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MOBILE VIRTUAL COMMUNITIES FOR TELEMEDICINE: RESEARCH CHALLENGES AND OPPORTUNITIES

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Today's mobile devices have become increasingly powerful with enhanced features such as increased CPU power and memory, internet connectivity in multiple ways (multi-homing) and interfacing with external peripheral devices (for instance GPS receiver, medical sensors). The proliferation of these mobile devices combined with an increasing willingness of users to share information available on and around mobile device (e.g. location, user activity) has given rise to Mobile Virtual Communities (MVC). This way, social interaction is now feasible anywhere and anytime. In another paradigm referred to as telemedicine, information and communication technologies are being investigated and employed in areas such as health maintenance and alleviation, cure and prevention of diseases. In general, (mobile) virtual communities have been explored in the telemedicine domain where they were found to be promising in many cases. However, evidence for their effectiveness has yet to be established. With this background and based on our expertise with MVCs and telemedicine, we address a number of aspects including: 1) basic concepts in telemedicine and MVC and analysis of effectiveness and success factors of MVCs in the telemedicine domain; 2) a prototype architecture addressing mobility issues for the MVC in the telemedicine domain; and 3) reflection on the opportunities and research challenges involved in using MVCs in the telemedicine domain.

Keywords: telemedicine, health, mobile virtual communities, mobility, ICT platforms, Service Oriented Architecture, Jini, Jini Surrogate Architecture.

1. Introduction

A virtual community is usually defined as group of people who gather or interact because of a common interest, problem or task and whose members interact independent of time and space [Leimeister *et al.*, (2002)]. Owing to the ongoing advances in computing and communication, full independence of time and space seems to be in reach with the present day mobile devices and wireless communication technologies. We refer to such virtual communities as *Mobile Virtual Communities* (MVC).

Telemedicine, as the name suggests, is the term for medicine at a distance. In one Telemedicine discipline, known as telemonitoring, a patient is equipped with body-worn sensors which collect patient's biosignals and transmit them to the mobile device the patient is carrying which in turn uses wireless communication technologies to send these signals remotely to a data center for purposes like biosignal analysis, patient monitoring and emergency assistance if needed. These functions are supported in principle by other actors such as technicians, healthcare professionals, doctors and caregivers. The latter are also relatively mobile and are notified when there is a need to provide the patient with assistance or intervention [van Halteren *et al.*, (2004)]. In essence, such telemedicine scenarios may be viewed as a Virtual Community (VC) if the patient and other actors can communicate with each other for the purpose of providing medical assistance and counseling to the patient and the systems that support the realization of the scenarios may be viewed as comprising a virtual community platform. The inclusion of the mobility aspect in the scenario and thus in the virtual community corresponds to an MVC and the system that supports the MVC is referred to as MVC platform.

The work reported in [El Morr and Kawash, (2007)] groups MVC research interests into *technology-centered* interest, *user-centered* interest and *business-centered* interest and analyses inter-dependencies between them. The technology-centered aspects include issues in platform design, the development framework, mobile network bandwidth limits and intelligent agents. The user-centered issues include user interface, behavior, personalization, privacy, data security and trust while the business-centered aspects are marketing, investment and business models.

In this paper MVCs are considered in the specific setting of telemedicine, this is because of our expertise of the telemedicine research domain [van Halteren *et al.*, (2004)] and our recent experiences in MVC design and development [Pawar *et al.*, (2008)]. This particular application domain is interesting for several reasons; mainly because in telemedicine various issues, problems and tasks are reasonably well understood, and this creates the opportunity to consider inter-MVC aspects in a controlled way (that is, guided by knowledge about the application domain). Although in some definitions of VCs and

MVCs people are the actors, others explicitly include the possibility that software agents can participate in a VC [Rakotonirainy *et al.*, (2000)]. Considering architectural aspects in [Pawar *et al.*, (2008)], we argue that the MVC potentially evolves around a set of services which are based on the principles of Service Oriented Architecture (SOA) [Papazoglou and Georgakopoulos, (2003)]. Based on past experience, we have proposed a SOA based architecture for building MVCs. Here, services are produced by e.g. mobile agents acting on behalf of MVC members, and the MVC platform provides MVC supporting services. The MVC supporting services may vary from basic communication and information services, to service orchestration services, and MVC management services (such as service fulfillment, assurance and billing services).

The remainder of this paper is organized as follows. Section 2 describes the basic concepts relevant for this article. Section 3 is on the effectiveness of and the success factors of MVCs in the telemedicine domain. Mobility aspects are considered in Section 4. A proposal for a mobile virtual community platform is discussed in Section 5. A set of research challenges and opportunities are discussed in Section 6. A discussion is given in Section 7.

2. Basic Concepts

This section presents necessary terms and definitions in the telemedicine domain which will be used in the remainder of the paper. It also provides a brief characterization of mobile virtual communities.

