Body Area Networks for Ambulant Patient Monitoring Over Next Generation Public Wireless Networks

Richard Bults[1], Katarzyna Wac[1,2], Aart Van Halteren[1]
Dimitri Konstantas[1,2], Val Jones[1], Ing Widya[1]

[1] University of Twente, EWI/CTIT
P.O.Box 217, NL-7500 AE Enschede, The Netherlands
{*firstname.lastname*}@ewi.utwente.nl

[2] University of Geneva – CUI
24 rue General Dufour, CH-1211 Geneva 4, Switzerland
{konstantas,wac}@cui.unige.ch

ABSTRACT

The forthcoming wide availability of high bandwidth public wireless networks combined with the evolution of performant body area networks will give rise to new mobile health care services. The MobiHealth[1,2], project has developed and trialed a customisable vital signals' monitoring system based on a Body Area Network (BAN) and an m-health service platform utilizing UMTS and GPRS 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 healthcare 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..

I. INTRODUCTION

One of the major technological advances of the 21st century will be the implementation and wide availability of public broadband wireless networks, and namely 3G (UMTS) and 4G networks. Today many public network operators in Europe and around the world are installing and operating or testing UMTS networks, providing coverage and high mobile bandwidth to important parts of the population. In the next few years it is expected that the coverage will increase and eventually will cover almost the totality of the population, as it is the case today with the GSM networks.

This expansion and availability of high (mobile) bandwidth, 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 to 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 what we can call "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). This is achieved with the integration of sensors to a Wireless Body Area Network (BAN) [2][3][4]. The BAN connected sensors continuously measure and transmit vital constants, audio, images or positioning information to health service providers and brokers. This way the BAN facilitates remote monitoring of patients' vital signs and therefore enables 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

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

[2] The project site http://www.mobihealth.org provides more information regarding the project.

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.

II. THE MOBIHEALTH SYSTEM AND SERVICES

MobiHealth has developed a mobile health BAN and a generic service platform for BAN services for patients and health professionals. Remote (patient) monitoring services are just one of the kinds of services that can be provided.
The healthcare BAN is an innovative health monitoring tool that consists of sensors, actuators, communication and processing facilities. Communication between entities within a BAN is called intra-BAN communication. To use the BAN for remote monitoring external communication is required which is called extra-BAN communication. The gateway that facilitates extra-BAN communication is called the Mobile Base Unit (MBU).

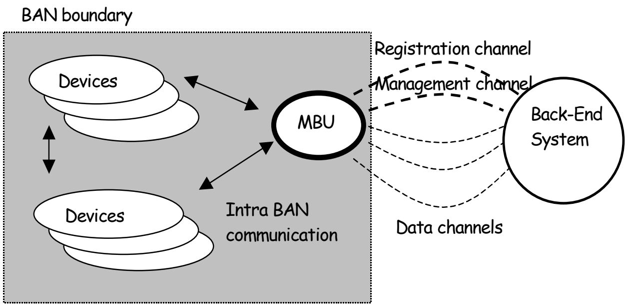

Figure 1 BAN architecture

Figure 1 shows the architecture of a BAN and the system communication. Sensors and actuators establish an ad-hoc network and use the MBU to communicate outside the BAN. The MBU could be a sensor or actuator that also provides extra-BAN communication services
A sensor is responsible for the data acquisition process. A sensor ensures that a physical phenomenon, such as patient movement, muscle activity or blood flow, is first converted to an electrical signal. This signal is then amplified, conditioned, digitized and communicated inside the BAN.
Sensors can be either self-supporting or front-end supported. Self-supporting sensors have a power supply and facilities for amplification, conditioning, digitization and communication. In case of front-end supported sensors, multiple sensors share a 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. Self-supporting sensors are independent building blocks of a BAN and ensure a highly configurable BAN. However, each sensor runs at its own internal clock and may have a different sample frequency. Consequently, synchronization between sensors may be needed.
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 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.

