Mobile Patient Monitoring: the MobiHealth System

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Abstract. The forthcoming wide availability of high bandwidth public wireless networks will give rise to new mobile health care services. Towards this direction the MobiHealth[1] project has developed and trialed a highly customisable vital signals' monitoring system based on a Body Area Network (BAN) and an 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 signals over public wireless networks to healthcare providers. Nine trials with different health care cases and patient groups in four different European countries have been conducted to test and verify the system, the service and the network infrastructure for its suitability and the restrictions it imposes to mobile health care applications.

1 Introduction

This expansion and availability of high (mobile) bandwidth (GPRS/UMTS), combined with the ever-advancing miniaturization of sensor devices and computers, will give rise to new services and applications that will affect and change the daily life of citizens. An area where these new technological advances will have a major effect is health care. Citizens, being patients or non-patients, will not only be able get medical advice from a distance but will also be able to send from any location full, detailed and accurate vital signal measurements, as if they had been taken in a medical center, implementing the "ubiquitous medical care".

The MobiHealth project, started in May 2002 and completed in February 2004, has developed innovative value-added mobile health services, based on 2.5 (GPRS) and 3G (UMTS) networks. MobiHealth has developed a mobile health BAN and a generic service platform for Body Area Network (BAN) services for patients and health professionals. Remote (patient) monitoring services are just one of the kinds of services that can be provided. This is achieved with the integration of sensors to a wireless BAN. The BAN connected sensors continuously measure and transmit vital constants to health service providers and brokers. This way the BAN facilitates remote monitoring of patients' vital signs and therefore enables

[1] The MobiHealth project was supported by the Commission of the European Union in the frame of the 5th research Framework under the project number IST-2001-36006.

proactive disease prevention and management by continuous monitoring of patients' health condition 'anytime and everywhere'.

The use of health BANs together with advanced wireless communications enables remote management of chronic conditions and detection of health emergencies whilst maximising patient mobility. MobiHealth has developed a generic Body Area Network (BAN) for healthcare and an m-health service platform. The BAN incorporates a set of body-worn devices and handles communication amongst those devices. It also handles external communication with a remote location. During the MobiHealth project the main devices used are medical sensors and positioning (GPS) devices, and the remote healthcare location is a healthcare provider (a hospital or medical call center). Biosignals measured by sensors connected to the BAN are transmitted to the remote healthcare location over wireless telephony services.

The results of the project include an architecture for, and a prototype of, a generic service platform for provision of ubiquitous healthcare services based on Body Area Networks. The MobiHealth BAN and service platform are trialled in four European countries with a variety of patient groups. The MobiHealth System can support not only sensors, but potentially any body worn device, hence the system has potentially very many applications in healthcare which allow healthcare services to delivered in the community.

In the last months of the project 9 different trials scenarios were implemented for different types of patients. These trials allowed us to identify problems and issues in the development of mobile e-health services and identify limitations and shortcomings of the existing and forthcoming public network infrastructure.

First results indicate that several issues need to be resolved by both network operators and hardware manufacturers for a better support to mobile health services. Ambulatory monitoring is more successful for some biosignals than others, for example some measurements are severely disrupted by movement artefacts. Some monitoring equipment is still too cumbersome for ambulatory use, because of the nature of the equipment or because of power requirements, while even with 2.5 and 3G we still suffer from limited bandwidth for applications that serve many simultaneous users. Other challenges relate to security, integrity and privacy of data during transmission to both local transmission (eg. intra-BAN) and long range (eg. extra-BAN) communications. Powering always on devices and continuous transmission will continue to raise technical challenges. Business models for healthcare and accounting and billing models for network services need to evolve if technical innovations are to be exploited fully. Standardisation at all levels is essential for open solutions to prevail. At the same time specialization, customisation and personalisation are widely considered to be success criteria for innovative services.