2.1. *Telemedicine and Health*

The term telemedicine has been in use for a long time, and many definitions and descriptions of the term have been given over the years. One category of definitions is based on the components from which the term is constructed: *tele*, meaning distance, and *medicine*. So, telemedicine is considered to be medicine at a distance. Textbooks on telemedicine, for instance [Wootton *et al.*, (2006)] and [Norris, (2002)], adopt this definition. A similar definition is adopted by the American Telemedicine Association and the Telemedicine Alliance.

A precise definition of telemedicine is necessary, especially because over the years a multitude of related terms have been introduced, e.g. *telehealth*, *telecare*, *e-health*, *mobile health (m-Health)* and *health telematics.* According to the Longman dictionary of the English language (1984), one of the meanings of medicine is: “the science and art of the maintenance of health and the prevention, alleviation or cure of disease”. This definition makes explicit, at a high level, what the purpose of medicine is, we add to this the target to which these goals relate, namely patients. Although traditionally, the prefix *tele* means distance (geographically), today’s connotation of the term often implies the use of both communication and information technologies to bridge distance and time. Therefore, we define telemedicine as follows.

> *Telemedicine – the science and art of the maintenance of health and prevention, alleviation or cure of disease in patients using information and communication technologies.*

To further operationalize this definition we have to elaborate on health and diseases and we need to consider the potential impact of using information and communication technologies. Regarding the last, it may be observed sometimes that telemedicine is merely extending the geographical reach of traditional medicine; hence it is the sum of the two. Our position differs in that we believe that the combination of ICT and medicine offers new ways to deliver health maintenance and disease prevention, alleviation and cure which were not possible before ICT was available. In fact, various research projects, e.g. AWARENESS [Wegdam, (2005)], support this viewpoint.

Clearly, the purpose of telemedicine is to contribute to the improvement of the health status or condition, however what constitutes the health condition of a person? Often the health condition (and the assessment thereof) is linked to diseases; the World Health Organization's ICD-10 [ICD, (2004)] standardizes the taxonomy of diseases. Recently, a medical, psycho-social model has been developed for health and is specified in the International Classification of Functioning, Disabilities and Health (ICF), [ICF, (2001)]. The ICF defines *health* in terms of a number of categories, namely: *body functions* & *structures*, *activities* and *participation*. Body functions refer to physiological functions, whereas body structures relates to the anatomical parts and subparts of the body. Activities refer to the actions and tasks executed by an individual; and participation encompasses the interactions between individuals, i.e. life situations.

The health condition of an individual is not considered in isolation, it is affected by so called contextual factors, and these include personal and environmental factors. The ICF defines the environmental factors in great detail; personal factors are not further defined by the ICF due to the many cultural and social differences (i.e. no world wide acceptable model or definition is thought possible). The framework underlying the ICF is shown in the Figure 1.

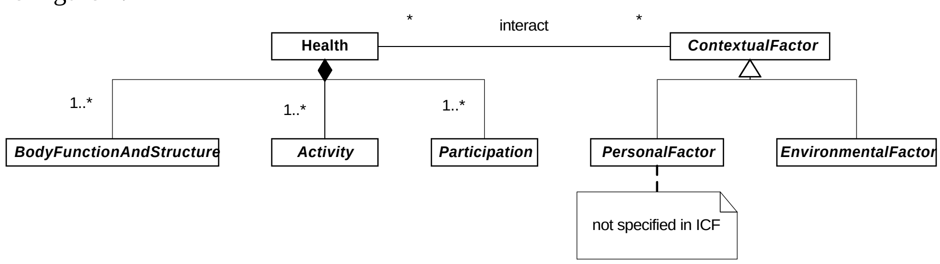

Figure 1: WHO's ICF as a framework for health.

Telemedicine as a discipline and telemedicine systems are, in the context of the ICF, to be considered as an Environmental factor affecting the health condition of individuals. Its purpose is to positively affect one or more aspects of the health status of one or more individuals.

2.2. *Characterization of Mobile Virtual Communities*

Several researchers have proposed different criteria to characterize (mobile) virtual communities. Such characterizations are useful for instance in a review study on communities, but also in the creation and configuration of mobile virtual communities. Also, it is believed that different virtual attribute values impact the critical success factors of a community.

[Porter, (2004)] uses the 5P attributes to characterize virtual communities, these are:

- *Purpose* – The raison d'étre for the community to exists and shared among its members;
- *Place* – Place refers to the structural property of the virtual community where the interaction happens; whether the community members interact in a physical location or mediated by technology in order to interact whilst in different geographic location;
- *Platform* – Platform refers to the interaction modes among community members supported, this can be synchronous, asynchronous and hybrid forms;
- *Population* – Three different options are defined here, virtual communities as computer-supported social networks, virtual communities as small groups or networks;
- *Profit model* – This attribute refers to whether the community is revenue generating or non-revenue generating.