A. Implementation

The BAN has been implemented using both front-end supported and self-supporting sensors. Fig. 2 shows the MobiHealth system with TMSI front-end sensors, configured for GPRS communication, while figure 3 shows the UMTS configurations (excluding the sensors). Both configurations use Bluetooth for intra-BAN

Figure 2 MobiHealth GPRS Pregnancy BAN

Figure 3 MobiHealth UMTS Trauma BAN

communication. The front-end also allows ZigBee [1] 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. Sensor data is processed by the front-end before being transmitted to the MBU. A range of front-ends can be associated with an MBU, enabling customization of the BAN. Although the MBU currently used in the MobiHealth trials is based on the HP iPAQ platform, future plans include porting to a cell phone platform such as the Sony Ericsson P800. The MBU was implemented on an iPAQ H3870. This device has built-in Bluetooth capabilities and can be extended with a GPRS extension jacket.

B. Transport system

The MobiHealth transport service is not delivered by one transport system belonging to one organizational entity, but by different transport providers. In general the transport system consists of three transport systems belonging to at least three organizations. It's therefore necessary to identify these systems through decomposition of the transport system. If each sub-system is responsible for a section of the 'end-to-end' communication path used between MobiHealth system components, then the 'end-to-end' communication path can be decomposed according to Figure 4. The fine tuning of all parts of the transport system is thus crucial in the operation of the overall system. The evaluation of the UMTS part of the system was one of the main tasks of the project

healthcare services. For this a number of trials was organized. The trials span four European countries and cover a range of conditions including pregnancy, trauma, cardiology, respiratory insufficiency and rheumatoid arthritis, and make use of patient 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 (e.g. 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. The medical trials conducted, were [6]:

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

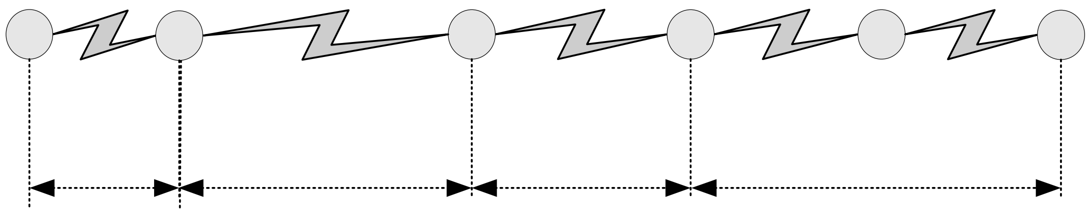

Figure 4. MobiHealth Transport system

The BANip [5] has been implemented using Java 2 Micro Edition (J2ME). 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. Jini provides the implementation for auto-discovery and registration of the BAN. Other components, such as the BAN data storage component, are service users from the perspective of the surrogate.

III. THE MOBIHEALTH TRIALS

The overall goal of the MobiHealth project is to test the ability of 2.5/3G infrastructures to support value added

IV. CONCLUSIONS AND RECOMANDATIONS

In March 2004 the trials were completed and a first analysis of the evaluation data was performed, proving us with results regarding the performance of the UMTS networks and technical issues related to MobiHealth BAN. Although the current UMTS networks are stable and functional, there are many barriers and technological details that need to be resolved before stable and viable services can be introduced in the market. In this section we present a description of the issues and problems identified during the project in the areas of communications and technology infrastructures.

A. Operators

The analysis of the collected measurement data during the trials allowed us to identify a number of problems that need to be resolved by the operators in order to allow the development of robust mobile health services. In the following we summarize the most important results and recommendations regarding the current status of UMTS networks.

Data rate

An important problem of the UMTS network is the difficulty for the user to establish high uplink and downlink bandwidth for variable and fixed data rate transmissions.

The UMTS network allocates different dedicated bearers for uplink and downlink channels depending on the data volume generated (uplink) or requested (downlink) by the user. When a user is generating or requesting low data volumes, the network allocates the common bearer (lowest bandwidth). On the other hand, if the user is generating or requesting high data volumes the network will allocate a dedicated bearer; uplink bearer 1 (64 Kbps) and downlink bearer 1 (64 Kbps), bearer 2 (128 Kbps) and bearer 3 (384 Kbps).

