical ward at UNN

The initial studies, carried out in the oncology ward at UNN, investigated the usage of mobile phones. However, the findings from this study may not apply in surgical wards since, oncologists have long-term relationships with patients with few emergencies and surgeons normally have short-term relationships with many emergencies. Thus, we contacted several surgical wards at UNN and got in contact with the gastro-surgical department, where we confirmed that interruptions are a problem, especially in surgical theatres, outpatient wards, emergency wards and inpatient rooms. We did extensive non-structured interviews and open ended discussions with one surgeon at the department, a presentation of potential context-aware solutions at a meeting with the surgeons, followed by a question and answer session and a discussion with the head of the department. The study was published (P2) as a research article by Solvoll and Scholl [8]: "Strategies to reduce interruptions from mobile communication systems in surgical wards" in Journal of Telemedicine and Telecare, 2008. One of the findings in this study was that also surgeons experienced a lot of unnecessary interruptions from mobile devices. One of the surgeons said *"when you are at the most critical stage of an operation, and just a small error could have tremendous consequences, the beeper always goes off"* [8]. He also said that such interruptions also were a problem when they were having serious talks with patients in patients' rooms: *"It is not beneficial if the beeper constantly goes off when you are telling a patient that he/she has a serious illness"* [8].

This study confirmed that health care workers in hospital settings, especially surgeons and physicians, need a better communication system. A system that integrates both the pager and the phone system in a single device, which integrates and makes use of context information to control interruptions automatically, would be highly appreciated by the users. Therefore, it was important to investigate surgical wards more in detail. This includes observations, interviews and recording of how often the staffs are interrupted, and by whom. This can be used as a basis when designing and developing the system.

4.1.3 Observations and interviews at St. Olavs Hospital

Following the study at UNN, we decided to gather data from another hospital to get a broader perspective of the situation and also to investigate surgical wards more in detail. I contacted St. Olavs hospital, where I had the opportunity to observe and interview physicians and surgeons at different level of the hierarchy in different situations of their work, for a total of two months, at the ear, nose and throat and the child and youth clinics,. The study was published as a research paper (P3) by Solvoll, Scholl and Hartvigsen: "Physicians interrupted by mobile devices in hospitals – understanding the interaction between devices, roles and duties" in JMIR 2013 [9]. Here I demonstrate the degree of interruptions from mobile devices that physicians experience in their daily work, and in which situations they are interrupted. The physicians attending the study indicated that wireless phones probably lead to more interruption immediately after introduction in a clinic when compared to a pager. This seemed to change after a short while, explained by the unpleasant feeling the caller experiences immediately when interrupting someone by calling them, compared to sending a page message, which is more asynchronous and leaves it up to the receiver when to return the call.

The study shows that physicians were interrupted several times in situations where they should not be unnecessarily interrupted. In the identified situations most of the interruptions were considered as "not important" and could have been answered when the physician became available, or answered by others. This was emphasized by a physician after several incoming phone calls/pages: *"If somebody tries to call me on the phone, and it is busy, they page me, why? I'm busy in the phone and cannot return the call immediately."* Another assistant physician also expressed her frustration after several interruptions; *"I really want a system that could separate the important/critical calls from those that could wait."* [9]. Regarding if the users were satisfied with carrying a wireless phone compared with pagers, one physician said: "*People are generally satisfied with carrying phones compared to the old days when we only had pagers, but it took a while to adjust to the new system. After some time you learn to screen the calls, the important ones from those that are not so important. With a pager you never know and, therefore, you have to return the call as soon as possible".* When asking if he thought the phone is more interruptive compared to the pager, he said: *"The phone is less interruptive compared to the pager. I do not know if it is me who has been better to tell people when I'm available and manage the communication, or if it is the others who have been better."*[9].

The UNN physicians that participated on the studies presented in [3, 8] were concerned that a wireless phone was going to be much more interruptive, when compared to a pager, and that a phone call interrupts more than a page. This was challenged by some of the physicians we met at St. Olavs Hospital, which thought the phone was more interruptive than the pager in the beginning, but changed their opinion after a while. They said that, after a while, it would go back to the same level of interruptions, or even fewer interruptions with the phone, explained by being more unpleasant to call someone, and interrupt their work, than just page them [9].

From this study we conclude that "mobile devices, which frequently interrupt physicians in hospitals, are a problem for both physicians and patients" [9]. We used the results from the study at the St. Olavs Hospital, in combination with the findings from earlier studies [3, 8], as input when designing and developing the prototype for a context-sensitive communication system for mobile communication suitable for hospitals, CallMeSmart.

4.2 Scenarios

Several different scenarios were described after the observation and interview studies. Some of these scenarios were used in a simulation study using a method called PAM for recognizing awareness, which was published in P7 by Talaei-Khoei, Solvoll, et al. [110]. This is a method developed by the research group, APuHC, with which I cooperated during my research visit in Sydney, Australia. The scenarios were used as input data for the simulation experiments for applying PAM in the wireless communication system at St. Olavs Hospital. The objective was to see the efficacy and cost-efficiency of PAM in such scenarios [110]. On the paper we conclude that PAM, in theory, could be an effective tool for recognizing awareness, which is also illustrated, and tested with the same scenarios, in P8 by Talaei-Khoei, Solvoll, et al. [111].

Some of these scenarios were also used as the scenarios simulated when testing the first version of CallMeSmart [112], and the "mock-up" prototype of the GUI presenting the Ascom phones used in P6 [113], and the softphone in P10 [100].

We used the scenarios in a more advanced stage to re-design CallMeSmart, and further as a fundament when defining conceptual scenarios and user stories, which were used to test and improve CallMeSmart. This is presented on the study P11: Interruption management for hospital communication systems: A user requirements specification, by Talsma, Solvoll and Hartvigsen, was submitted as a research paper for AMIA 2013 in March 2013. "The scenario describes a generalized day of a physician, performing several recognizable tasks, such as handover meetings, consultations, surgery, and patient rounds. In this conceptual scenario, the CallMeSmart system is used for managing mobile communications. The scenario was presented and discussed together with a parallel user story, mirroring the same tasks, but without the interruption management system." [114]. The feedback from the users has been used to improve the user experience of CallMeSmart.

4.3 Prototyping and evaluation

4.3.1 Performance tests and evaluation of Ascom/trixbox

Before we could start implement the first version of CallMeSmart, we had to test the Ascom UNITE system and the DECT platform we had available in the Context Laboratory, in combination with trixbox. The tests regarded the data transfer performance and the design opportunities offered to develop context-sensitive applications, and were published by Solvoll et al. P5 [115]: Evaluation of an Ascom/trixbox system for context-sensitive communication in hospitals, at 8th Scandinavian Conference on Health Informatics in Copenhagen 2010. The paper concluded that: "there are several serious limitations of the Ascom/trixbox system in order to be efficiently used for context-sensitive communication in hospitals. The main problems are related to the programming platforms, along with a narrow application field of the location devices."[115].

4.3.2 The first prototype of CallMeSmart

The limitations of the Ascom/trixbox system, mentioned in section 4.3.1, made me pursuit other solutions to develop CallMeSmart. Thus, I thought of build up a Context Laboratory, consisting of Cisco Call Manager [116] instead of Ascom UNITE. The project had a contact at Cisco Norway and collaborations were established, where we could borrow the software from Cisco, as the hardware we needed to run the software was too expensive for the project.

I could not totally give up on the Ascom UNITE system and decided to try to develop a first prototype of CallMeSmart in the Context Laboratory we had available, illustrated in Figure 4-3.

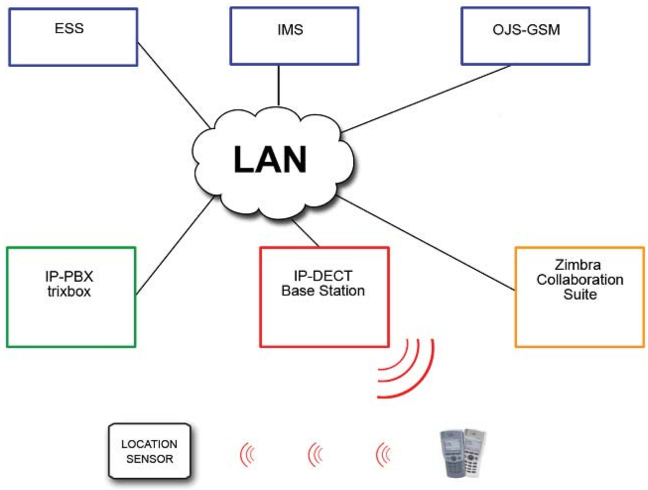

Figure 4-3: Context laboratory for the first prototype of CallMeSmart (ref P9)

After a while we were able to develop a version that worked satisfactorily and we could test the version in the Context Laboratory, using physicians as test users and the developed scenarios to simulate real situations. The results are submitted as a research paper, P9, to IEEE-ICISA 2013: CallMeSmart: An Ascom/trixbox based prototype for context controlled mobile communication in hospitals, by Solvoll, Gironi and Hartvigsen (ref P9). The paper concludes that; “Future works should aim at filling the gaps raised during the tests, integrate the system with different kind of devices providing advanced functionalities and find better strategies to effectively improve the performances in order to deploy the system even in large hospitals.” [112].

4.3.3 Including VoIP based softphones using SIP

Since our performance tests, and evaluation of the Ascom/trixbox, show that the system has serious limits in order to be efficiently used for context-sensitive communication in hospitals, we decided to try to integrate Android based smartphones using WiFi, VoIP and SIP. This will help us be more independent of the Ascom system and migrate from DECT to Smartphones, while still having the opportunity to use the pager and alarm system from the existing infrastructure, including the DECT phones, in a seamless way together with the Smartphones. To do this we had to expand the Context Laboratory to include WiFi and Android based smartphones, as illustrated in Figure 3-6.