According to [Fremuth *et al.*, (2003)], MVCs differ in the following three aspects compared to traditional VCs:

- Unlike traditional VCs wherein communication between community members is limited to the services offered by the virtual community itself, MVCs can make use of basic mobile services such as short messaging service (SMS) or voice call to communicate with community members.
- With mobile technology, enhanced mobile services provide users with the ability to interact within the community anytime and anywhere. This could be attributed to the ubiquitous access, instant delivery of the community contents to and from the mobile device, in built security mechanisms in the mobile device (e.g. identification using SIM card or PIN) as well as provisioning of location based services due to enhanced mobile device capabilities (e.g. inbuilt GPS).
- As compared to the traditional virtual communities, MVC results in entirely different usage patterns; this is mainly personalized as MVC focuses on an individual user rather than around specific topics or interests. For example, results on a study by [Fremuth *et al.*, (2003)] show that mobile telephony is used to communicate to close friends or relatives or people who are already known by the person who wants to communicate.

The basic and enhanced mobile services provide MVC an ability to enhance communication and facilitate activities [Fremuth *et al.*, (2003)]. Based on the services provided by the mobile communities and the prospects of providing personalized interactions El Morr and Kawash [El Morr and Kawash, (2007)] suggest that MVCs can be classified using three criteria:

- *Degree of openness* (private/public): This criterion refers to the communication between participants, which could either be exclusive to members of a certain community only (private) or open to non-members as well (public);
- *Degree of contextual information present* (contextual/non-contextual): Context information is any information that can be used to characterize the situation of an entity or a community member. This criterion refers to whether the information present in the MVC is contextual or non-contextual;
- *Degree of interaction they permit* (synchronous/asynchronous): This criterion refers to the design of interaction in terms of whether the interaction is synchronous or asynchronous. In a synchronous interaction, the members are required to be simultaneously present when interacting. In an asynchronous interaction, the communication of members occurs in a deferred way.

3. Viewpoints on Mobile Virtual Communities for Telemedicine

By building on the overview of telemedicine and MVCs in the Section 2, this section presents some viewpoints on the MVCs for telemedicine. We particularly focus on the effectiveness of MVCs in telemedicine and success factors for such MVCs.

3.1. *On the effectiveness of (Mobile) Virtual Communities for Telemedicine*

The design, implementation and testing of telemedicine systems is often motivated by economic and accessibility reasons. For instance, telemedicine is expected to help solve the challenges of an increasingly aging population in the western world and decreasing number of people to provide for healthcare services. Yet another example is to make healthcare services available in rural areas where patients and healthcare professionals are often geographically dispersed.

The concern addressed here is however on the effectiveness of telemedicine and in particular of MVCs for telemedicine. Hence, the degree to which the use of a telemedicine system affects the health status of patients positively compared to those who do not make use of a telemedicine system.

Over the past two decades a vast number of telemedicine systems have been realized and experimented with. Also, VCs have been studied in the context of health. MVCs are a more recent direction in research and yet little is known on its effectiveness. Nevertheless, we may draw some general conclusions based on the results derived from telemedicine systems and VCs that have been used and reported in the literature and that are useful to identify challenges to be faced for designing effective MVCs for telemedicine.

Eysenbach [Eysenbach *et al.* (2004)] has investigated the effectiveness of health related virtual communities (and electronic support groups). The objective of their research was to find evidence “for the efficacy of VCs as stand alone or adjunct interventions in health care and their impact on health related outcome measures”. In the context of this study a VC is defined as a group of individuals forming a social network with similar or common interest in health related problems or conditions, furthermore the group is assumed to consist of mainly non-medical experts. The interest considered in this study includes: emotional and social support, health education and health related behavioral change. The output measured included: knowledge of health, psychological or social outcomes, and use of health services. The final constraint was the use of a control group and reporting of outcome measures. Out of 12,288 references retrieved from database queries only 38 studies satisfied the set of criteria. In 12 studies depression was the measure of interest, only 3 of them found a significant improvement in depression score. Social support was the measure in 12 studies, out of which 5 studies found significant effect. Three studies on healthcare measures had contradictory results. Nine studies addressed structured weight loss or healthy body weight interventions, results on effects reported are mixed and non-significant in most cases. One out of five studies on communities for diabetics patients showed significant improvement. The authors reach the following striking conclusion: “Despite extensive searches in the health, social sciences, communication, and informatics literature we failed to find robust evidence on the health benefits of virtual communities and peer to peer online support”. Among implications for future research identified by the authors, the following requires specific attention: “quantitative research is required to evaluate under which conditions and for whom virtual communities are effective and how effectiveness in delivering social support can be maximized” [Eysenbach *et al.*, (2004)]. Their suggested methodological approach is a factorial design randomized controlled trial.

