31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Mobile Patient Monitoring: the MobiHealth System

K. Wac, *Student Member, IEEE*, R. Bults, B. van Beijnum, *Member, IEEE*, I. Widya, *Member, IEEE*, V. Jones, D. Konstantas, *Member, IEEE*, M. Vollenbroek-Hutten, H. Hermens

***Abstract*—The emergence of high bandwidth public wireless networks and miniaturized personal mobile devices give rise to new mobile healthcare services. To this end, the MobiHealth system provides highly customizable vital signs tele-monitoring and tele-treatment system based on a body area network (BAN) and a mobile health care (m-health) service platform utilizing next generation public wireless networks. The developed system allows the incorporation of diverse medical sensors via wireless connections, and the live transmission of the measured vital signs to healthcare providers as well as real-time feedback to the patient. Since 2002 the system has undergone substantial development in consecutive EU and national research projects. Diverse trials with different healthcare scenarios and patient groups in different European countries have been conducted in all projects. These have been performed to test the service and the network infrastructure including its suitability for m-health applications.**

I. INTRODUCTION

THE expansion and availability of high bandwidth wireless networks (i.e. 2.5/3/3.5G) combined with the ever-advancing miniaturization of sensor devices and computers, give rise to new services and applications that affects and change our daily life [1]. An area where these new technological advances will have a major effect is healthcare. The vision we strive for is that patients are able to send full, detailed and accurate vital signs measurements and receive medical advice from a distance, irrespective of where and when they are. This data is to be of an equivalent standard to that obtained in a medical centre, implementing the concept of 'ubiquitous medical care' [2].

In keeping with this vision, the MobiHealth project (supported by the Commission of the European Union in the frame of the 5th research Framework under the project number FP5-IST-2001-36006, conducted in 2002-2004) has started a development of an innovative value-added mobile health service platform for patients and health professionals [3]. This service platform has been then named MobiHealth and it has been further developed in the European HealthService24 research project (FP6-eTen-517352, 2005-2006), Dutch national Freeband-Awareness project (BSIK-5902390, 2004-2008) [4], as well as the currently executed European MyoTel project (FP7-eTen-046230, 2007-2009). The MobiHealth Service Platform™ in its current development stage is owned by created in 2007 University of Twente spin-off named MobiHealth B.V. [5].

The platform enables remote patient monitoring and treatment through the use of advanced wireless communications and integration of sensors to a wireless Body Area Network (BAN) [6]. The platform permits a remote management of chronic conditions whilst maximizing patient mobility. Our research goal is to enable automatic prediction, detection and tele-treatment of health emergencies by the platform based on the monitored health state of a patient.

II. MOBIHEALTH SYSTEM

The MobiHealth system provides a complete end-to-end m-health platform for an ambulant patient monitoring and treatment, deployed over the next generation wireless networks. The MobiHealth patient is equipped with different sensors that continuously monitor his vital signals, *e.g.*, blood pressure, heart rate, respiration, electrocardiogram (ECG). These are interconnected via a healthcare BAN. A BAN consists of sensors, actuators, communication and processing facilities connected via a short-range wireless network. The BAN is worn on the body and moves around with the person, i.e. the BAN is a roaming unit [6, 7].

The central point of the healthcare BAN is a Mobile Base Unit (MBU). It aggregates the vital sensor measurements

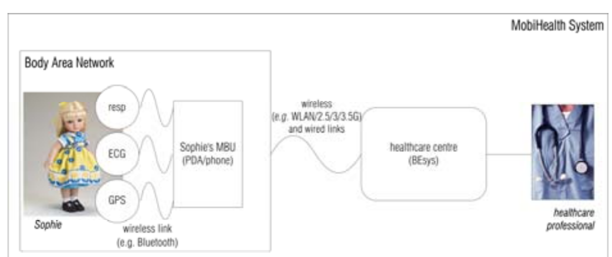

Fig. 1. MobiHealth system high-level architecture.

and transmits them via a long-range wireless network to the application-server, i.e. back-end system (BEsys). The BEsys system can be located within the healthcare provider premises or be a part of the wireless services provider. From there, the measurements are dispatched to the healthcare

Manuscript received June 20, 2009. This work is partially supported by the European Commission MyoTel project (FP7-eTEN-046230).

K. Wac and D. Konstantas are with University of Geneva, CH-1227 Geneva, Switzerland, K. Wac is also with and University of Twente, the Netherlands (phone: +41-22-379-0242; fax: +41-22-379-1215; e-mail: {wac, konstantas}@cui.unige.ch).