2 The MobiHealth system

The MobiHealth system provides a complete end-to-end e-health platform for ambulant patient monitoring, deployed over UMTS and GPRS networks. The MobiHealth patient/user is equipped with different vital constant sensors, like blood pressure, pulse rate and ECG interconnected via the *healthcare Body Area Network* (BAN). The *Mobile Base Unit* (MBU) is the central point of the healthcare BAN, aggregating the vital sensor measurements and transmitting them via UMTS or GPRS to the back-end system, which can be located within the health broker premises or be part of wireless services provider. From there the measurements are dispatched to the health care broker where the medical personnel monitor them. It must be noted that automated monitoring and patient feedback is currently not supported by the MobiHealth system, as this was outside the scope of the project.

In the context of the MobiHealth project the *Healthcare BAN* (Body Area Network [1][2][3][4]) is a health monitoring tool that consists of sensors, actuators, communication and processing facilities connected via a wireless network which is worn on the body and which moves around with the person (i.e., the BAN is the unit of roaming).

We call communication between entities within a BAN *intra-BAN communication*. To allow external communication of the BAN for remote monitoring we use a gateway, the Mobile Base Unit (MBU), which provides the *extra-BAN communication*. Intra-BAN communication is based on wireless networks like Bluetooth[5] and Zigbee[6], while the extra-BAN communications is done via GPRS and UMTS.[2] **Error! Reference source not found.** shows the architecture of a healthcare BAN. Sensors and actuators establish an ad-hoc network and use the MBU to communicate outside the BAN. The MBU could also be implemented as a sensor or actuator that provides extra-BAN communication services.

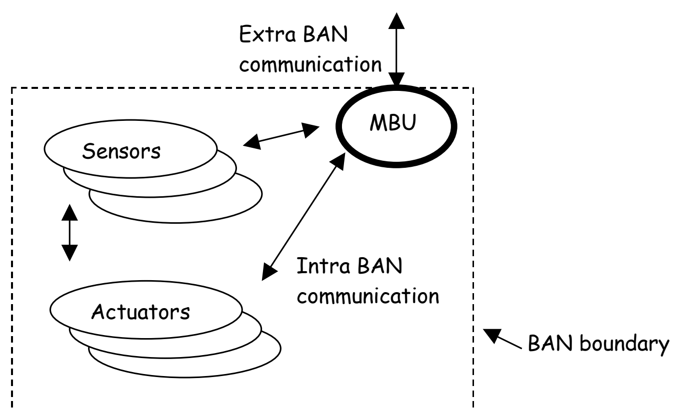

Figure 1 Healthcare BAN architecture

A sensor is responsible for the data acquisition process, ensuring that a physical phenomenon, such as patient movement, muscle activity or blood flow, is first converted to an electrical signal, which is then amplified, conditioned, digitised and communicated within the BAN.

The Healthcare BAN sensors can be self-supporting and/or front-end supported. Self-supporting sensors have a power supply and facilities for amplification, conditioning, digitisation and communication. Self-supporting sensors are independent building blocks of a BAN and ensure a highly configurable healthcare BAN. However, each sensor runs at its own internal clock and may have a different sample frequency. Consequently, mechanisms for the synchronization between sensors may be needed.

Front-end supported sensors share a common power supply and data acquisition facilities. Consequently, front-end supported sensors typically operate on the same front-end clock and jointly provide multiplexed sensor samples as a single data block. This avoids the need for synchronization between sensors.

2.1 Service platform architecture

Collecting and transmitting the vital signal measurements is only part of the healthcare service developed in the MobiHealth project. The Healthcare BAN is only one part of a service platform that integrates the mobile part (healthcare BAN) and the health broker resident system. Figure 1 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 executing. The rounded boxes represent the functional layers of the architecture. The M-health

[2] WLAN was also used in the initial stages of the project for testing purposes.

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 communication networks (e.g. UMTS), respectively. The M-health service layer integrates and adds value to the intra-BAN and extra-BAN communication providers. The M-health service layer masks applications from specific characteristics of the underlying communication providers, such as the inverted consumer-producer roles.