We developed the CallMeSmart SoftPhone, which is a VoIP Softphone on Android based mobile devices using SIP. This was published as a research paper by Solvoll et al. in P10 [100]: CallMeSmart: A VoIP Softphone on Android based mobile devices using SIP, at eTELEMED 2013. In this paper it is concluded that; "our implementation of the softphone is working just as well as on the DECT system, and since the smartphones has a wider area of usage, for instance to include patient information, medical reference work, etc., we conclude that the first version of CallMeSmart SoftPhone is ready to be tested in real life within health care settings." [100].

4.3.4 New version of CallMeSmart

Considering the feedback from the users during the tests and evaluation of the previously developed parts of CallMeSmart, we re-design and re-develop the system to make it ready for testing in clinical settings and then for the commercial market. We started out by describing the users in more detail regarding the use of the CallMeSmart. The information listed below, and illustrated in Figure 4-4, was used as input to the system design process, and was continuously refined.

Physicians:

- Often grouped in teams
- Often responsible for different patients
- Often associated with a patient and this link is decided when the patient is moved inside the hospital
- Often have specializations
- Often have a role
- Often lead ward teams

Nurses:

- Nurses could have different roles (Role's names? tasks for each role?)
- Nurses could be part of/grouped in different teams, each team takes care of a number of patients
- Each nurse could have different responsible physicians
- Nurses are the natural users for group messages
- There is a relation between location, role and the team nurses belong to
- The responsibilities of nurses change on a daily basis
- Each nurse can have different responsibilities
- Nurses do the planning… *which planning are we talking about? Need to understand what exactly is this planning.*
- Nurses' teams operate in specific areas in a ward
- Teams are hierarchical
- Nursing teams operate in specific areas of a ward
- The so called 'ward team' is the ward itself (the biggest team)
- Each nurse team is composed by different persons and different roles
- Nurses receive calls from patient's relatives
- Nurses receive calls from primary care

- Nurses receive calls from nursing homes
- An interesting point is that calls from relatives are screened by switchboard or secretaries
- Nurse cancer teams: are more specialized, they contain specialized and different workers with different specializations
- Note that different hospitals could give different meanings to the same role!

Relationships between physicians and nurses, illustrated in Figure 4-4:

- Each *physician could have nursing teams*
- One *nurse* might belong to *more than one team*
- Each *patient* has a *nursing team* and one main physician (or many physicians)
- Morning meetings: Pass information from the day to the night shift
- On call type of persons/roles: Physicians, nurses and administrative persons

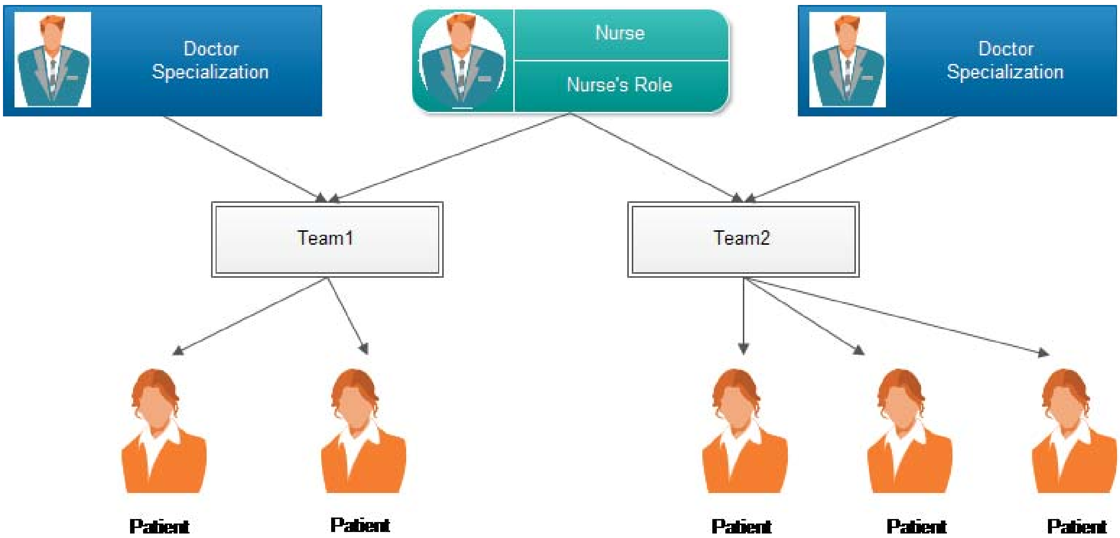

Figure 4-4: Relationships between Doctors and Nurses

After the characterization of users regarding their usage of CallMeSmart, the functionality for the different versions of the system was defined. Examples of such functionalities, here from version 0.x1., are listed below:

- The SoftPhone for the android platform provides the possibility to make calls within the existing Ascom/trixbox platform. In particular, the SoftPhone is capable of making calls between Android devices provided with the CallMeSmart App and the Ascom phones
- Support of DTMF tones for interacting with the Context-Aware System already in place. This means that when the Context-Aware System prompt the user to pick up a choice through a vocal message, by pressing the numeric buttons on the phone, the user is able to choose which action to take
- Functionality which allows the user carrying the phone to change the availability status of: Available, Busy or Pager Mode, through suitable buttons

- Support for 3G network, in case of lack of available WiFi connections. The phone is capable to automatically switch to the 3G network when the WiFi connection is not available anymore
- The CallMeSmart App provides an authentication mechanism which allows the users to log in on the context-aware system and to the SIP server. The UserProfile is defined inside the phone, by editing an account list stored inside the CallMeSmart App. (This is just a temporary solution and for testing purposes, in the future the user will be authenticated on the Context-Aware side)

Further we developed a set of system functional and development requirements with different priorities. Examples of such requirements, here from priority 1, are listed below:

Priority 1 Requirements:
- REQ1: Log In/Log Out Procedure (Android)
- REQ2: Make and Receive Calls (DECT and Android – must interoperate)
- REQ3: Send/Receive Messages (DECT and Android – must interoperate)
- REQ4: Predefined Contact List (Android)
- REQ5: Call Log (Android)
- REQ6: Store Call History (data needed to evaluate PoC)

In Figure 4-5 are illustrated the use cases from priority 1 and an example of one of the cases is shown in Figure 4-6.

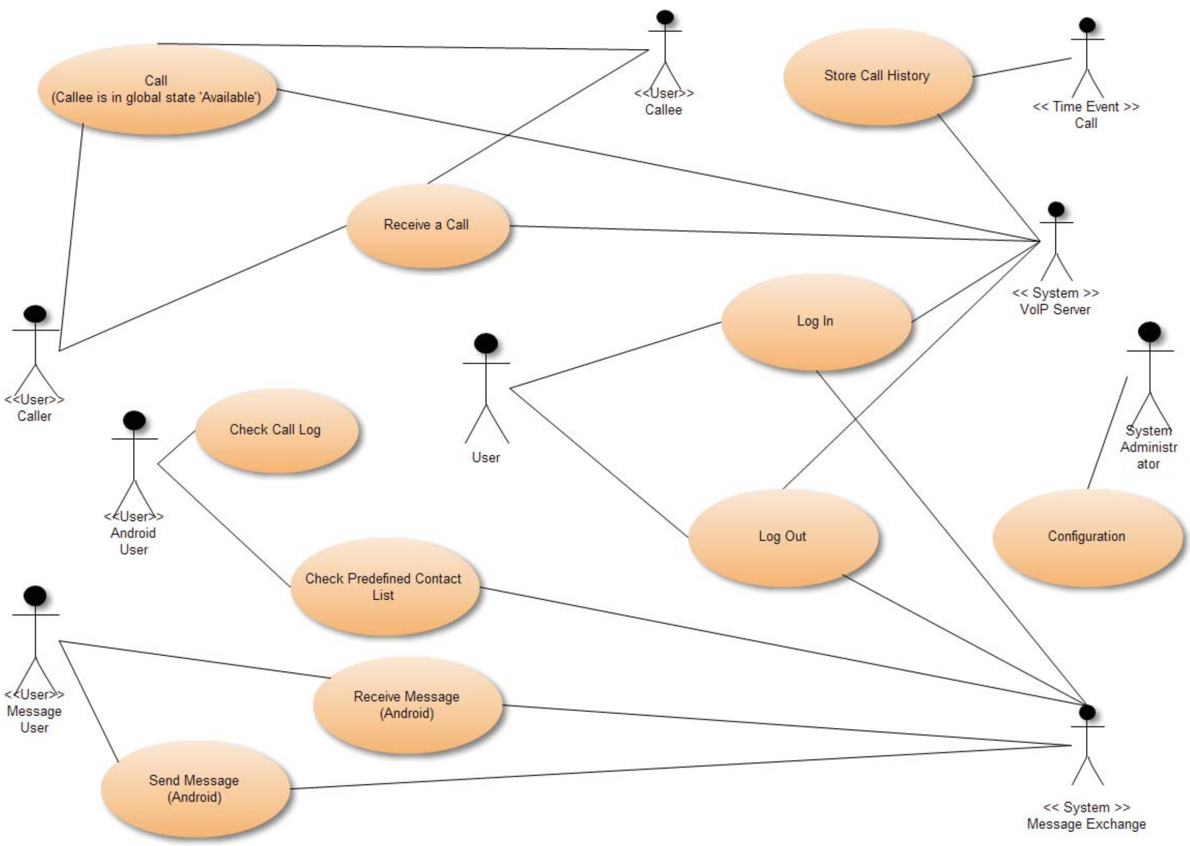

Figure 4-5: CallMeSmart use cases priority 1

Log In Procedure (Android)

Use Case ID:	UC1		
Use Case Name:	Log In Procedure		
Requirement ID:	REQ5		
Created By:	Terje Solvoll	Last Updated By:	Terje Solvoll
Date Created:	25th October 2012	Date Last Updated:	10th November 2012

Actor:	User
Description:	Describes the Log In procedure for Android devices.
Preconditions:	The User is registered into the system. The User is not Logged in. The User opened the CallMeSmart Android Application.
Post conditions:	The User is Logged into the system in case of 'login success. The User is Not logged into the system in case of 'login failure'.
Priority:	Priority 2
Frequency of Use:	High
Course of Events:	1. The user enters username and password from a suitable App Screen. 2. The user presses the 'Log In' button. 3. The system processes the Log In request and: a. Grants the access to the user if username and password match. i. The user state is 'Logged In'. ii. The user is linked to the device used for making the 'Login' procedure. b. Does not grant the access if the username and password do not match, the username is not present or the password is wrong. The user is being presented with an error message saying that the log in failed. i. The user state is 'Not Logged'.
Exceptions:	
Includes:	
Special Requirements:	
Assumptions:	The Android device is properly connected to the Network.
Notes and Issues:	Once a user has logged in, it is subscribed to all the system services (Calling, Messaging and Interruption Management services). To be concrete here we have the registration to trixbox and XMPP). *[Note] DECT Phones register only to the VoIP trixbox server.* **[TODO]** Here the critical problem to solve at later stage (in case of PoC successful) is guaranteeing a mutual exclusive access to the system. In particular, the main problem is trixbox. When two phones attempt a registration with the same account, they are logged both (due to the SIP registration process). A solution for the issue mentioned above could be using a centralized authentication server for all the services.