The quantitative approach advocated by Eysenbach [Eysenbach *et al.*, (2004)] is strongly argued by Jadad [Jadad *et al.*, (2006)]. Instead of traditional quantitative methods used in medicine, they argue that the value of virtual communities transcends these traditional quantitative measures of clinical outcome. The authors advocate a strategy that is based on understanding how people cope with complex health issues (for instance chronic diseases) and the role that VCs play in this. The sheer number of health related virtual communities (Yahoo maintained over 15,000 such communities in 2006), and self-organization through which cohesive virtual communities are formed seems to be enough proof that virtual communities serve a valid purpose.

The above shows that different views exist on how to look at the effects and effectiveness of virtual communities. Most likely, both viewpoints are correct. Relative to the ICF discussed before, the communities considered mainly focus on participation aspects, with the main objective of facilitating the exchange and sharing of experiences among peers. These communities do not aim directly at positively affecting for instance body functions or activities of patients. In case (mobile) VCs aim at positively affecting body functions or activities, current medical practice mandates an evidence based methodology as considered by Eysenbach [Eysenbach *et al.*, (2004)]. So, MVCs for telemedicine using the broad definition of health as advocated by the ICF, a quantitative analysis of the effectiveness is required, and an MVC platform could provide support services for such analysis. In addition services assisting in the analysis of how people cope with health issues need to be in place whenever MVCs are used for participation purposes.

3.2. *Success factors of (Mobile) Virtual Communities and Telemedicine*

As can be inferred from the Section 3.1, it is evident that no specific guidelines are available for building successful MVC in the telemedicine.

ICT technology to realize virtual communities aims at realizing economic, social, psychological, or medical impact. It is therefore important to understand the success factors of (mobile) VCs. Our primary focus in this paper is on the success factors relative to the purpose of a virtual community. Maloney-Krichmar and Preece [Maloney-Krichmar and Preece, (2005)] have reported on an in depth investigation on sociability, usability and dynamics of the Kneeboard online community. They observed the following factors that impact the success of a VC: a narrowly focused purpose; the social context of the community (specifically the mix of stable long-term members and newcomers).

A systematic exploration of success factors has been carried out by [Leimeister *et al.*, (2002)] for the design and implementation of a MVC for cancer patients. Their findings and results indicate that the following factors are to be considered: provisioning of an information and communication space; means to support and develop trust (hence using some proper authentication and authorization mechanism); collaboration services for making content; community leader or moderator. Although these findings apply to a very specific target group, they are very indicative for the kind of requirements that must be fulfilled by an MVC platform.

Broens et al. [Broens *et al.*, (2007)] have made a qualitative literature study on the factors that impact the success of telemedicine implementation. Given the scope of the MVC platform we have in mind, these factors apply here as well. From the perspective of the end-users of the platform, there are four major technology related factors: availability of support to end-users; training on the use of the equipment; ease of use and degree of comfort (in those cases where e.g. body sensors are to be worn); technical robustness of the systems. Other factors have been identified, for instance the review concludes that working protocols for telemedicine are often lacking, and that telemedicine might require changes in collaboration models often deployed today. Introduction of telemedicine systems is often hampered by a lack of legislation and policy. Finally, trust relationships between e.g. patients and (formal and informal) caregivers and adequate security measures (both patient's physical security, and patient information security) are essential factors for success. Similar factors have been identified by Demires [Demiris, (2006)] regarding virtual communities in health care.

In conclusion, in order for a mobile virtual community platform to be successful in the telemedicine domain, these non-functional aspects must be taken into account.

4. Mobile Aspects in Mobile Virtual Communities

With the advent of wireless communication technologies and the wide spread penetration of mobile devices, members can now access and interact via virtual communities anytime anywhere. In addition, when location can be determined and this information is made available, services can be enriched i.e. giving rise to location based services.

Most often, the term Mobile as used in MVCs refers to a mobile device. For instance, Kawash et al. [Kawash *et al.*, (2007)] adopted Dix' taxonomy of mobility. Dix [Dix *et al.*, (2000)] introduced the following taxonomy of mobility, these emerge around considering mobile systems: i) The level of mobility (fixed, mobile, autonomous); ii) Relation to other devices (free, embedded or pervasive); and iii) Cooperative nature of the applications (personal, group, public). This scope of mobility is predominantly derived from the domain considered, namely Human Computer Interactions. However, in computer networking, mobility has a broader scope. Other forms of mobility have been identified by Schulzrinne [Schulzrinne and Wedlund, (2000)]. These other forms of mobility are derived from considering other system aspects. For instance, we do not only deal with systems, but may also deal with services or multimedia sessions. A user may have multiple end-devices (e.g. PDA, Monitor, etc) and as services often allow some degree of personalization or personal configuration, the services configured according to these personal setting would ideally be available across end-systems accessible for the end-user. Schulzrinne and Wedlund [Schulzrinne and Wedlund, (2000)] defined the following four basic modes of mobility:

- *Terminal Mobility* – This form of mobility allows an end-device to be on-line (i.e. connected to the communication network) while being on the move.
- *Session Mobility* – With session mobility a user changing from using one terminal for another maintains the ongoing media session (or sessions).
- *Personal Mobility* – With personal mobility a user having multiple terminals can be addressed by one and the same logical address.
- *Service Mobility* – Service mobility is the capability of using services in the case of moving or changing devices and network service providers. This form of mobility includes any relevant personal service configuration setting or preferences.