R. Bults, B. van Beijnum, I. Widya, V.M. Jones, M. Vollenbroek-Hutten and H. Hermens are with University of Twente, R.Bults is also with MobiHealth B.V., M. Vollenbroek-Hutten and H. Hermens are also with Roessingh Research and Development, Enschede, the Netherlands (e-mail: {r.g.a.bults, b.j.f.vanbeijnum, i.a.widya, v.m.jones, m.vollenbroek, h.j.hermens} @ utwente.nl).

provider where they can be examined by medical personnel. Automated monitoring and patient feedback is equally supported by the MobiHealth system.

Communication between entities within a BAN is referred to as *intra-BAN* communication. *Extra-BAN* communication is used for the MBU- BEsys communication and enables remote monitoring. Intra-BAN communication is based on short-range wireless networks like Bluetooth, while extra-BAN communication employs 2.5/3/3.5G long-range wireless technologies (e.g. 3G-UMTS in Europe). Figure 1 shows the high-level architecture of the MobiHealth system.

The sensors used in the BAN are responsible for the data acquisition process. They monitor and capture a physical phenomenon, such as patient movement, heart rate, muscle activity or blood flow. This is converted to an electrical signal, which is then amplified, conditioned, digitized and communicated within the BAN. The healthcare BAN sensors can be self-supporting and/or front-end supported.

Self-supporting sensors have their own power supply and facilities for amplification, conditioning, digitization and communication. Self-supporting sensors are independent building blocks of a BAN, communicating directly with the MBU (or even the BEsys). However, each sensor runs to its own internal clock and may have a different sampling frequency. Consequently, mechanisms for synchronization between sensors may be needed at the MBU (or the BEsys).

Front-end supported sensors share a common power supply and data acquisition facilities. Consequently, the front-end supported sensors typically operate on the same front-end clock and jointly provide multiplexed sensor samples as a single data block. The front-end synchronizes sensors data before communicating it to the MBU.

III. Service Platform Architecture

The healthcare BAN is only one part of the MobiHealth service platform. The platform integrates the mobile part (healthcare BAN) and the BEsys system. Figure 2 shows the overall functional architecture of the MobiHealth service platform. The dotted square boxes indicate the physical location where parts of the service platform are executed. The rounded boxes represent the functional layers of the architecture. The m-health service platform consists of sensor and actuator services, intra-BAN and extra-BAN communication providers and an m-health service layer. The intra-BAN and extra- BAN communication providers represent the communication services offered by intra-BAN communication networks (e.g. Bluetooth) and extra-BAN

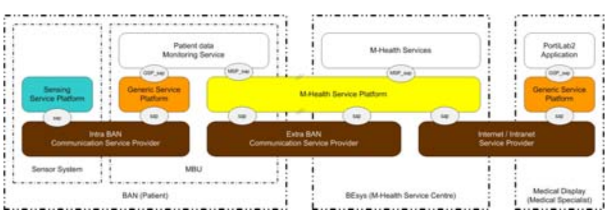

Fig. 2. MobiHealth Service Platform ® Functional Architecture.

communication networks (e.g. 3G), respectively. The m-health service layer integrates and adds value to the intra-BAN and extra-BAN communication providers.

Applications that run on top of the service platform can either be deployed on the MBU (for on-site use, e.g. by a visiting nurse) or on the servers or workstations of the healthcare provider, e.g. a call centre or secondary care centre. Applications that use the m-health service layer can range from simple viewer applications (*e.g.*, PortiLab2 of Twente Medical Systems International (TMSI)) that provide a graphical display of the BAN data, to complicated applications that analyze the data and provide personalized feedback to a patient.

Fig. 3. Example of front-end based MobiHealth BAN.

We have experimented to implement the MobiHealth healthcare BAN using both front-end supported and self-supporting sensors. Figure 3 presents a front-end provided by TMSI (the blue box on the right side) with 4-leads ECG sensors and a respiration belt attached to it. It uses Bluetooth for intra-BAN communication. A movement sensor, a temperature sensor, pulse oximeter, Galvanic Skin response sensor or an alarm button are examples of other sensors that can be attached to this front-end. The MBU presented in the Figure was implemented on an HTC Qtek 9090 device. The MBU is currently also implemented on other HTC devices such as HTC TyTN II, Touch and MAX 4G.

IV. MobiHealth System Trials

The primary question addressed by the MobiHealth project in 2002 was whether 2.5G and 3G generation communications technologies can support the MobiHealth vision, i.e., enable empowered managed care based on mobile health care systems. In the HealthService24 project we researched a market potential for remote monitoring systems. Similarly, now in MyoTel project, we research a market potential for myo-feedback-based remote monitoring and treatment systems for patients suffering from chronic shoulder-back pain. Freeband-Awareness project aimed at developing context-aware service platform, e.g. adapting service delivery to the user’s location, time and the activity he is engaged in.