When the user is silent for a couple of seconds the allocated bearer is switched to the common bearer. If the user now wishes to transmit or receive a high volume of data again, he will not have immediately available the required highest bearer (i.e. highest bandwidth). The UMTS network will have to switch the uplink incrementally from the common bearer to bearer 1, and the downlink from the common bearer via 1 and 2 to the highest bearer 3. As a result the application risks loosing data due to buffer overflow due to the inability to transmit data at the required bandwidth. Thus variable data rate transmission is more complicated than other wireless or wired networks.

On the other hand fixed data rate transmissions also face some problems. It takes (too much) time for the UMTS network to switch from the common bearer to a dedicated bearer, and thus data has to be buffered at the sending end (e.g. MobiHealth BAN). Buffering data will result in a variable delay and buffer overflow due to capacity limitation which may result in temporal application termination or data loss.

The exact conditions and policy for bearer allocation should thus be made available by the operators to the application designers so that an optimal method for the use of the available bandwidth can be designed.

Delays

During the trials we observed that the uplink delays in the UMTS network increased linearly with the size of packets. However the observed delay variation (jitter) was very high due to bearer switching. The implication of the high jitter is that buffering of data is required to compensate for the delays. This is in line with the use of IPv4, which does not provide any Quality of Service (QoS), but it will not be acceptable in the future IPv6 environment where a far better QoS will be required. Further fine-tuning of the network will be required

Handovers

The operators associated with the MobiHealth project have implemented UMTS soft handovers (from one cell to another). In some occasions we observed connection loss during horizontal handover. The reasons of this connection loss were not clear to us, and we were not able to consistently reproduce the problem, which seemed to be random. We presume that it was due to transient problems. In any case further analysis might be needed to resolve this problem.

A GPRS to UMTS (and vice versa) hard handover scenario was not supported by all the operators participating in the project. However we had the opportunity to test (in an ad hoc manner) UMTS to GPRS handover using dual mode terminals. Although the handover worked correctly (i.e. the IP context remained the same), we observed a high delay during the handover process and a temporary interruption of the communications. The delay observed was between 10 and 20 seconds. This created problems in the MobiHealth application since during this time the data needed to be buffered leading in many cases to buffer overflow and data loss.

In addition we were not able to find out (neither our contacts in the participating operators were able to tell us) when and under what conditions the handover between UMTS and GPRS takes place.

We thus would like the operators to define the handover policy (when and how) and to reduce the handover delays. The information regarding the handover (when, what bandwidth will be next available etc) should also be available to the application designers.

Bandwidth

A major issue in our trials was the available UMTS bandwidth. For the time the available bandwidth of the UMTS network is far bellow the “dream” 2 Mbps, the operators do not yet support this bandwidth. Nevertheless, we measured a steady bandwidth for downlink of 384 Kbps (netto: 270Kbps due to overhead), and 64 Kbps (netto: 57 Kbps) for uplink. These figures were stable and were tested also with moving terminals (up to 60 Km/h). However the traffic model of UMTS networks should be reviewed by the operators and industry so that it takes into consideration the fact that end users can also be producers of information and not only consumers (inverted producer – consumer paradigm). This will have implications in the bandwidth allocation and the design of terminals, all of which do not allow, for the time being, high data transmission from the user.

IP address allocation

Different operators have different policies regarding IP address allocation of the mobile devices. Some allocated public IP addresses, thus making them visible directly from the Internet, while others use private addresses making the mobile devices invisible from the Internet. Both solutions have advantages and disadvantages, depending on the application. We believe that the operators should allow the application providers to choose which model they want to use for their applications and not impose the one or the other model.