Terminal mobility has already become a capability familiar to and used by almost everyone. Today, mobile devices also include multiple interfaces and thus allow different ways to be on-line (so called multi-homing). One of the research issues and challenges is to exploit multi-homing as to achieve optimal network connectivity and service provisioning. For this purpose vertical hand-over mechanisms can be put in place; we refer to [Pawar *et al.*, (2007)] for further details.

Although session mobility has been around as a concept for almost a decade, it took some more time before research efforts have put forward the protocols to realize session mobility. A SIP based partial specification and implementation of a session mobility protocol has been designed and implemented by Tuin [Tuijn, (2007)].

The four basic forms of mobility, collectively offer a much richer mobility concept that may proof to be useful for MVCs in general, including telemedicine.

5. An MVC Platform Architecture Addressing Terminal Mobility

In this section an architecture for a Mobile Virtual Community Platform for Telemedicine is discussed. The architecture builds on the following ideas. Firstly, there exist already many VC platforms, for instance Dolphin [Dolphin, (2008)], that could be customized according to the specific needs. Reusing such a platform has the obvious advantages. Secondly, we reuse an existing mobility middleware that allows mobile devices to take on a service provider and service consumer role, this mobility middleware is called the Mobile Services Platform (MSP) [van Halteren and Pawar, (2006)]. Thirdly, we adopt Web Services to integrate Dolphin and MSP. This way, we maximize the reuse of existing technologies and platforms, and focus on the integration issues, and the telemedicine domain specific aspects. In the following, each of these platforms will be discussed.

5.1. *Mobile Services Platform*

In ambulant telemonitoring and teletreatment scenarios there is a need for an ICT infrastructure that can accommodate services at any place and any time. In addition, the ICT infrastructure must be capable of supporting and realizing the specific requirements of such scenarios. The Mobile Services Platform (MSP) described in [van Halteren and Pawar, (2006)] supports patient and caregiver mobility. Depending on the requirements of specific tele-monitoring and treatment case, the Remote Patient Monitoring System built on top of MSP is capable of bridging location and time for actor interactions. Furthermore, the system comprises generic components and facilitates the design and development of telemonitoring and teletreatment case specific functionality, such as for instance case specific biosignal processing and distribution. Case specific functionality has been developed for epileptic seizure predictions, neck pain monitoring and treatment and cardiac patient monitoring. Remote Patient Monitoring Systems based on MSP make use of the following four basic architectures.

- *Service Oriented Architecture:* this architecture realizes a loose coupling between tasks and applications, and as such an enabler for dynamic (at run-time) orchestration of services. In addition it provides the means to built robust and high available services. Our technology choice for SOA is Jini [Jini, (2009)].
- *Jini Surrogate Architecture:* This architecture solves the problems related to using mobile devices as hosts for service producers and service consumers in SOA, we refer to [JiniSA, (2009)].
- *Body Area Network (BAN) Architecture:* The Body Area Network Architecture comprises one or more communicating on-body sensors and actuators able to measure biosignals and able to process measured data for analysis and decision making, and to provide feedback to patients or to control actuators. Central in the BAN Architecture is the Mobile Base Unit, which is a PDA or mobile phone that acts as a gateway to communicate with devices outside of the BAN and makes available services to interested remote clients. The BAN architecture supports message based communication and streaming.
- *Web-Based Access Architecture:* This standard architecture complements the mainly programmatic nature of the former architectures, to provide for enhanced means of interactions to monitor and control BAN and Patient related information by authorized persons (e.g. professional caregivers).

The complete architecture of the Remote Patient Monitoring System is shown in Figure 2.

The architecture is best understood by starting out with the SOA part of the system. In our current system, the Java based Jini technology has been adopted for the realization of the SOA. Briefly, Jini service producers publish their interfaces (so called *stubs*) in the Jini Lookup Service. Any Jini service consumer can look up a service of interest, this look up gives the Jini service consumer the information or objects needed to bind to the service. After binding, the Jini service consumer and Jini service producer can interact.

The Jini technology requires the support of an extensive set of protocols. This is a bottleneck for mobile devices. In addition, when considering full user mobility, with regularly changing point of network attachment (and associated IP address changes of the mobile device) and potential NAT and Firewall issues, a dedicated solution has been adopted. This solution is based on the Jini Surrogate Architecture. In this architecture, a Jini service producer or consumer at a mobile device always consists of two associated services: a *device service* and a *surrogate service*. The surrogate service fully participates in the Jini Network and the device service is the service running on the mobile device, in fact theaurrogate service represents the device service in the Jini network. The communication between the surrogate service and device service uses an extra-BAN communication stack called *MSP-Interconnect*. The export server plays a role at service start up. Typically, a device service starts up and provides the surrogate host with the information for surrogate service loading.