Figure 4-6: Example of use case

Figure 4-7 and Figure 4-8 illustrate the phones automatic behaviour according to the collected context information and the relations between the phones mode and the context, respectively.

Action	Actor	Available	Busy	Pager
Call	**Caller**	Hears Ringing Tone	Caller Hears vocal message (or sees a popup) and can choose to; - ***Force*** *the Call to the callee.* *- Leave a message to* ***Voice Mail.*** - *Being* ***Forwarded*** *to the next available person (escalation).* - ***Send*** *a Message.* - ***Hang Up*** *the call.*	Caller Hears vocal message (or sees a popup) and can choose to; - ***Page*** *the callee.* *- Leave a message to* ***Voice Mail.*** - *Being* ***Forwarded*** *to the next available person (escalation).* - ***Hang Up*** *the call.*
Receive Call	**Callee**	Rings	According to the caller action, the callee's phone; - ***Rings****, if the caller* ***Forces*** *the call.* - ***Does Nothing****, if the caller* ***forwards*** *the call.*	According to the caller action, the callee's phone; - **Receives a 'Page Message'**, if the caller **paged**. - **Does Nothing,** if the caller **forwards** the call. *-* ***Does Nothing****, if the caller* ***hang up****.*
Incoming Message	**Receiver**	Beeps	Silent	Beeps

Figure 4-7: Remainder for phone's behaviour according the automatic configuration based on collected context information

AV = Available
BS = Busy
PG = Pager
Auto = Automatic

Manual Mode	Critical Area OR Meeting	GLOBAL STATE
AV		Available
AV	x	Available
BS		Busy
BS	x	Busy
PG		Pager
PG	x	Pager
Auto		Available
Auto	x	Busy

Figure 4-8: Relations between phone mode and context

Decisions on the availability are taken by applying predefined or customized rules to the contextual information collected in real time from suitable modules, as illustrated in Figure 4-9. The decision making process module is used by CallMeSmart to provide interruption management services. The interruption management service, shown in Figure 4-10, before allowing a call between two users it first determines if the called person is not involved in critical activity (Step 1), through the analysis of the information collected from the availability, location and schedule modules (Step 2). If the called person is not available, the system notifies the caller about the status of the callee through a vocal message and subsequently prompts the user to choose several options, which change according to the callee context (Step 3b). For example, if the callee is inside a defined critical area, the caller can choose between force the call (in case of emergency) (6a) or being put in contact with the on call person on duty (6b). The escalation process (6c) is the process where the CallMeSmart System picks up a random available person who has the same role as the called person (i.e. if you called a busy doctor, the call can be routed to another physician). The on-call person is determined by the system by checking an electronic schedule where the on-call shifts for each hospital's department are stored.

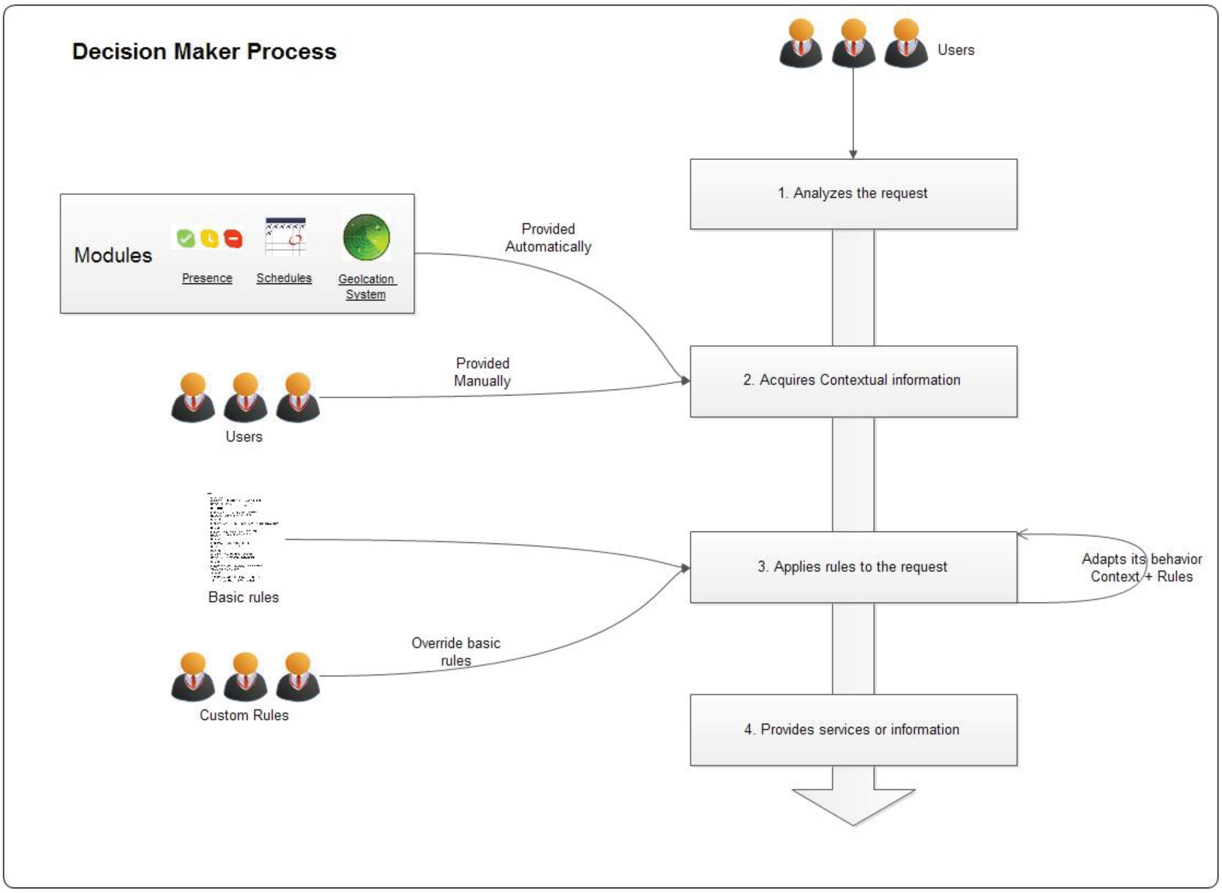

Figure 4-9: Illustration of the decision making process

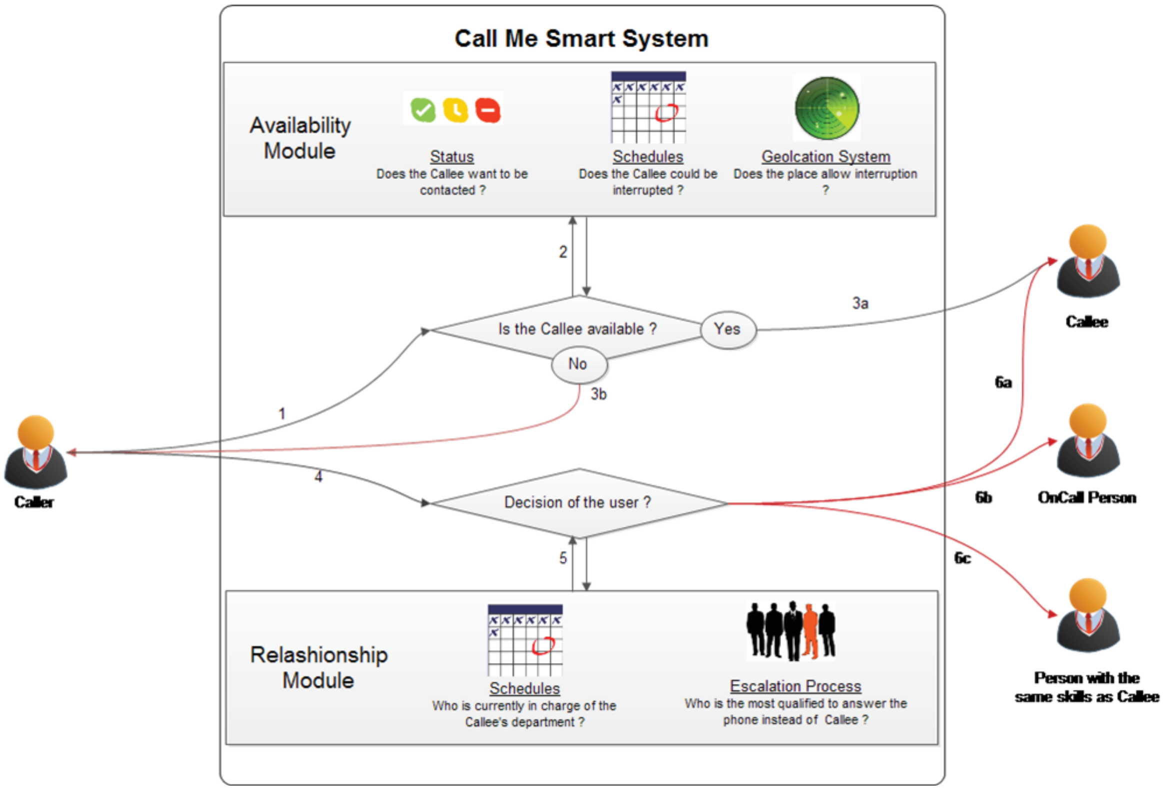

Figure 4-10: The interruption management service

A "presence solution" enables users also to manually change their availability status. A context-aware server permits to centralize all data provided by the components, in addition to share information between them, providing useful information to users, through the sending of messages. The context reasoning process flow is illustrated in the flow chart in Figure 4-11:

