Supporting the Developers of Context-Aware Mobile Telemedicine Applications*

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Abstract. Telemedicine, which is defined as providing healthcare and sharing of medical knowledge over distance using telecommunication means, is a promising approach to improve and enhance the healthcare provisioning process. However, only recently, technology has evolved (i.e. miniaturization of high power mobile devices that can use high bandwidth mobile communication mechanisms) such that feasible advanced telemedicine applications can be developed. Current telemedicine systems offer proprietary solutions that are used in specific disease domains. For the acceptation, rapid development and introduction of novel and advanced telemedicine applications, there is a need for architectural mechanisms that supports developers in rapidly developing such telemedicine applications. The research discussed in this paper, focuses on the development of such mechanisms.

1 Introduction

Healthcare is intrinsic to human existence. Humanity has always been in need of solutions to various health related issues, such as childbirth and cure for diseases.

In the last decades, the introduction of ICT in this domain, was recognized as a valuable development to improve the healthcare provisioning process [1, 2]. The sub-domain of healthcare that uses ICT in its healthcare provisioning process is called *E-health* [3]. The evolution of ICT (e.g., growing processing power, mobile communication technologies) offers new possibilities to develop advanced e-health applications.

There are some major social-economic trends that stimulate and justify the need for E-health solutions [4]:

- *Patient-centric healthcare*: the offering of healthcare is shifting from offer- to demand-driven. The government does not primarily control the healthcare process anymore; the influence of the patient is increasing.
- *Cost savings and efficiency:* the society is aging. Currently, in Europe 16 to 18% of the population is over the age of 65. Estimations indicate that this will rise to 25%

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in 2010 [4]. This increasing number of elderly results in an increasing number of potential healthcare consumers with a decreasing number of healthcare professionals.
- *Cross-domain integration:* to provide demand-driven healthcare and to keep costs in limit, the different domains in healthcare need to collaborate.

An example that supports the previous discussed issues is the current trend of extra-mural care compared to institutional care. Patients are treated as long as possible in their home environment instead of in care institutions. When they are hospitalized, the period of stay is minimized. This is both to save costs of hospitalization and to improve the patient's wellbeing.

The research areas in e-health are very diverse (electronic patient record, teleconsultation, patient management) and have their own specific issues. One interesting sub-domain of e-health, which is our particular focus of interest, is telemedicine.

Telemedicine is defined as providing healthcare and sharing of medical knowledge over distance using telecommunication means [1]. Although Telemedicine is already early recognized as a valuable improvement of the healthcare process, only recently technology has advanced in such a way that feasible advanced telemedicine applications can be developed (i.e. near real-time, high quality 24/7 telemedicine applications with relative low costs). On the one hand we see the rise of high bandwidth mobile communication mechanisms (e.g., GPRS, UMTS) and on the other hand we see the miniaturization of high power mobile devices [5]. However, still certain challenges limit or even block the development and introduction of these novel telemedicine applications. These issues are discussed in the following sections.

Section 2, gives an overview of the telemedicine domain and discuss the challenges in telemedicine by investigating current telemedicine applications. In section 3, the objectives for this research are presented. Section 4 discusses the approach taken to tackle the objectives. Section 5 gives the current status of this research. Section 6 discusses related work and in section 7 presents some conclusions and future work.

2 Overview of the Telemedicine Domain and Its Challenges

Telemedicine in itself consists of two sub-domains: (i) telemonitoring and (ii) teletreatment. Essentially, *telemonitoring* focuses on the unidirectional communication of vital signs from a patient to a healthcare professional. The *teletreatment* domain focuses on bidirectional communication, which also incorporates treatment data from the healthcare professional to the patient.

There are several fundamental problem domains that need attention for a successful introduction of telemedicine applications (and e-health in general) [4]:

- *Technology and Infrastructure:* what technologies and infrastructures are needed to develop efficient and useful telemedicine applications?
- *Political commitment:* To be able to create successful telemedicine application there has to be commitment by governments. For example, subsidising health innovation.