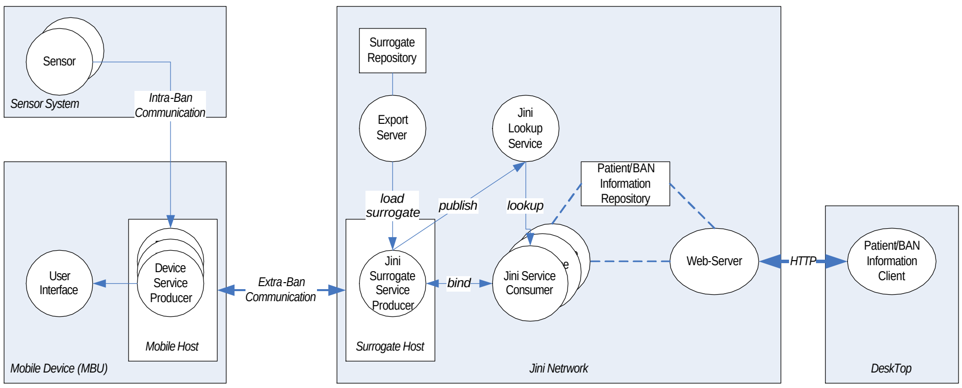

Figure 2: Overview of the Remote Patient Monitoring System based on Mobile Services Platform.

The BAN Architecture comprises one or more sensor systems (and possibly actuator systems) and a Mobile Device (PDA or smart phone) acting as a Mobile Base Unit. The Mobile Base Unit is responsible for the following three tasks: *intra-BAN communication* (with the Sensor and Actuator Systems), *local processing* and *extra-BAN communication* (to consume and/or produce services). Whenever required, the MBU supports Human-Computer interaction, usually by some appropriate graphical user interface. A sensor system comprises of one or more sensors and basic electronics such as A/D converter, sensor data multiplexing and possibly some elementary filtering or signal shaping.

Using the Jini Architecture, some common services such as biosignal processing and a biosignal storage service are realized. Services made available and biosignals stored are made accessible remotely to e.g. (authorized) formal caregivers, using web technology: a Web server acts as a portal to BAN and Patient related information, which can be monitored and (to some limited extent) controlled by a clinician using a standard web-browser application.

Regarding the physical architecture adopted for the trials, the export server (and surrogate repository), the lookup service, surrogate host and common services are all deployed on one back-end system. This choice of deployment was possible due to the limited number of patients involved in various trials and the limited processing capacity required. However, the architectural principles adopted allow a full physical distribution of these functionalities.

5.2. *Mobile Service Platform based Mobile Virtual Community Platform*

The MVC platform provides supporting services and mediates services provided by Mobile Devices. In [Pawar *et al.*, (2008)], the services to be supported by the Virtual Community Platform have been defined. These are:

- *Member Management Service:* This service provides functions such as registration of new members, managing member profiles, their roles (e.g. commercial service provider), login, and session handling.
- *Directory Service:* The directory service provides functionality for the commercial service (product) providers and community support providers to list the offered services (products) and content. Thus, it basically results in the creation of yellow pages.
- *Community Management Service:* This service consists of the functionalities required to create, join, access and search sub-communities, publish, get and subscribe information in the existing sub-communities.
- *Social Interaction Service:* This service handles the one-to-one, one-to-many or many-to-many interactions between the community members. This includes interaction functions such as live chat, notifications, and subscription to the member information.
- *Context-Aware Matchmaking Service:* The matchmaking functionality of this service is used to find potential members for the new sub-community automatically by providing the semantic description of the community. The matchmaking service is vital to support the business model described herewith. If a community member is interested in a particular type of the service, the matchmaking service performs the final selection of the services based on context information of the members and services using the approach proposed in [Hesselman *et al.*, (2006)].
- *Mediation Service for Commercial Aspects:* The role of the mediation service is to provide access for the members to the listed services and products through the community platform and to handle financial transactions on behalf of the members. For this purpose, the mediation service consists of a centralized billing module. The Community Platform provisions a database which stores information such as the member profiles, services and product listings and billing information. The social

interaction between the community members is also stored in this database along with their profiles.

5.3. *Integration Layer*

The purpose of the integration layer is to integrate the MSP and with the VC Platform built using Dolphin. The integration layer supports MSP based service producers that make available services to the virtual community platform, and service consumers that make use of services provided by the community platform itself, or those that are mediated by the virtual community platform. The integration technology adopted is Web Services. The principles of the integration are shown in the Figure 3. A Device Service Producer is made available via its associated Surrogate Service Producer. A (Jini) service consumer binds to the Surrogate Service Producer and embeds a producer based on Web Services; this web service producer publishes its service to the community platform (see Figure 3(a)). In the case of a Device Service Consumer, the Surrogate Service Consumer embeds the Web Service Consumer that binds with services provided by the community platform using SOAP over HTTP, see Figure 3.(b).