To address these particular questions, in each project we conducted MobiHealth system use trials in different European countries. These trials also enabled us to elicit user requirements and to identify problems and issues in the development of m-health services. They enabled us to identify limitations and shortcomings of the existing and forthcoming service and network infrastructures. It should be made clear that the primary aim of these projects was to evaluate technical feasibility and added value of MobiHealth system in a healthcare, and not to clinically validate new medical tools and processes.

The MobiHealth project trials were targeted at the areas of acute (trauma) care, chronic and high-risk patient monitoring, and home care. A range of medical conditions was covered including high-risk pregnancy, trauma, cardiology (arrhythmias), rheumatoid arthritis (RA) and respiratory insufficiency (chronic obstructive pulmonary disease COPD). HealthService24 trials focused on high-risk pregnancy, cardiac arrhythmia and COPD. Freeband-Awareness trials focused on epileptic and spasticity patients. MyoTel project trials focused on monitoring and treatment trials for patients suffering from chronic shoulder-back pain. The treatment services included a feedback to the patient, based on his current health state. This feedback was aiming to motivate the patient either to change their body position, do little exercise or simply to consciously relax their shoulder-back muscles. The feedback was implemented through a visual, auditory or kinesthetic (i.e. vibration) modality on the MBU, depending to the patient's preferences and needs.

In all projects, the trials were selected to represent a range of bandwidth requirements: low (less than 12 kbps), medium (12–24 kbps) and high (greater than 24 kbps), and to include both non-real-time (e.g. routine transmission of tri-weekly ECG) and real-time requirements (e.g. alarms or transmission of vital signs in a critical trauma situation or epilepsy seizure). For each application, the generic MobiHealth BAN was customized by addition of the appropriate sensor set and corresponding application software.

Currently, the MobiHealth B.V. company uses its service platform to provide remote mobile monitoring and treatment services for (chronic) patients as well as remote mobile data capturing services for drug research [5].

V. Results

From the MobiHealth project trials, we learned that mobile remote monitoring of patient's vital signs is possible over 2.5G-GPRS and 3G-UMTS public access networks. We discovered that these public networks are designed for applications where the end-user is a consumer of information, i.e. a typical user sending small amounts of data (i.e. in the uplink) and receiving (i.e. in the downlink) large amounts of data. The MobiHealth system, however, is based on the reverse model: the end-user is the producer of information and not the consumer. The network and terminal devices in their configuration are not designed to support high bandwidth transmissions emanating from the end-user in the uplink. This limits the volume of data that a mobile patient, can send to the BEsys. For the GPRS network, this limit is around 26 kbps, while for UMTS – around 64 kbps. Nowadays, when HSPA networks become available, we see the story repeating itself. Namely, operators implement their network with a downlink bandwidth of 1.8-7.2 Mbps, while leaving the option of implementing uplink (1.4 Mbps), highly unclear.

When setting up the consecutive generations of a prototype of the MobiHealth system, we also encountered set of issues related to standardization and lack of interoperability.

Already in the MobiHealth project we proved that mobile remote monitoring of patients is potentially cost saving, as it reduces frequent routine examination at hospital and increases patient's quality of life.

HealthService24 trials showed that GPRS/UMTS networks are sufficiently reliable for non-critical cases and that remote monitoring of patients is cost saving as it changes the care professional to patient ratio. We proved that there is a market potential. However, MobiHealth system users required a miniaturization and/or integration of BAN devices, as well as an increase of battery lifetime of BAN devices beyond currently achieved 8-18 hours.

Awareness project trials enabled us to develop adaptive application protocols for health monitoring and treatment, taking into consideration *e.g.* location and activity of the patient being monitored and treated. In this project we also elicited requirements and prototyped solutions for security and privacy being incorporated in the MobiHealth system. These mechanisms comprised user authentication and authorization (based on the user roles: a patient, a healthcare practitioner or a nurse), as well as use of encryption techniques for medical data exchange.

MyoTel project, similarly to HealthService24, showed a market potential for monitoring and treatment services provided for patients suffering from chronic shoulder-back pain.

VI. Discussion

MobiHealth system aims to give patients a more active role in the healthcare process while at the same time enabling healthcare payers to manage costs more efficiently. The healthcare BAN and supporting service platform is an emerging technology that promises to support this aim.