- *Legal & Ethics:* the exchange of private patient over public communication mechanisms is subject to legislation and ethical discussion.
- *Organization & Financing:* introduction of advanced telemedicine applications require drastic changes in the organization process of all stakeholders in the healthcare domain (e.g. professionals, government, insurance companies).

Although all problem areas need attention for an integrated and successful introduction of telemedicine applications, our research focuses on the technology and infrastructure issues which we discuss now in more detail.

We distinguished some key technological issues why the development of telemedicine applications is highly complex and costly (see [6]):

- *Limited generality and flexibility:* Currently available telemedicine equipment and infrastructures are proprietary solutions that do not provide generic capabilities for monitoring and treating arbitrary diseases. They focus on a single disease domain, like diabetics or hearth failure. This has several consequences for developing novel telemedicine applications:
  - *High learning curves:* Currently only proprietary telemedicine equipment and protocols are available which impose high learning, design and deployment curves.
  - *Costly:* Because of its specific use, telemedicine devices are very costly.
  - *Limited reuse:* Due to the focusing of current equipment and infrastructures on a specific disease domain (e.g. diabetic diseases), reusing applications for different domains is hard or even impossible and different equipment is needed. This is again costly.
- *Overload of information:* A side effect of using telemedicine applications is the fact that a huge amount of medical data is made available and has to be processed to be able to make good decision [7]. Furthermore, with the creation of health value-chains also other relevant healthcare information is coming available and has to be coupled with the primary healthcare data (e.g., vital signs). Without a mechanism to streamline these information flows, decision making based on this information becomes hard or even impossible. We claim that by using contextual information [8, 9] this streamlining can be done in an efficient manner.

3 Research Objectives, Questions and Scope

The previous section indicated some key technological issues that limit or even block the successful introduction and development of telemedicine applications. This leads us to the main objective of this research:

To develop architectural mechanisms that support application developers in developing context-aware mobile telemedicine applications.

This objective can be divided into several more focused sub-objectives:

- Propose an application framework that enables application developers to easily and rapidly develop context-aware mobile telemedicine applications.
- Distinguish generic and domain specific mobile telemedicine functions as part of the application framework.
- Analyze the impact of the proposed framework on the development process.

As discussed earlier, our main focus lies on the technological issues in telemedicine applications. This leads us to the following research question:

- What are the technological characteristics of telemedicine applications and how does this influence the development process?

We claim contextual information of all the entities involved in the healthcare process is needed to support integrated, efficient and patient-centric healthcare. This leads us to the following research questions:

- What contextual information is important in telemedicine applications and what are the consequences of introducing context in the development process?
- How can telemedicine applications benefit from contextual information?

The scope of this research is in the context of the Freeband AWARENESS project [10]. The AWARENESS project focuses on the research of an infrastructure that supports the development of context-aware and pro-active services and applications. AWARENESS validates this infrastructure through prototyping with mobile health applications. AWARENESS considers a three-layered architecture. The bottom layer of the architecture is the network infrastructure layer, offering seamless mobile connectivity. The middle layer is the service infrastructure layer that provides an execution environment for context-aware and pro-active services. It provides generic functionality like service life-cycle management, service discovery and security mechanisms. The top layer consists of the mobile health applications.

We position our research at the border of the two top layers. We have to incorporate the requirements and wishes of the telemedicine application developers and healthcare professionals and use the supporting functionality from the service infrastructure.