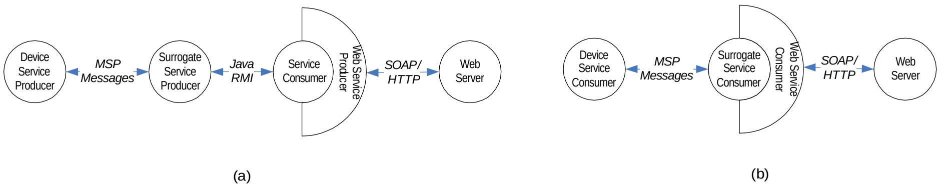

Figure 3: Service Integration: (a) integrating a device service producer; (b) integrating a device service consumer.

6. Research Challenges and Opportunities

In this section we discuss the research challenges and opportunities in the context of the application domain, i.e. Telemedicine, and the MVC architecture described in the Section 5. We start out with challenges specific to Telemedicine; we then address platform services and the management of the platform.

6.1. *A prototypical architecture for patient management systems*

With advanced ICT technologies becoming available, telemedicine is transforming from teleconsultation and remote treatment to systems empowering the patient with self-management capabilities. Pour [Pour, (2006)] advocates this view and proposes framework based on multi-agent autonomic architectures for patient self-management systems. This framework is based on the autonomic computing archetype [Kephart and Chess, (2003)] and it applies to any telemedicine system. The functions needed to realize self-managing patients are:

- *Monitoring*: Monitor the patient's health condition, and relevant patient environmental conditions.
- *Analyze*: Analyze these monitored parameters (short term to detect acute situations, or long term to detect trends)

- *Plan*: Devise or adjust a treatment plan based on the outcome of analysis.
- *Effectuate*: Based on the plan, take the actions (or sequence of actions) that are needed to realize the plan.

The generic decision making model for clinical decision support systems proposed by [Carson *et al.*, (1998)] essentially includes these processes so as to realize a feedback loop used to manage the patient's health status.

With respect to the MVC platform for telemedicine, it must accommodate the inclusion of the services realizing the telemedicine specific intelligence (e.g. as third party services), and to use these in specified workflows.

6.2. *Defining the purpose of an MVC*

One of the observations made previously is that the purpose of an MVC must be sufficiently narrowly scoped in order to be effective. As an example, an MVC can serve a single person with a single disease and focus on the monitoring of body functions and may in addition provide means to give feedback or training advice, or an MVC could have the purpose to provide support in organizing and realizing daily activities, or an MVC may have as purpose to support social interactions among peers. These are all examples of different communities each with their own specific focus regarding one or more categories that comprises health status. These categories help in defining the attribute values of a MVC, purpose statements typically would make explicit what positive health status effect is expected to be realized. The International Classification of Functioning, Disability and Health [ICF, (2001)] and its category qualifiers enable an explicit representation of these goals and with proper instrumentation support by the MVC platform enable the monitoring and analysis of these goals. In existing community platforms such as Dolphin, the purpose of a community can be described as text, which is mainly useful for end-users and not for goal directed analysis and evaluation. Today, the ICF is mainly used as a means for acquiring health status information from persons, usually by means of questionnaires. The use of the ICF we have in mind here is that of goal setting. Design, implementation and evaluation of a system such as an MVC platform for telemedicine using the ICF for goal setting (and associated monitoring and analysis tools) is a challenge both from a research perspective and would move the ICF a step forward.

6.3. *Configuration and Autonomic Adaptation*

Considering MVC platform supporting potentially many different communities, it must be properly equipped with capabilities to configure each community so that it conforms to requirements derived from the community goals. One of the main differences with traditional VC platforms is the need for support of enforcing the rights, obligations and prohibitions associated with the roles fulfilled by the members of an MVC. This need directly originates from e.g. legal and privacy conditions that apply. On a per community basis, these rights, obligations and prohibitions must be configurable, and whenever applicable, medical protocols may guide this configuration. Configurations may differ substantially among different mobile virtual communities depending on the purpose of the community. These differences become clear in case we look at the properties of a community discussed earlier. A community with the goal to monitor some specified subset of body functions will usually be classified as purely medical, thus enforcing rules related to the ownership of medical data and the privacy and security mechanisms for the transfer and storage of such data. As a result, such a community will be a closed community and strict rules will apply to create or alter the community. A community focusing on participation, such as the Kneeboard community studied in [Maloney-Krichmar and Preece, (2005)], is an open community where also non-members can access information.

Also, the health status of an individual may change over time, with proper monitoring functionality in place, the services may autonomically adapt to the new situation. This form, in the spirit of [Pour, (2006)] and [Carson *et al.*, (1998)] focuses on the autonomic adaptation of the functionality to manage the patient. Similar techniques can be adapted to the ICT components themselves as to achieve system robustness.