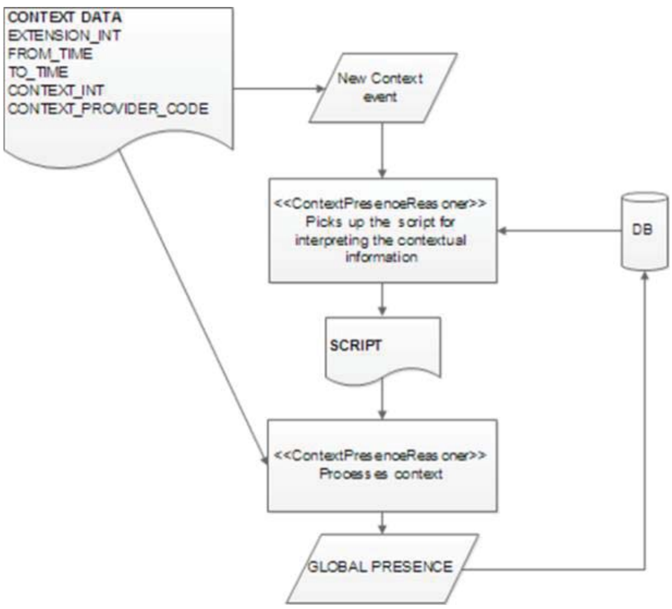

Figure 4-11: Context reasoning process flow

A UML diagram was developed to design the different software components needed to implement each use case. Figure 4-12 illustrates the UML diagram for the software components needed to implement use cases from priority 1.

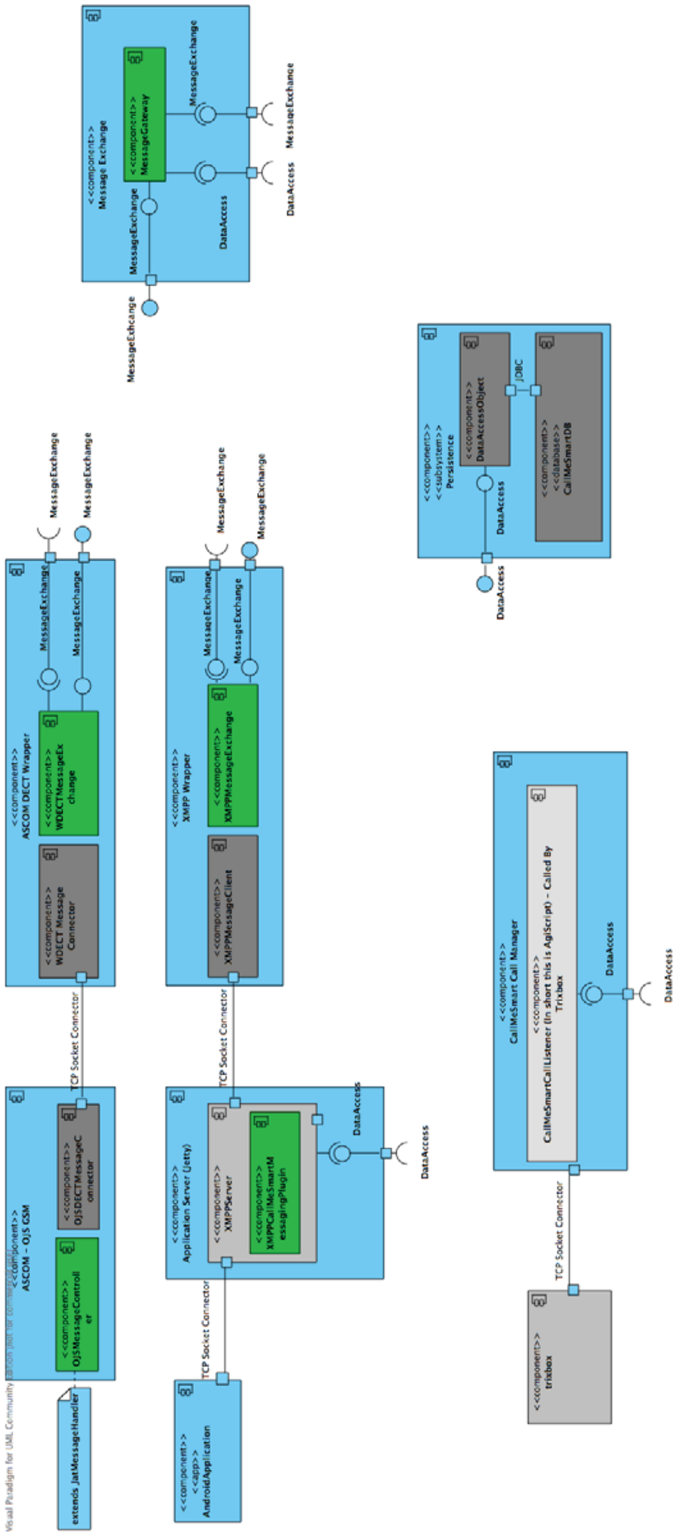

Figure 4-12: CallMeSmart – Software Components Diagram (UML 2.0 Standard [117]) needed to implement use cases from priority 1

The call, messages and data flow is illustrated in Figure 4-13. The information coming from the DECT (or ASCOM) phones uses the OJS client to access the application. In particular when a new message, containing location or user data, is sent from a DECT phone, it is first received by the base station, propagated to the IMS and then to the OJS. A customized Java program, hereafter referred to as *Client*, mounted on the OJS, enables the final communication path towards the context-aware application. It routes data received by the OJS from the IMS and implements specific methods exploiting the functionalities offered by the underlying Java server that allow to send messages and data back to the phones. All the communications between the client and the application are handled through TCP-IP sockets. The information coming from Android phones is sent by opening socket connection between the phones themselves and the listener implemented inside the context-aware application.

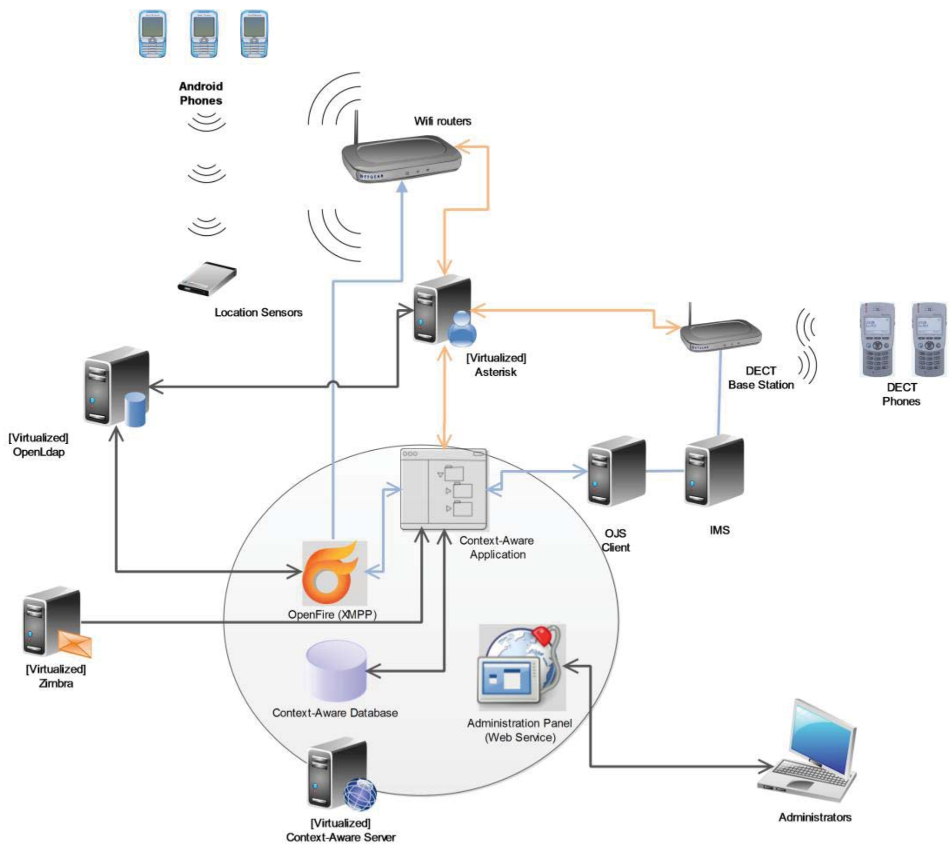

Figure 4-13: Call and data flow: The yellow line describes the path followed by calls, the black line describes the path followed by data, and the blue line describes the path followed by messages.

The overall software architecture of CallMeSmart and the CallMeSmart SoftPhone is shown in Figure 4-14 and Figure 4-15, respectively. There are different software components, each of which providing specific functionalities. As shown in Figure 4-14, the application interacts differently with the DECT and Android phones. This is because the DECT phones communicate through the *Client* running on the OJS and Android phones communicate directly with the application.