4 Approach

The approach taken in this research is divided into three main phases that are visualized, with their corresponding actions, in Figure 1:

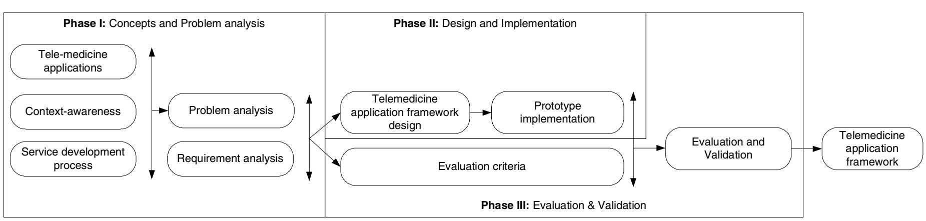

Fig. 1. Approach

Phase I: Consists of two major parts: (i) research on the state-of-the art in telemedicine applications, context-awareness and service development process (e.g., aspects important for software developers like development time, reusability, flexibility and modularity, and (ii) research on the requirements of stakeholders in the healthcare domain. Analysis of both areas results in a problem analysis that identifies issues in the domain of current telemedicine applications.

Phase II: Design and implementation of the telemedicine application framework in a proof-of-concept prototype.

Phase III: Evaluation and validation of the developed framework based on criteria derived from research performed in phase I (e.g. development time, reusability). The validation is done by means of prototyping mobile telemedicine applications using our proof-of-concept application framework.

5 Current Status

The research discussed in this paper started in August 2004 and is therefore in its starting phase. Currently, we are working in three main areas of research that we discuss subsequently in the remainder of this section.

5.1 Application Framework for Mobile Telemedicine Applications

Although the benefits of telemedicine applications are widely recognized, implementations are scarce because of their current lack of flexibility, costly nature and the generation of an overload of information.

To improve the development time and reusability of these kinds of application, developers of telemedicine applications need mechanisms that provide them with flexible, extensible, portable, reliable, scalable and affordable ways to develop telemedicine applications. An *application framework* is an integrated set of software artifacts that collaborate to provide a reusable architecture for a family of related applications which has the potential to offer these characteristics [11].

In [12], we discuss our initial ideas on an application framework for mobile telemedicine applications that offers a generic execution environment. We consider an application as a set of collaborating application components deployed in the framework. The framework (see Figure 2) is positioned on top of the AWARENESS service infrastructure that was discussed in Section 3.

We distinguish three levels of generality within the functions a telemedicine application framework should provide. These levels relate to the different stakeholders in the development process of telemedicine applications:

- *Application container & Generic container functions* offer the generic execution environment for application components. These functionalities are developed by so called ‘infrastructure developers’. This layer also offers the glue between the service infrastructure and the applications.
- *Domain specific functions* offer generic functionality for a particular domain. For instance, we distinguish two generic blocks of functionality (BANManagement and Signal processing), highly needed within the whole telemedicine domain. These functions can be reused by different applications. So called ‘domain application developers’ should develop these domain specific functions. Domain specific application developers

can be for instance a consortium of telemedicine organizations that have a similar interest.
- *Application components* represent the application for a particular end-user in a domain. Consider for instance a telemonitoring application for a particular doctor that wants to have the medical history of a patient specifically filtered to his need.