Communication costs

A major issue in the development of new medical services will be the communication costs. From our trials we have observed that continuous monitoring of vital signals will generate data in the order of magnitude of 10 MB per day per user. With the existing cost policies the overall communication costs over a period of just one month will make the application cost prohibitive (around 1 Euro per MB). We expect that the operators will introduce a different cost model for continuous transmission applications, like for example a flat charge for unlimited data and usage (as is the case today of some operators offering flat cost unlimited use for GSM communications).

B. Technology suppliers

Communication information and control

One of the problems we observed in our trials was the inability to obtain information on available bandwidth during the operation of the system. Although the UMTS PC cards support a proprietary interface that provides information of the available bandwidth, this interface can only be accessed when the card is not under operation. We would thus like the card manufactures to provide a standard API for communication control and information.
Some of the functionalities we would like to access are, dynamic available bandwidth information, the actually used bearer, bearer changes, and control of UMTS to GPRS (and vice versa) handover. Clearly some of these functionalities can only become available if the operators are able to provide the related information and control.

Power supply for the terminals

A major problem in the mobile medical applications is the limited power supply. A UMTS terminal (e.g. Nokia telephone) transmitting data continuously will empty its battery in less than 2 hours (at best). More research in alternative power sources need to be conducted.

Bluetooth IntraBan communication

A bandwidth limitation for the intra-BAN communication comes from the limited bandwidth of the Bluetooth interface supported by the UMTS telephones. Although the USB connection of the telephone supports high bandwidth, the Bluetooth connection has a bandwidth limited to 115 Kbps, much lower than the 384 Kbps of the UMTS downlink. We hope that in the future the Bluetooth connection will support higher bandwidth, so that it is not the communication bottleneck.

The processing power of the Bluetooth hardware in the front-end device (a.k.a. Mobi) also proved a bottleneck. Only a maximum throughput of 160kbps of the theoretical maximum of 720kpbs could be achieved. Although this has been sufficient for the trials executed in the MobiHealth context, with other trials that require more sensors (for example additional ExG signals) this will soon become a bottleneck.

Standardization

Within the next few years the mobile health services will start becoming available at a large scale. However, to promote the development of value added services and to facilitate the interoperation of these services, several standards need to be designed and applied. Standards for medical systems being operational in a MobiHealth BAN need be developed, as well as the standards for representation and transmission of vital signal measurements (of the many that exist today) might need to be revised or tailored for mobile applications.

REFERENCES

[1] ZigBee Alliance, “IEEE 802.15.4, ZigBee standard”, http://www.zigbee.org/

[2] Zimmerman, T.G., 1999, ‘Wireless networked devices: A new paradigm for computing and communication’, IBM Systems Journal, Vol. 38, No 4.

[3] van Dam, K, S. Pitchers and M. Barnard, ‘Body Area Networks: Towards a Wearable Future’, Proc. WWRF kick off meeting, Munich, Germany, 6-7 March 2001; http://www.wireless-world-research.org/.

[4] Jones, V. M., Bults, R. A. G., Konstantas, D., Vierhout, P. A. M., 2001a, “Healthcare PANs: Personal Area Networks for trauma care and home care”, Proceedings Fourth International Symposium on Wireless Personal Multimedia Communications (WPMC), Sept. 9-12, 2001, Aalborg, Denmark, ISBN 87-988568-0-4

[5] Nikolay Dokovsky, Aart van Halteren, Ing Widya, "BANip: enabling remote healthcare monitoring with Body Area Networks", FIJI, International Workshop on scientiFic engIneering of Distributed Java applIcations, November 27-28, 2003, Luxembourg.

[6] Val Jones, Aart van Halteren, Nikolai Dokovsky, George Koprinkov, Jan Peuscher, Richard Bults, Dimitri Konstantas, Ing Widya and Rainer Herzog, *MobiHealth : Mobile Services for Health Professionals*. In "M-Health: Emerging Mobile Health Systems", Robert H. Istepanian, Swamy Laxminarayan, Constantinos S. Pattichis, Editors, Kluwer Academic/Plenum publishers (to Appear in 2004)