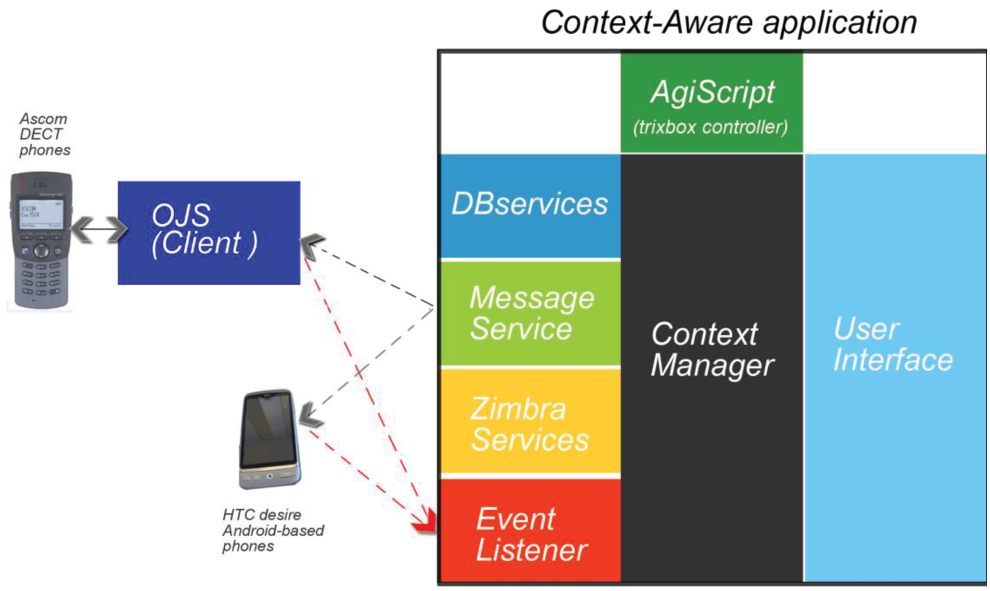

Figure 4-14: CallMeSmart overall software architecture

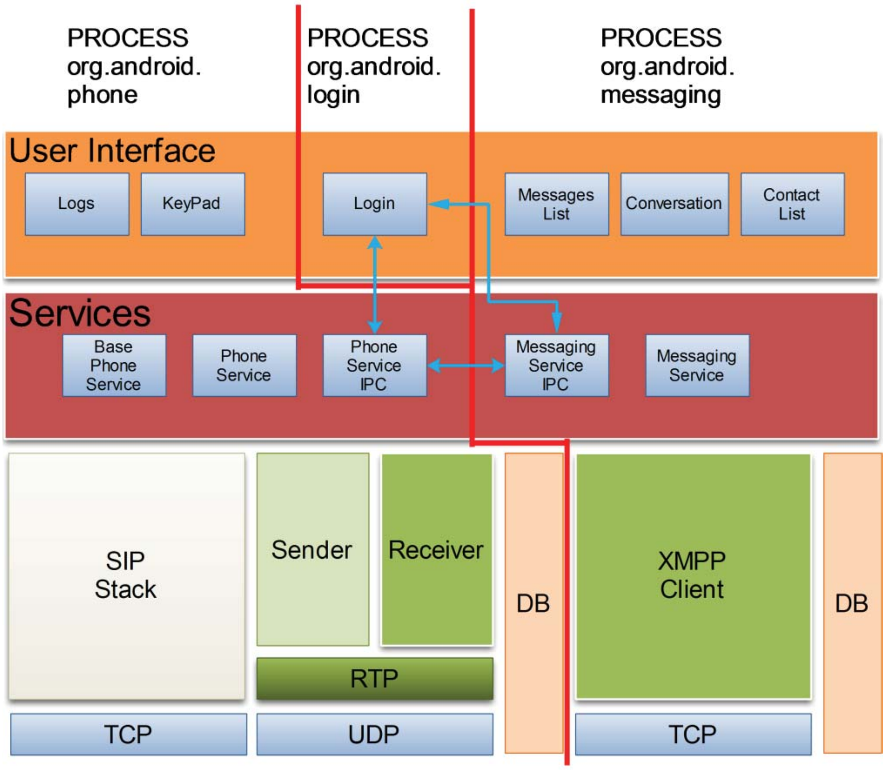

Figure 4-15: Overall software architecture of the CallMeSmart SoftPhone

Figure 4-16, Figure 4-17,

Figure 4-18 and Figure 4-19 shows the class diagrams for the CallMeSmart OJS, CallMeSmart Context Server, and CallMeSmart Android SoftPhone – phone and messaging, respectively.