6.4. *Interactions between Communities*

To safeguard the effectiveness of a community a narrowly scoped purpose has been shown the better option. This could mean that a single person with some well defined health problem can be a member of multiple mobile virtual communities. For instance, the person could be a patient in a community for monitoring certain specified body functions, and a care taker in an activity support community, and a member of a participation support community. For either of these communities to be optimally effective, health status information gained from the other communities may be needed or desired, or services used and provided by these other communities may be needed or desired as support services. In the context of telemedicine, with a concrete focus and application domain, inter-community interaction can be studied and research in a more scoped way.

Membership of multiple communities will also hold for healthcare professionals. In such case, access to the communities must be made possible with single sign-on.

6.5. *Mobility Support Beyond Terminal Mobility*

In MVC the mobility aspect considered usually is terminal mobility. Other forms of mobility may however prove to be useful. Usefulness is to be considered here as function of the community member roles, community purpose and the tasks and responsibilities. This is yet a fully open issue in MVCs, and could open ways to further enhance the usefulness.

6.6. *Support for evaluation of the effectiveness*

Effectiveness may be evaluated with regard to many different aspects. Among these are organizational and economic effectiveness. In the following we consider in particular the effectiveness with regard to the effect of a mobile virtual community on the health status of a person. With an explicit expression of the health status using the ICF and installed health status monitors, gradual and acute changes in the health status can be monitored over time. In order to reach conclusions about the effectiveness, comparison with control groups is needed. A MVC platform with support for longitudinal evaluation of individuals and populations and combined with information collected and processed from control groups may aid in further deployment of such systems.

6.7. *Operational Management of an MVC platform*

Like any ICT infrastructure, the operational management of the MVC platform and the services it provides is of paramount importance, especially when applied to telemedicine. One of the most important challenges is the local and remote management of the mobile systems that are in use, especially in those cases where these are used to in a BAN to monitor biosignals. Critical issues here are fault management, performance management and configuration management. Regarding the operational management of the mobile services platform, we are about to complete a first prototype for BAN management using JMX in a way that fully conforms to the surrogate architecture discussed earlier. Management of the Dolphin platform can be based on the standard management provisioning of the apache web server. An integrated management of the two platforms is an issue that is to be started. It is a critical aspect for the practical application of the approach.

7. Concluding Remarks

In present day Mobile Virtual Communities (MVC), full independence of time and space seem to be within reach thanks to the latest mobile devices and wireless communication technologies. In the telemedicine domain, information and communication technologies are being investigated and employed in areas such as health maintenance, alleviation, cure and prevention of diseases. Nevertheless, advanced sensors, mobile devices and wireless communication technologies play a significant role to monitor the patient while being on the move and provide necessary assistance in the case of emergency. Other computing paradigms such as Service Oriented Architecture and Web-Based Access Architecture are proving to be beneficial.

MVCs have been employed in the telemedicine domain to improve effectiveness of the basic healthcare systems. However, a number of studies show mixed and perhaps contradictory results and there are no proven guidelines available for quantifying success of such MVCs or for building a successful MVC in telemedicine domain. Moreover, it has been found that apart from the functional and technical aspects, the non-functional aspects such as legislation and government policies must be taken into account in order for a MVC to be successful in the telemedicine. On the technical aspects, though use of the mobile devices proves to be advantageous, a robust architecture and technical platform is nevertheless required to handle mobility aspects in such communities.

We have not covered all issues that are essential MVC and MVC platforms. Whenever mobility is involved, issues concerning trust must be addressed at various levels, for instance at the device level, but also at the human user level. The latter is of special concern whenever open MVCs are involved. Another concern is the ownership of data (in our case often medical data) and the issue of granting access to this data to others. Related to these issues are support for accountability and auditability. Especially in the domain of telemedicine adequate solutions for these issues may become a prerequisite for legal and user acceptance. Today's systems often overlook these issues or address these only in part.

Our contribution in this area is threefold: Firstly, we have given a brief overview of the current state of the art in MVC and discussed how MVCs can be used for telemedicine, and we have looked at the effectiveness and success factors for MVCs in the telemedicine domain. Secondly, we have outlined various mobility aspects and a robust MVC platform based on a number of computing paradigms such as mobile services, SOA, web based architecture and Body Area Network architecture has been presented. Thirdly, based on our experience in the telemedicine and MVC domains, we have put forward a number of research challenges and opportunities for MVC in telemedicine domain. We believe that a robust autonomic computing and management support is necessary to strengthen the existing architecture and improve its scalability, manageability and fault tolerance properties. Moreover, MVC needs to be focused; for example, supporting social interactions or organizing and realizing daily activities or provide support services such as training advice. Though mobility aspects have been researched extensively in other domains such as pervasive computing, they are yet to be considered for MVC in the telemedicine domain; where we see a significant research potential. Apart from these, explicit frameworks need to be developed for evaluating the effectiveness of MVC in the telemedicine domain.

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