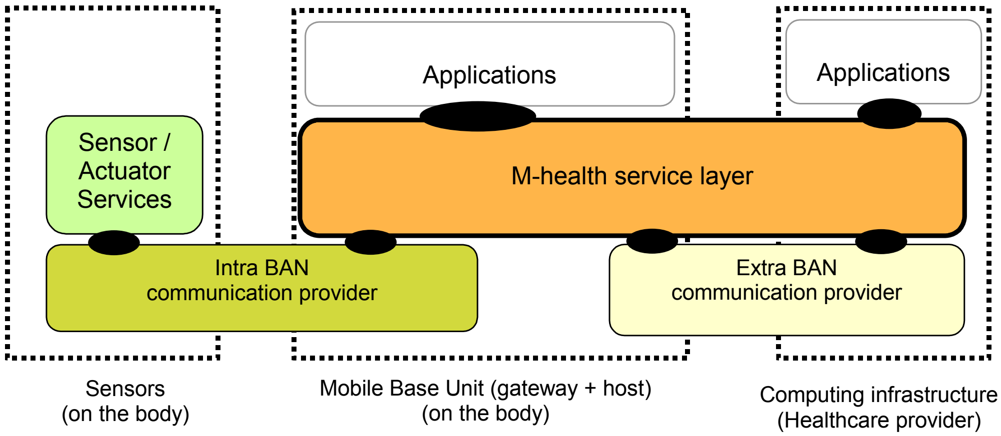

Figure 1 Service platform functional architecture

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, i.e. the call centre or the co-located secondary care centre in Figure 1 .

Applications that use the m-health service layer can range from simple viewer applications that provide a graphical display of the BAN data, to complicated applications that analyse the data.

The Healthcare BAN has been implemented using both front-end supported and self-supporting sensors. Figure 2 shows the self-supporting EISlab sensor [7] (left) and a TMSI front-end (right). Both approaches use Bluetooth for intra-BAN communication. The front-end also allows ZigBee as an alternative intra-BAN communication technology. Electrodes, a movement sensor, a pulse oximeter and an alarm button are examples of sensing devices that can be attached to the front-end.

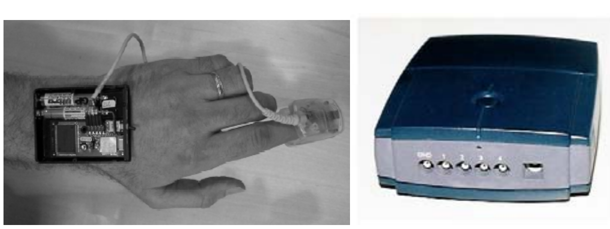

Figure 2 Self supporting sensor and a front-end

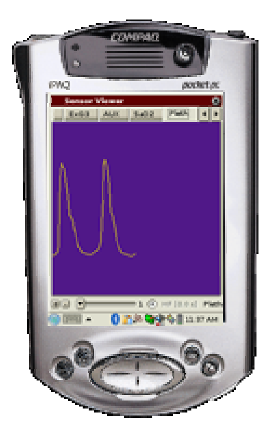

Figure 3 iPAQ H3870 acts as MBU

The MBU was implemented on an iPAQ H3870. This device has built-in Bluetooth capabilities and can be extended with a GPRS extension jacket. Figure 3 shows a picture of the MBU that also runs a viewer application.

The BANip has been implemented using Java 2 Micro Edition (J2ME)[8] The BANip is implemented on the MBU as an HTTP client that collects a number of samples into the payload of an HTTP POST request and invokes the post on the surrogate. We've used a standard HTTP proxy to act as a security gateway of the surrogate. In case the surrogate needs to control the MBU, these control commands are carried as payload of the HTTP reply.

The surrogate has been implemented using the Jini Surrogate architecture[9]. Jini provides the implementation for auto-discovery and registration of the BAN. In terms of the Jini architecture the surrogate is a service provider. Other components, such as the BAN data storage component, are service users from the perspective of the surrogate.