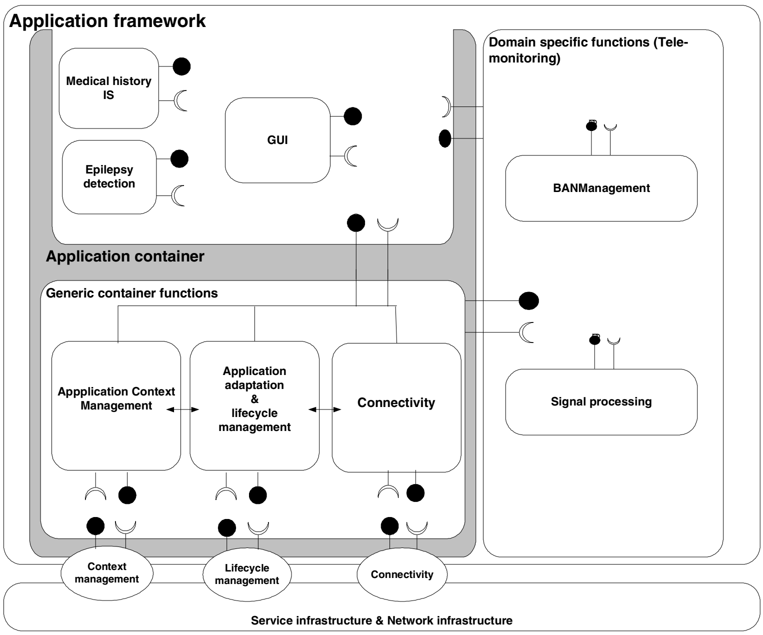

Fig. 2. Application framework for mobile telemedicine applications

The current design of the framework merely provides a functional decomposition. It does not (yet) elaborate on the functions and the mechanism needed to realize these functions except for BANManagement discussed in the next section. Designing the lacking functions are the next steps we want to take in the near future.

5.2 Modeling of Body Area Networks (BANManagement Component)

One of the domain specific functions mentioned in the application framework discussed in the previous section is the *BANManagement* component. In [13, 14], we discuss a realization of the BANManagement component. This component offers a toolbox for users and developers to manage a Body Area Network (BAN, i.e. network of body worn sensors/actuators and communication devices) of a particular patient. This includes the following activities:

- Configuration of the BAN;
- Instantiation of the BAN configuration;
- Reading vital signs and setting the parameters of actuators from the patient.

Again, several stakeholders are involved in the process of configuring, instantiating and reading data from a Body Area Network. We use the MDA (Model Driven Architecture) approach, based on the MOF Metadata Architecture [15], for the modeling of these Body Area Networks. See Figure 3 for an example of the process of managing a BAN for patient “Vic” using MDA meta-modeling.

A meta-model (M2 model) of a BAN is the basis for our toolbox. The model consists of *nodes* that are connected by *edges*. These nodes can be specialized as being sensors, actuators (leaf nodes) and aggregators, processors, stores, gateway (intermediate nodes).

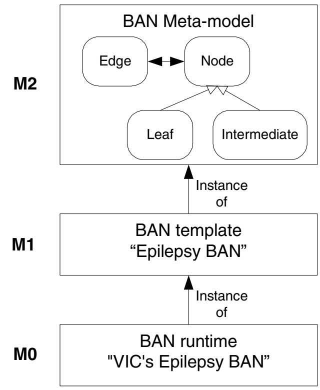

Fig. 3. MDA BAN modeling

Healthcare professionals, like specialists, can specify a BAN for a certain domain using this toolbox (e.g. epilepsy BAN (M1 model)). They create a kind of template. The healthcare specialist responsible for the primary care process, like nurses, can provide the specifics of a patients ban (e.g. Vic’s BAN (M0 model)) by filling in the parameters of the Epilepsy M1 model (e.g. name of the patient, serial number of devices). The M0 model is used to read the specific sensors and set the actuators.

Design of the discussed models is still current subject of research. In the future, we want to develop a prototype of the toolbox and subject it to case studies to evaluate it for usability by telemedicine application developers and healthcare professionals.

5.3 Prototyping Platform for Telemedicine Applications

Current BAN equipment is costly and inflexible. Therefore, we developed an telemedicine *prototyping platform* which can be applied for *prototyping* different problem domains (i.e. different diseases) using affordable, commonly available, off-the-shelf equipment.

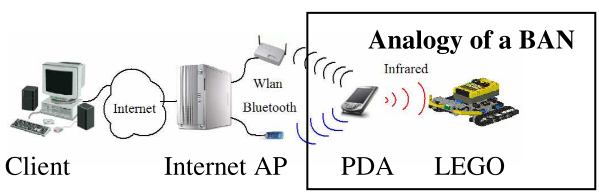

Fig. 4. Telemedicine prototyping platform overview

In this platform we use LEGO Mindstorms [16] technology and a PDA as analogy to a vital sign monitor with communication mechanisms. LEGO provides a so-called RCX unit that can handle three sensors (e.g., light, temperature) and three actuators (e.g., motors). Out of the box, LEGO transports this information with a proprietary infrared protocol to a USB tower connected to a PC. We replace the PC with a PDA such that an arbitrary client from the internet can connect to the RCX (see Figure 4).