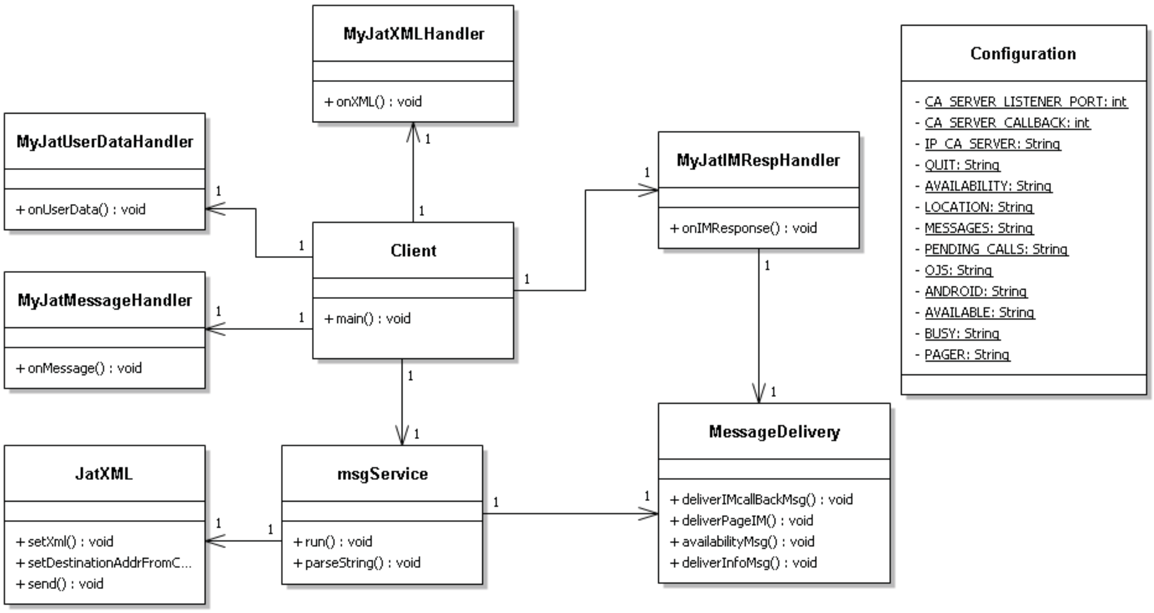

Figure 4-16: Class diagrams for the CallMeSmart OJS

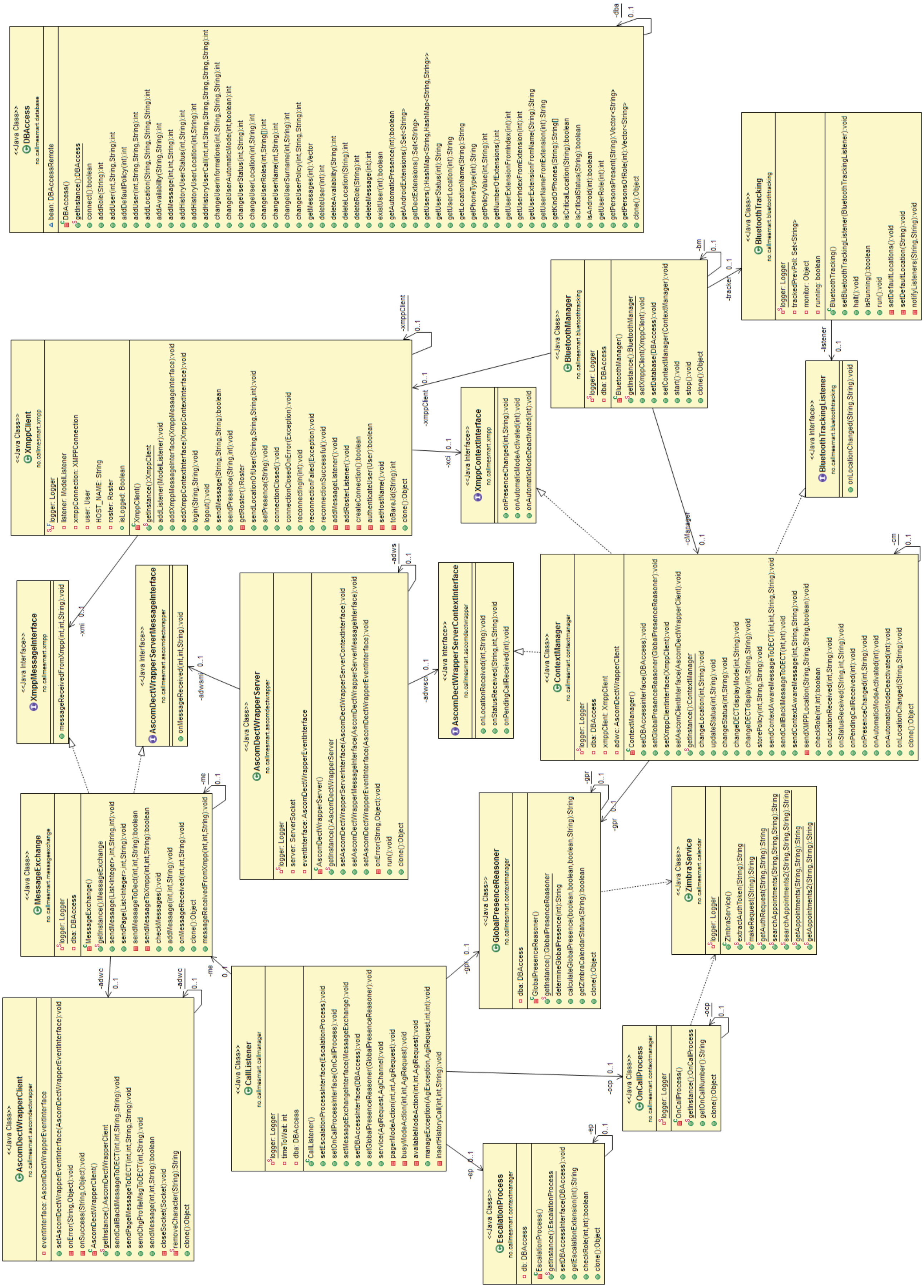

Figure 4-17: Class diagram for the CallMeSmart Context Server

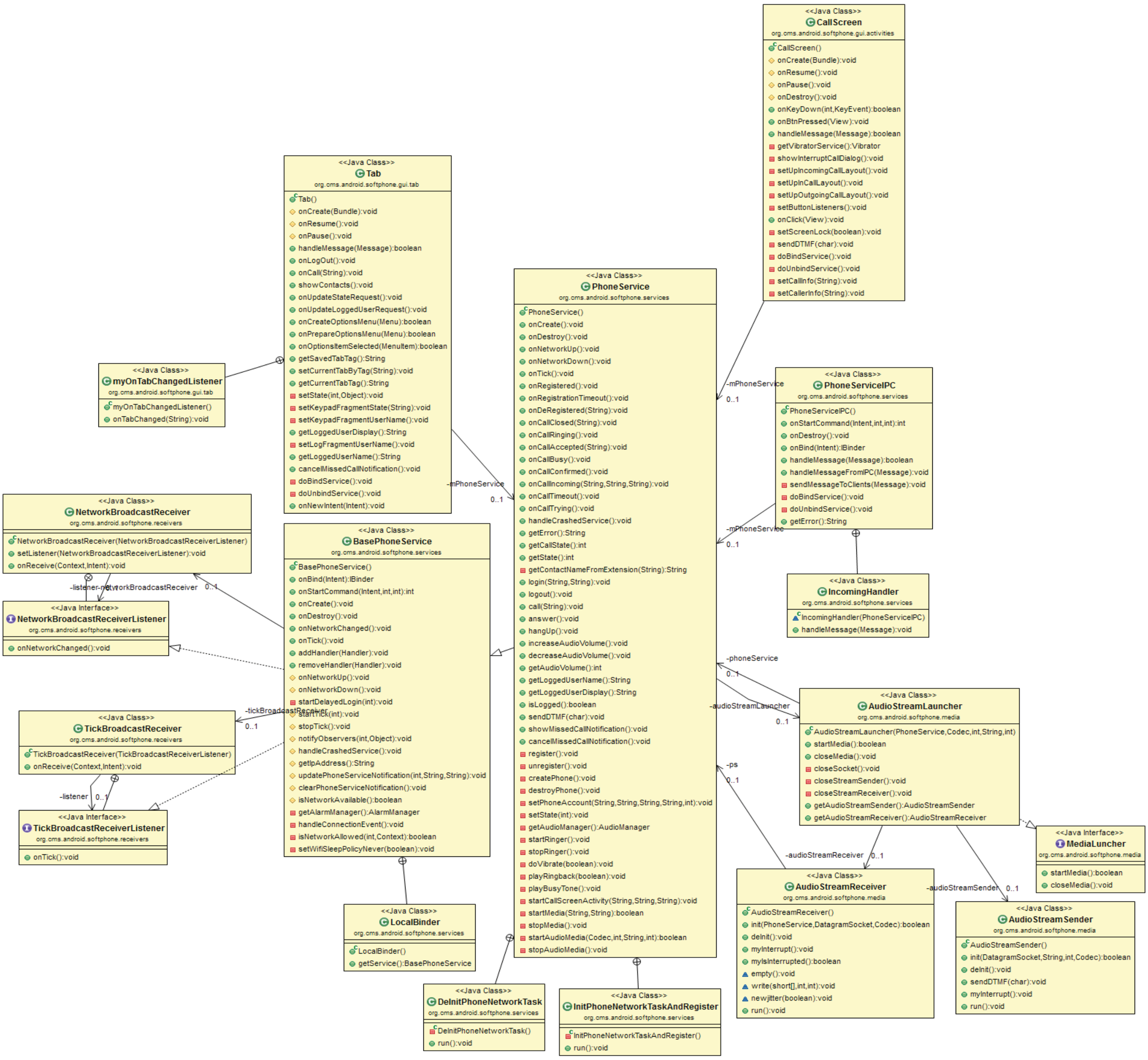

Figure 4-18: Class diagrams for the CallMeSmart Android SoftPhone – phone

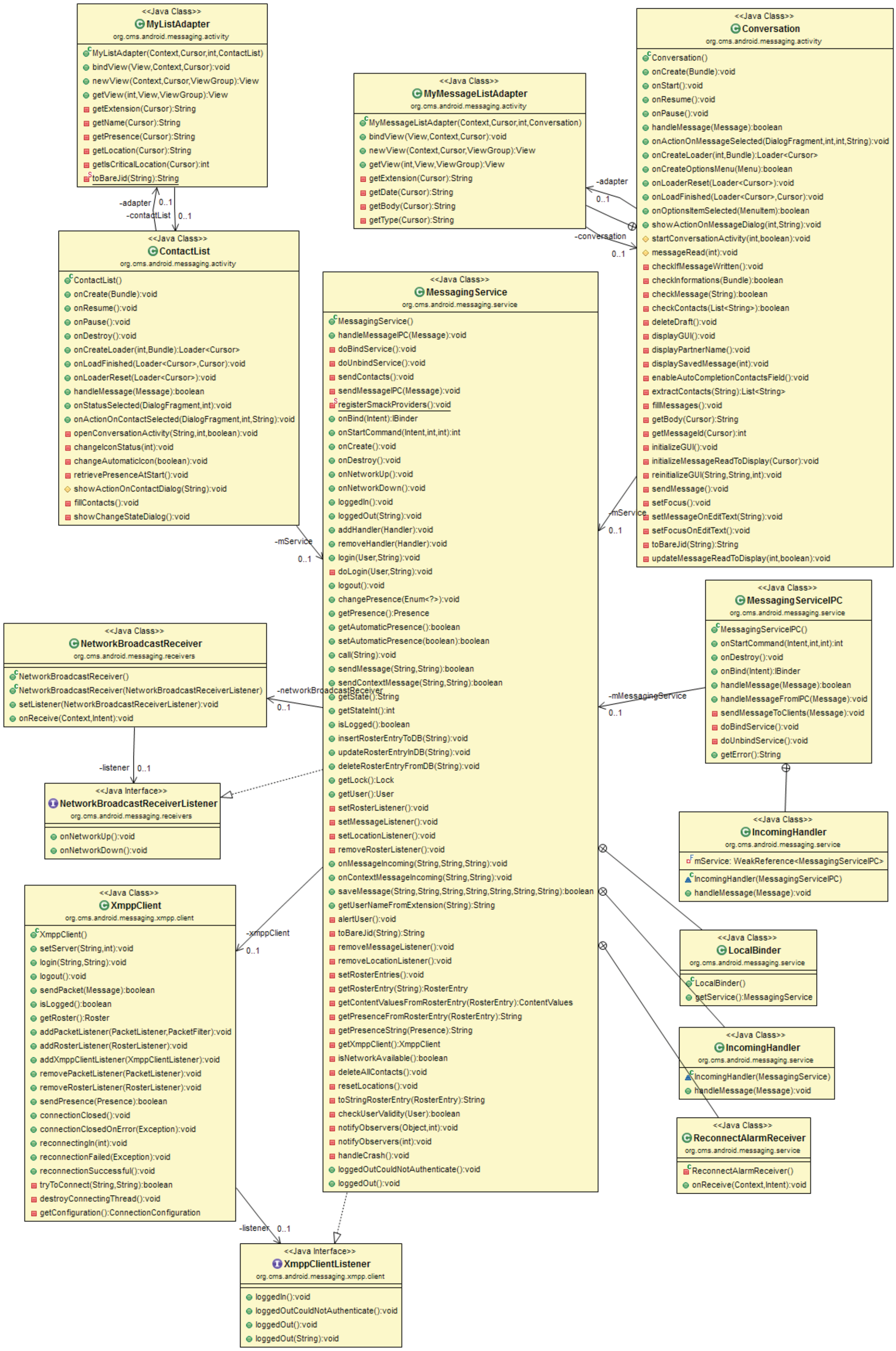

Figure 4-19: Class diagrams for the CallMeSmart Android SoftPhone – messaging

5 DISCUSSION

In this chapter I will discuss the results from the research attained in this project according to the findings presented in Table 4. All findings are related to the primary research questions presented in chapter 1.2.

Table 4: Relationship between the findings, the papers and research questions

#	Findings	Addressed in paper(s)	Research question
F1	Unnecessary interruptions from mobile devices are a problem for physicians and surgeons and a solution is wanted and needed	P1, P2, P3, P4	R1
F2	In which situations physicians are disturbed by interruptions from mobile devices in their daily work	P2, P3	R1
F3	A solution to handle the balance between availability and interruptions using context information	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11	R2
F4	A solution to integrate interruption management into existing infrastructure	P5, P6, P9, P11	R3
F5	A solution to integrate smartphones seamlessly into existing infrastructure using an Ascom/trixbox solution integrating messages and alarms	P10	R4

5.1 F1 Unnecessary interruptions from mobile devices are a problem for physicians and surgeons and a solution is wanted and needed

We knew from earlier international research on mobile communication in hospital settings, and from the initial study, that interruptions from mobile devices are a problem. Therefore the project intention was to find a solution to solve this problem. Before we could do this we needed to better understand the work situation of the users, in this case we focused on physicians and surgeons. Through the study published in P2, we learned that surgeons are interrupted during surgery and that the surgeons we interviewed, and had discussions with, wanted a solution to reduce such interruptions. I decided to do further investigations at St. Olavs Hospital, where the purpose of the study, published in P3, was to learn about a physician’s workday focusing on wireless communication. I intended to identify situations where unnecessary interruptions from mobile devices could be reduced; in which situations, what context, and which location physicians should not be interrupted; and generally the health care workers communication pattern. Based on the initial study [3], the results from P2, the study P3 and other international research on interruptions from mobile devices in hospital settings, I will argue that there is strong evidence that interruptions from mobile devices represent a problem in today’s hospital settings, and that a solution to reduce such interruptions is wanted and needed.