3 The MobiHealth Trials

The primary question addressed by the MobiHealth project was whether 2.5/3G communications technologies can support the MobiHealth vision, i.e., enable the move towards empowered managed care based on mobile health care systems. To obtain an (as much as possible) valid reply to this question, we organized and conducted nine different trials in four different countries around Europe, expecting that for some trials the existing infrastructure will be adequate while for others it may be insufficient. We must note however that the conducted trials were *not* clinical trials. The primary target of the project being the evaluation of the 2.5/3G infrastructures and *not* the clinical validation of new medical tools and processes.

The trials target at the areas of acute (trauma) care, chronic and high-risk patient monitoring and monitoring of patients in home-care settings, covering a range of conditions including pregnancy, trauma, cardiology (ventricular arrhythmia), rheumatoid arthritis and respiratory insufficiency (chronic obstructive pulmonary disease), covering both use of patient BANs and health professional BANs (nurse BAN, paramedic BAN). 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 (like routine transmission of tri-weekly ECG) and real time requirements (e.g. alarms, transmission of vital signs in a critical trauma situation). For each application the generic MobiHealth BAN is specialized by addition of the appropriate sensor set and corresponding application software.

Nine trials were organized in four different countries, and namely:

1. Germany - Telemonitoring of patients with cardiac arrhythmia
2. The Netherlands - Integrated homecare for women with high-risk pregnancies
3. The Netherlands -Tele trauma team
4. Spain - Support of home-based healthcare services
5. Spain - Outdoor patient rehabilitation
6. Sweden - Lighthouse alarm and locator trial
7. Sweden - Physical activity and impediments to activity for women with RA
8. Sweden - Monitoring of vital parameters in patients with respiratory insufficiency
9. Sweden - Home care and remote consultation for recently released patients in a rural area

More details on the trials can be found in [10].

During the trials different types of data were collected in view of an evaluation of the results. The target of the evaluation was dual: first we wanted to verify the state of the UMTS (and GPRS) infrastructure and its suitability for mobile health applications, and second we wanted to explore the added value that the MobiHealth system can bring to different healthcare domains.

At the moment of the writing of this paper (February 2004), the trials are still ongoing and the evaluation was not yet completed. Nevertheless some preliminary results are available and will be presented in the following sections. We must however note that the results are preliminary and that they have not yet been analysed. Thus definitive conclusions cannot be (yet) drawn. We present here some of the results from the UMTS tests and trials performed in the Netherlands using the Vodafone pre-commercial UMTS network. We must note however that the MobiHealth project is the *only* user of the Vodafone UMTS network in the Twente region. Thus we are running under the best-case environment, that is, on an empty network.

One of the first problems that we encountered in the use of the UTMS (and GPRS) networks the *reverse producer-consumer* model. The public networks were designed for applications where the end-user is a consumer of information, i.e, a typical user will send small requests and will receive massive data as a response. The MobiHealth system however is based on the reverse model: the end-user is the producer of information and not the consumer. The consequence of this reversal is that the network and terminal devices cannot support (in their present configuration) high bandwidth transmission emanating from the end-user. This is a limiting factor for the measurements that the MobiHealth system can send to the health broker.

To enhance portability and for being compatible with the operating systems available on portable telephones, the MobiHealth application on the MBU was programmed in Java under the CLDC Java Virtual Machine [11]. As a result we have been forced to use the HTTP protocol for transporting vital signals. However the current HTTP protocol implementation under the CLDC Java VM does not allow for persistent HTTP connections. That means that whenever the MBU needs to send data it must establish a new TCP/IP connection. This however is very expensive, in terms of performance. A better option would have been for the mobile telephones were able to use the CDC [12] platform that allows direct access to the TCP/IP layer.

A second issue related to the use of the HTTP protocol is the fact that every time a request is sent, the communication is blocked until an acknowledgment or reply is received. To solve this problem we used a technique called *chunking* [13] where multiple requests are sent without having to wait for a reply. However not all operators allow the use of chunking for their GPRS network. This eventually might cause standardization problems for services and applications that transmit continuous real time data over the GPRS and possibly UMTS

During the UMTS performance tests (active measurements) we performed tests trying to emulate a high load of the network by running 10 simultaneous UMTS transmissions. The tests (which are still on-going) indicate a performance degradation (network failure) when high bandwidth from 10 UMTS connections are simultaneously transmitted (form the same room, with each UMTS connection running from its own unique terminal). The reason for this failure is not clear yet we hope to have more data and information at the end of the tests.