To enable this, we developed a daemon on the PDA with gateway functionality. This daemon bridges the gap between the client somewhere on the internet, and the RCX. Therefore, we implemented two protocols: (i) LEGO infrared protocol and (ii) light-weight TCP/IP based protocol for connection from the internet.

6 Related Work

The first research area we discuss in this paper is an application framework for telemedicine applications. Several types of application frameworks exist, offering functionality ranging from specific functionality like the Xerces XML parsing framework [17], more generic domain specific functionality like the Placelab positioning framework [18], to generic application support environments like CCM [19], J2EE (EJB) [20], J2ME (Midlets) [21], OSGi [22] and JADABS [23].

In general, we are mostly interested in the last category of application frameworks. Due to their big footprint, some of the frameworks (CCM, J2EE) are not suitable for use on mobile devices. Other frameworks, although suitable for mobile devices, are unchanged too limited for advanced telemedicine applications (J2ME Midlets). However, certain frameworks seem very interesting for realizing our telemedicine application framework (OSGi, JADABS). They are suitable for mobile devices and offer flexible mechanisms for application component deployment and communication.

The question that rises is how to use the mechanisms created by the discussed frameworks in our telemedicine application framework. Furthermore, the frameworks do not deal with the deployment of context-aware applications and the management of contextual information. However, several initiatives may help to compensate for the latter omission. Bardram [24] discusses a context-aware programming framework (JCAF) and Dey [25] discusses a toolkit for context management (Context Toolkit). These initiatives provide ways to acquire contextual information and transfer them to context-aware application. An interesting question is then how to integrate these context management mechanisms into a generic telemedicine framework.

Another aspect of our research is modeling of Body Area Networks. This is a relatively new research area, since only recently interest emerged in telemedicine applications using BANs. The IST Mobihealth project [26] takes a pragmatic approach in configuring a BAN which lacks flexibility for generic BANs. Laerhoven [27] discusses a XML based sensor model driven by similar issues as our BANManagement component. This model offers more flexibility but lacks mechanisms to define complex nodes in BAN like storage and processing nodes.

The final research area we discuss in this paper is a generic telemedicine prototyping platform. Again, this is a relative novel research area. There exist many disease specific platforms like Elite care [28] and Cardionet [29] which are not suitable for generic prototyping due to their specific nature. The Mobihealth project [26] and BSN networks [30] offer a more generic and extendible platform for telemedicine applications. However, they use specific sensor devices that are costly for prototyping activities. Furthermore, they lack the integration of contextual information.

7 Conclusion and Future Work

This paper discusses a PhD trajectory that focuses on the development of mechanisms to support application developers in developing context-aware mobile telemedicine applications. We indicate several reasons why there is a growing need for such applications. However, the currently deployed applications are too specific and costly to be useful in a generic way. This limits the development of such applications. Therefore, we research generic mechanisms to support the developer in rapidly developing telemedicine applications. We propose a context-aware application framework that separates generic functionality from domain specific and application specific functionality. This paper discusses one domain specific function that we want to offer to developers, namely BANManagement. Finally, this paper discusses a cost-efficient and flexible telemedicine prototyping platform that is going to be used for future prototyping efforts. Future directions we are exploring are:

- Extension of the application framework. This includes the identification of other relevant functional blocks and the realization of the distinguished blocks. Development of a useful component model and researching the application of available application frameworks like OSGi and JADABS for our framework.
- Prototyping and evaluation of the BANManagement component. This includes researching the characteristics of BAN and developing a demonstrator. This demonstrator is going to be evaluated by healthcare professionals and telemedicine application developers.
- Prototyping and evaluation of the application framework using the prototyping platform. This is the combination of the three discussed research areas in this paper. We want to deploy a prototype that incorporate the application framework and BANManagement component using the prototyping platform.

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