Another interesting finding at St. Olavs Hospital was that the physicians participating in this study may have experienced fewer interruptions from phones, compared to pagers, when health care workers were used to carrying a wireless phone. They also thought a pager was slightly more interruptive since they had to locate a phone, even interrupt somebody else to borrow a phone, every time they wanted to return a page. Compared to the findings in the initial study [3], where the physicians expect an increased interruptions rate if wireless phones were introduced to all health care workers in the department, may indicate that the physicians in [3], P1 and P2 may be wrong. This is again challenged by the findings in a recent study in Sweden [118] where widespread use of phones seemed to cause people to contact each other more often. In this study they suggest that even though interruptions is a problem when introducing wireless phones to hospital staff, cultural shifts, which develop over time, might be able to effectively reduce the problem of interruptions at some hospitals.

We conclude from the studies P1, P2, P3 and P4, that physicians in hospitals are interrupted unnecessarily by mobile devices. The introduction of IP-based phones at St Olavs Hospital, P3, has shown that this transition in itself is not sufficient to reduce the number of interruptions. The study illustrates the need for an integrated context-sensitive phone system that reduces unnecessary interruptions and eliminates the use of multiple communication devices. P4 demonstrates that such system does not yet exist and that it lacks in hospital settings.

5.2 F2 In which situations physicians are disturbed by interruptions from mobile devices in their daily work

From the studies at UNN, presented in the P2, and the initial study [3], we learned that physicians are interrupted in situations such as surgery, patient examinations and conversations with patent/relatives. The study at St. Olavs Hospital, presented in P3, confirmed this premise as, during our time of observations at this hospital, we recorded the number and situation of interruptions from different mobile communication devices the physicians participating in this study experienced. The collected data is presented in Table 5 and Table 6, where we made a version of the tables presented in P3 [9].

Table 5: Overview of total amount of interruptions from mobile devises at the Ear Nose and Throat department at St. Olavs Hospital during observations [9].

a = wireless IP-phone, ***b*** = on-call-duty pager, ***c*** = backup on-call-duty GSM-phone, ***d*** = private GSM, ***e*** = Wired IP-phone, ***f*** = personal pager, ***g*** = Other			**Assistant physician**	**Chief physician**
Preparatory/complementary work		**Answered**	3*a*	8*a*
		Ignored		
Outpatient ward	**No patient**	**Answered**	1*b*	3*a*
		Ignored		
	With patient	**Answered**	2*a*,8*b*,1*c*, 3*e*,1*g*	
		Ignored		
Inpatient ward	**No patient**	**Answered**		1*a*
		Ignored		
	With patient	**Answered**		
		Ignored		1*a*
Surgical theatre		**Answered**	1*a*	5*a*
		Ignored		1*a*
Meeting		**Answered**	3*a*	2*a*
		Ignored		
Cancer meetings		**Answered**		3*a*, 1*b*
		Ignored		1*a*, 2*b*
Other situations		**Answered**	1*a*, 1*b*	11*a*
		Ignored		

Table 6: Overview of total amount of interruptions from mobile devises at the Child and Youth department at St. Olavs Hospital during observations [9].

a = wireless IP-phone, *b* = on-call-duty pager, *c* = backup on-call-duty GSM-phone, *d* = private GSM, *e* = Wired IP-phone, *f* = personal pager, *g* = Other			Assistant physician	Chief physician
Preparatory/complementary work		Answered	2*a*, 2*b*	7*a*
		Ignored		
Outpatient ward	No patient	Answered		5*a*
		Ignored		
	With patient	Answered		1*a*, 1*d*
		Ignored		1*a*
Maternity/intensive/labour ward	No patient	Answered	2*a*,2*b*,1*f*	3*a*, 1*d*
		Ignored		
	With patient	Answered		6*a*, 1*b*, 1*g*
		Ignored	1*b*	1*a*, 1*g*
Surgical theatre		Answered		1*a*
		Ignored		
Meeting		Answered		6*a*, 1*d*
		Ignored		
Conversation room		Answered	1*a*	
		Ignored		1*a*, 1*d*
Other situations		Answered	6*a*,2*b*,1*f*	17*a*, 3*d*
		Ignored	1*b*, 1*d*	

Table 5 and 6 show that these physicians are interrupted in situations where interruptions of any kind should be avoided. Such interruptions are unwanted and unaccepted, thus a solution to reduce the interruptions from mobile devices should be developed.

5.3 F3 A solution to handle the balance between availability and interruptions using context information

To handle the balance between availability and interruptions, there could be used a solution were a combination of a pager for incoming calls and a wireless phone for outgoing calls, like some of the physicians in [3] had. However, this solution would not solve the problem of knowing who is calling or the importance of the call, or even the interruption itself, just the problem of finding a phone for returning the page. A better solution would be to use context information to help decide on the availability of a person and then use this information to automatically block and reroute calls if the receiver of the call is unavailable. A lot of context-sensitive systems were developed, as presented in chapter 2, but few or none of these has been developed for hospital settings regarding the reduction of interruptions, with exception to the Aware Phone systems to by Bardram et al. [32, 40]. We used the results from the initial study, together with the observations and interviews from UNN and St. Olavs Hospital, as input for finding a solution using context, as proposed in P1, P2, P3 and P4. I believe, by knowing and understanding the physicians' working conditions and the nature of the interruptions, and also by involving the physicians in the design process, it is possible to make a system suited for their communication pattern and working conditions. The lack of user involvement is an important issue to consider when designing and developing eHealth applications [49].

We started by designing scenarios, from the observations at St. Olavs Hospital, and used them to simulate the communication system at this hospital in a theoretical experiment where we used agents to decide the awareness and context of a phone call. The results are published in P7 and P8. This was an interesting study but highly theoretical, thus it would be very difficult to implement. Instead we used the results as input to design an interruption management system to reduce some of the unnecessary interruptions a physician experiences throughout the day, and especially in situations where they should not be disturbed. From the initial study we had a communication system from Ascom available in our Laboratory, which was the same as UNN had, and decided to build a Context Laboratory (Figure 3-6: Context laboratory framework architecture) based on this equipment. In this lab we were able to implement a context-sensitive communication system able to balance between availability and interruptions from mobile devices. I believe that it will be easier to get acceptance from the users, and also less expensive, if we were able to integrate the interruption management into the existing infrastructure of a hospital, and in this case UNN. This will be further discussed in the next sub-section 5.4.

5.4 F4 A solution to integrate interruption management into existing infrastructure

Before we started designing and implementing the suggested system from P1, P2, P3 and P4, we needed to confirm if the Ascom/trixbox system we had set up in our Context Laboratory, simulating UNN's communication system, was suitable, or if it actually was possible, to integrate a context-sensitive interruption management system into this infrastructure. We found out, in the performance analysis, that data transfer between the system and the handsets was not satisfactory. The throughput of short messages took too much time and, thereby, jeopardizes the possibility to implement effective context-sensitive applications in hospitals environments. If location devices, standard and interactive messages, calls and applications mounted on both the OAS and OJS are used simultaneously, the data transfer time will be high for single users which, thereby, also will increase the latency time for each message. With high latency time on messages it is hard, if not impossible, to develop reliable context-sensitive applications which usually transfer far more data, due to their dynamic behaviours and their need to continuously retrieve information from sensors. The situation is even worse in hospital settings, where huge amounts of data are constantly required [119]. Significant delays make data become outdated, which in many situation can have serious consequences. Adequate data communication performance is essential in order to use a context-sensitive system in hospitals. Unfortunately, the tests we did with the Ascom/trixbox technology did not fulfil this requirement. Therefore, we needed to consider how to shorten the messages and reduce the number to a minimum using this infrastructure. The results from this study were published, and the limits of the system discussed in more detail, in P5.

We also did some tests on the GUI on the Ascom phones. New user interfaces were designed aiming to improve the usability of the two wireless Ascom phones available in our Context Laboratory. We implemented the design in a low-fidelity prototype, not resembling the actual physical design of the device, which consisted of an image of the phone with different screens, being the navigation between them made by interacting with mouse clicks on buttons within the image. The intention was to give test users an impression of the design, choice of soft key functions and the menu structure. The most important usability challenges were related to the phone itself and design issues which were not possible to change due to hardware limitations. The low-fidelity prototype presented to the users was considered as an improvement compared to the old GUI. From this study we learned that a context-sensitive system, operating in this infrastructure using the Ascom phones, has to be controlled from the server side due to limitations on running software on the phones and because the system needs to be simple with only a few options due to the existence of only three programmable buttons on these phones. The results from this study were published in P6.

From what we have learned in the previous studies, we started out designing the system. The system is specifically designed to support activities within hospitals and manages interruptions considering contextual information related to users, such as location, availability status and personal commitments. It is able to automatically manage the reachability of the devices, reducing the number of interruptions, and helping the users to better focus on their daily activities. This means that the system is able to increase awareness by sending feedback messages explaining the cause of an unreachable recipient, and sending pending call messages collected during the unavailability status when a critical area or status is left. A feature that allows routing the calls to the on-call person, according to the shift schedule, was also designed. This provides a useful way to easily get in contact with the on-call doctor on duty, also avoiding the need to for this person to carry an extra device when covering this role. A pager mode was also designed to model the behaviour of a pager. This feature overcomes one of the major drawbacks of these devices: the call functionality. With this feature users can be paged on the phone and at the same time call back the person who put the page without the need to search for a phone.