On the positive side we were able to confirm the stability of the Vodafone UMTS network in the Netherlands. Tests done with a moving station (a car roaming within the Enschede coverage area) allowed us to maintain a connection of at least 64Kbps (up and down link) crossing over cell boundaries and under different speeds. The maximum bandwidth available for a fixed station of 64Kbps uplink and 384 downlink is readily available and stable thought out the coverage area (our terminal devices – Nokia UMTS telephones – do not allow us to obtain higher bandwidths).

The available data bandwidth over GPRS (and UMTS) depends on the strength of the signal at the user location. Although the GPRS and UMTS telephones do indicate the signal strength during operation, this is not the case for the PCMCIA cards integrated with the iPAQ. PCMCIA cards allow the control of the signal strength using proprietary software, *but only during set up*. During data transmission the signal strength information is not available. However this information is of major importance for the MobiHealth application, since it will allow us to estimate the available bandwidth and to control the data transmission rate accordingly. Currently, we have the situation that when transmitting at high bandwidth at an area with strong signal and we pass to an area where the signal is low, we are not able to lower the data transmission rate and as a consequence the connection breaks down. We thus believe that the signal rate as well as the encoding schema used during the transmission should be available to the application under a standardized API for all types of GPRS/UMTS terminals, whether these terminals are PCMCIA cards or regular mobile phones.

4 Conclusions

In the rather short duration of the project a great many problems and challenges have been encountered and much progress has been made. The starting point was a vision of ubiquitous mobile health services based on Body Area Networks. During the project we have designed and prototyped a health BAN and a BAN service platform and developed services for different patient groups according to the requirements specified by the clinical partners. Patient trials have begun and evaluation data are under collection for further analysis.

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

MobiHealth has resulted in an early prototype of the BAN, engineered mainly by integration of existing technologies without focusing on miniaturization or optimisation of power consumption. The main focus has been on the architecture, design and implementation of an m-health service platform. The result is a first version of a service platform whose architecture is comprised of a set of clearly defined components.

It should not be thought however that all problems can be overcomed even with use of current technologies. Ambulatory monitoring is more successful for some biosignals than others, for example some measurements are severely disrupted by movement artefacts. Some monitoring equipment is still too cumbersome for ambulatory use, because of the nature of the equipment or because of power requirements. In the area of wireless (tele)communication technologies (even with 2.5 and 3G) we still suffer from limited bandwidth for some applications, such as those which require serving many simultaneous users with applications requiring high bandwidth.

The use of BANs and wireless communications in personal healthcare systems still raises important challenges relating to security, integrity and privacy of data during transmission. End-to-end security and Quality of Service guarantees need to be implemented. Safety of hardware (eg. electrical safety, emissions, interference) and reliability and correctness of applications must also be a priority in deployment of mobile services. Comfort and convenience of sensors or BANs worn long term for continuous monitoring is important for usability and user acceptance. Timeliness of information availability in the face of unreliable performance of underlying network services is another issue. Provision of seamless services across regional and national boundaries multiplies these difficulties. Powering *always on* devices and continuous transmission will continue to raise technical challenges. Business models for healthcare and accounting and billing models for network services need to evolve if technical innovations are to be exploited fully. Standardisation at all levels is essential for open solutions to prevail. At the same time specialization, customisation and personalisation are widely considered to be success criteria for innovative services.

Although our formal work in the MobiHealth project will be completed in the end of February of 2004, plans are underway for the creation of a venture for the further development and commercialisation of the results. The great interest shown by healthcare organizations and commercial companies, as well as the products that become available in the market every day and the interest shown by patients encourages us to proceed as fast as possible in the creation of a company that will promote and commercialise the MobiHealth services and platform. We expect that by the end of the 2004 to have a first version of a commercial system available to interested users in different European countries.

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