MobiHealth project has resulted in an early prototype of a BAN (Q1 2002), engineered mainly by integration of existing technologies without focusing on miniaturization or optimization of power consumption. The main focus has been on the architecture, design and implementation of an m-health service platform. The result was a first version of a service platform, which architecture is comprised of a set of clearly defined components. In our further research projects, we have elicited precise user requirements and we have continued the development of service platform accordingly. Therefore, the MobiHealth Service Platform™ in its current development stage is a versatile remote mobile monitoring system (i.e., not specific to one disease), it enables patient mobility, supports different modes of data transmission (stand alone MBU-based monitoring, non-real time and real time), with all wireless sensor systems data time-synchronized. The platform can incorporate up to 8 wireless sensor systems and it is not “locked-in” to a specific sensor system manufacturers. The platform is flexible to support any new (wireless) sensor and actuator systems and scalable for large scale mobile remote health monitoring and treatment. For the Mobihealth system, we also research on automatic health monitoring application behavior adaptation due to changing network characteristics and on application resiliency during network handover [8, 9].

Currently, we research on business models for healthcare and accounting and billing models for network services. We emphasize that standardization at all levels is essential for open solutions to prevail. At the same time we observe that specialization, customization and personalization are widely considered to be success criteria for innovative health monitoring and treatment services.

Throughout all research projects we observed much interest and enthusiasm for the project both from patients and healthcare professionals. As no standard questionnaire for mobile healthcare systems usability has been available, in the already MobiHealth project, we have developed our own questionnaire [10]. This questionnaire was a result of consensus between professionals participating in our project at different trail-sites as well as other professionals in the field. It principal dimension were: system functionality, user interface, effectiveness, efficiency, satisfaction, safety, functional and aspirational needs, mastery and empowerment, mobility and activity, quality of life, ethical considerations. Results indicated that users are content to have the system, but they pose very high expectations towards it. By means of this research, we have got valuable insights into user requirements. Since the success of the Mobihealth project, we continue to work closely with system users and we continue development along their requirements.

VII. Conclusive Remarks

The results of our research projects and commercial undertaking include architecture for, and an implementation of, a generic service platform for provision of ubiquitous healthcare services based on body area networks. The MobiHealth Service Platform™ can support not only health-state sensors, but potentially any body-worn or any personal devices. Consequently the MobiHealth system has potentially many tele-monitoring and tele-treatment applications not only in a healthcare domain. However, before the system can be used in routine practice in any application domain, we indicate a need for its technological assessment against its user requirements, as well as a need for business models, in which costs and revenues are split amongst the participating actors.

References

[1] U. Hansmann, L. Merk, M. Nicklous, and T. Stober, *Pervasive Computing: The Mobile World*: Springer, 2003.

[2] R. S. H. Istepanian, E. Jovanov, and Y. T. Zhang, "m-health: Beyond Seamless Mobility and Global Wireless Healthcare Connectivity," *IEEE Trans. Information Technology in Biomedicine*, vol. 8, pp. 405-414, 2004.

[3] A. van Halteren, R. Bults, K. Wac, D. Konstantas, I. Widya, N. Dokovsky, G. Koprinkov, V. Jones, and R. Herzog, "Mobile Patient Monitoring: The MobiHealth System," *The Journal on Information Technology in Healthcare*, vol. 2, pp. 365-373, 2004.

[4] M. Wegdam, "AWARENESS: A project on Context AWARE mobile NEtworks and ServiceS," presented at 14th Mobile & Wireless Communication Summit, Dresden, Germany, 2005.

[5] MobiHealth, "Putting care in motion," 2007.

[6] A. van Halteren, R. Bults, K. Wac, N. Dokovsky, G. Koprinkov, I. Widya, D. Konstantas, V. Jones, and R. Herzog, "Wireless Body Area Networks for Healthcare: the MobiHealth Project," in *Studies in Health Technology and Informatics*, vol. 108, *Technology and Informatics*, G. Demiris, Ed. Amsterdam, the Netherlands: IOS Press, 2004, pp. 181-193.

[7] R. Bults, K. Wac, A. van Halteren, D. Konstantas, V. Jones, and I. Widya, "Body Area Networks for Ambulant Patient Monitoring Over Next Generation Public Wireless Networks," presented at 13th IST Mobile and Wireless Communications Summit, Lyon, France, 2004.

[8] K. Wac, A. van Halteren, T. Broens, and R. Bults, "Context-aware QoS Provisioning in an m-health Service Platform," *International Journal of Internet Protocol Technology*, vol. 2, pp. 102-108, 2007.

[9] K. Wac, "QoS-predictions service: infrastructural support for proactive QoS- and context-aware mobile services," presented at On the Move to Meaningful Internet Systems 2006: OTM Workshops, Intl Workshop on Context-Aware Mobile Systems (CAMS), Monpellier, France, 2006.

[10] A. Melander-Wikman, M. Jansson, and G. Gard, "The MobiHealth Usability Evaluation Questionnaire," *eHealth International Journal*, vol. 2, 2005.