The implementation of the prototype reviled that it was not easy to manage the Ascom system, and we almost gave up believing this was not possible, which was actually expressed by some of the Ascom engineers, during a meeting in a early stage of the project. However, after several different approaches, we found a solution using sockets from OJS and, thereby, route the information to the context server before it was sent to the PBX. We could then present the context-sensitive solution, CallMeSmart, based on an Ascom UNITE communication platform combined with trixbox, which aims to reduce interruptions from wireless phones, and thereby improves the awareness between the users. It also aims to integrate the different pagers and phones, physicians normally carry due to their different roles, into one device. In order to evaluate the system, we tested it simulating the scenarios developed earlier and a number of tests were carried out with medical doctors as test users. The tests highlighted several gaps that should be solved before deploying the system in real hospital settings. Some of these gaps are easily corrected, like; how messages are received when becoming available, while others are more difficult if not impossible to attain, like; gaps related to the design of the phone or major changes to the GUI. The study was published in P9.

One way to avoid some of the gaps, related to hardware and performance limitations, is to integrate different kind of devices providing advanced functionalities and find better strategies to effectively improve the performances. We developed a solution to integrate Smartphones and Tablets into the system, which opens up an enormous number of potential context controlled hospitals systems that could be provided through CallMeSmart, like a mobile version of the electronic patient records. This is discussed further in the next section 5.5.

5.5 F5 A solution to integrate smartphones seamlessly into existing infrastructure using an Ascom/trixbox solution integrating messages and alarms

The fact that mobile phones usage enables higher availability and accessibility, it also introduces numerous interruptions. This often leads to user resistance against wireless phones in clinical settings. Having this in mind, we developed CallMeSmart, a system designed to reduce unnecessary interruptions from mobile devices in situations where interruptions should be avoided. Situations like: in surgery dressed in sterile clothing, during patient examination in the outpatient clinic, having high importance level conversations with patients/relatives. The easiest solution to solve this would be to introduce an already developed system, like the AwareMedia and the AwarePhone systems to Bardram et al. [32, 40]. This system is based on ordinary mobile phones using the GSM/3G network. A new hospital building up their infrastructure for mobile communication could make use of a solution like this, but we believe it is less expensive and we will experience less user resistance by utilizing an existing internal infrastructure. From the tests done with the first version of CallMeSmart, using only the DECT phones as presented in section 5.4, the feedback from the users was clear. The users want a user interface more similar to the conventional 3G/GSM mobile phones, which gave us the idea of including smartphones into CallMeSmart, using VoIP and SIP, resulting in the CallMeSmart Smartphone App presented in P10.

To develop the CallMeSmart Smartphone App we had to overcome several important requirements. Stretch battery life on the phone is one of the important requirements that had to be fulfilled. Therefore, we had to balance between the computational power required by the software, audio quality perceived by the users, which is close related to the bandwidth required, and the number of features introduced by the first version of the prototype of CallMeSmart Smartphone App. With the solutions we used and from the tests we made until now it seems like a Samsung Galaxy SIII with extended battery is able to last at least it a full shift, but it requires additional tests in a real scenario settings to verify this.

We also had to count up for other problems to make the stability and quality of the phone calls reliable. This included the unpredictability and variability of the network conditions, and to tackle this we used an adaptive jitter buffer on the phone and thereby keeping the buffering delay as short as possible and at the same time minimizing the number of packets arriving too late. This in combination really shortens the delay between the caller and the called phone.

We also had to face several other problems, such as solutions to work within low bandwidth networks like 3G and 2G, echo, tracking and roaming within Wi-Fi networks. This is further discussed in P10, where we have published the results from this implementation and testing study.

However, we managed to develop a softphone solution for smartphones which we have called CallMeSmart SoftPhone App. The solution is working just as well as the DECT system; it is stable; has good sound quality even in low bandwidth networks; does not drain the battery; and seamlessly integrates services like phone calls, messages and the alarm system from the underlying Ascom infrastructure. The app. has been tested by physicians as test users, which gave feedback on wanted features and welcome the system in their work. A Smartphone has a wider area of usage. It could, for instance, include patient information, medical reference work, etc. We conclude that the first version of CallMeSmart SoftPhone is ready to be tested in real life hospital settings. This also opens up for future work on including more features, like the suggestions from the test users, which include context controlled access to patient records and video calls.

5.6 Future work suggestion

Our system, CallMeSmart is designed to reduce unnecessary interruptions from mobile devices in situations where interruptions should be avoided, such as when physicians are in surgery dressed in sterile clothing, during patient examination in outpatient clinic, having high importance level conversations with patients/relatives. It integrates smartphones and is designed to eliminate the need of multiple communication devices for each user. The system senses the context of each user automatically, changes the physicians' availability on the phones' profile according to the context information collected, and also gives the caller feedback about the physicians' availability.

During our investigations we tested scenarios on users and discovered that medical personnel seemed very annoyed by calls from outside the hospital. We also got some interesting remarks on the symmetry of information sharing, some interesting the ideas for handling interruptions in 'receiver oriented', 'negotiated', and 'caller oriented' approaches [120], and 'Awareness' or 'presence' cues [121], were suggested as a way to reduce interruptions. Not only did the users suggested new ways of managing interruptions, which should be looked further into in the future, they also suggested integrating the communication system with other hospital IT systems, like the Electronic Patient Record system.

Bardram and Favela [92, 93] studied a computer supported workflow instead of managing interruptions directly, which also is interesting future work. Supporting workflow together with CallMeSmart could further reduce the need for interruptions.

The tracking of the CallMeSmart SopftPhone App is using Bluetooth adapters as sensors. This was not an optimal solution due to battery drainage, and unreliable tracking, therefore, we need to find a better solution. An ultrasound solution seems to be the most reliable and accurate. This solution requires an ultrasound tag on the phone and a microphone inside of each area we want to track the phones. This is planned to be tested in the next version of CallMeSmart.

6 CONCLUSION

The previous chapter discussed the results gained from the research attained in this project according to the findings, which is directly connected to the research problem and questions presented in chapter 1. This final chapter draws conclusions regarding the overall research problem and research questions.

The overall research problem targeted in this thesis was motivated by challenges regarding interruptions from mobile devices in hospital settings. This challenge leads to the following research problem (R):

> *How can a context-sensitive system for mobile communication in hospitals be designed? Such a system will support media, such as text, voice and paging services, while maximizing efficiency of communication and effectively manage interruptions.*

To focus the studies within the project, the targeted problem was addressed by secondary research problems. Before answering the overall research problem targeted in this thesis, the secondary research problems associated with the primary research problem, here denoted by research question R1 – R4, had to be answered. Following, each research question is presented and answered according to the findings.

R1. How do interruptions from mobile devices disturb physicians in their daily work?
The main conclusion, regarding the first research question, is that *physicians are unnecessarily interrupted by mobile communication devices during their daily work.* The interruptions are frustrating for the users and may have tremendous consequences for the patient. With this kind of interruptions, the physicians work situation is not optimal. If such interruptions were minimized, the healthcare workers efficiency, regarding the completion of their daily tasks, could be much higher and the communication overhead would be lower.

R2. How can the balance between availability and interruptions be handled?
The main conclusion, regarding the second research question, is that *a context-sensitive system for mobile communication in hospital settings is a suitable solution to manage the balance between a physician's availability and the interruptions they experience from mobile devices.* By collecting context information about the user's situation, it is possible to decide on the availability of a user and, thereby, block or reroute calls directed to this person. By combining the different devices physicians carry, for each role they are assign to, into one device, by routing several numbers to the same device, it will cover both the person specific and the role related calls. In this way, it is possible to route the role related calls to a different physician at the same level that is available thus handling the communication overhead.

R3. How can middleware that integrate interruption management into existing infrastructure be designed and developed?
The main conclusion, regarding the third research question, is that it *is possible to design and develop an interruption management system into existing infrastructure, in our case an Ascom UNITE communication platform, similar or compatible with the system used at UNN.* We were able to integrate software into the OJS to reroute the signals, when a phone call was made, into our context server. The context server contains context information about each

user and, thereby, it is able to make decisions on how to handle each call, page or message, before routing them back with the decision. The context information, which includes the information required to make a reasonable decision on how to handle the balance between availability and interruptions, such as work roles, work schedules, medical speciality and responsibilities, was used to decide on the availability of a user, and what to do with a call to a person that is not available.

R4. How can smartphones seamlessly be integrated into existing infrastructure, including integration of alarms and messaging systems?

The main conclusion, regarding the forth research question, is that *it is possible to seamlessly integrate smartphones into existing infrastructure including pagers, messages and alarm systems.* Since we were able to route the signals from the Ascom UNITE system through the OJS using IP, it was possible to integrate smartphones into the existing infrastructure. This has been achieved by using VoIP, WiFi and SIP on Android based devices to communicate with the Ascom phones/pagers and between different VoIP clients, either running on a smartphone or a computer. The solution offers both voice and text services, and also integrates the alarm system.

Overall conclusion

The main contribution of this PhD project is concentrated around the four research questions, which together answers the overall research problem targeted by this project. We confirmed that unnecessary interruptions from mobile devices are a problem for physicians and surgeons and a solution is wanted and needed. We identified in which situations physicians are disturbed by such interruptions, and suggested a solution to handle the balance between the availability and interruptions using context information. The solution was integrated into the existing infrastructure at UNN, which is widely used in hospitals, and managed to integrate smartphones seamlessly, including the pager, messaging and alarming systems. Summarising, we were able to design and develop a context-sensitive system for mobile communication aimed for hospital usage, which answers the overall research problem. To do this, we started out by learning as much about the users as possible. Then, we involved them in the design and testing process to be sure the system was designed and worked according to their needs. The developed system, CallMeSmart, has been tested by real test users, physicians, in the Context Laboratory simulating real scenarios. The users gave satisfactory feedback welcoming the system in their work, so the next step is to test and verify the system in real hospital settings.

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PART 2: INCLUDED PAPERS

ISBN xxx-xx-xxxx-xxx-x