

MOBILE HEALTH CARE OVER 3G NETWORKS: THE MOBIHEALTH PILOT SYSTEM AND SERVICE

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Abstract

Health care is one of the most prominent areas for the application of wireless technologies. New services and applications are today under research and development targeting different areas of health care, from high risk and chronic patients' remote monitoring to mobility tools for the medical personnel. In this direction the MobiHealth¹ project developed and trailed a system and a service that is using UMTS for the continuous monitoring and transmission of vital signals, like Pulse Oximeter sensor, temperature, Marker, Respiratory band, motion/activity detector etc., to the hospital. The system, based on the concept of the Body Area Network, is highly customisable, allowing sensors to be seamlessly connected and transmit the monitored vital signal measurements. The system and service was trialed in 4 European countries and it is presently under market validation.

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 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 target of the MobiHealth project, started in May 2002 and completed in February 2004, was the development and trial of new services and applications in the area of mobile health, promoting the use and deployment of GPRS and UMTS mobile services and technologies. The project developed innovative value-added mobile health services, based on 2.5 (GPRS) and 3G (UMTS) networks. This was achieved with the integration of sensors to a wireless Body Area Network (BAN) [1][2]. 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 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.

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

The results of the project include an architecture for, and a prototype of, a generic service platform for provision of mobile healthcare services based on Body Area Networks. The MobiHealth BAN and service platform were trialed 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 be 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.

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 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 the *Mobile Base Unit (MBU)*.

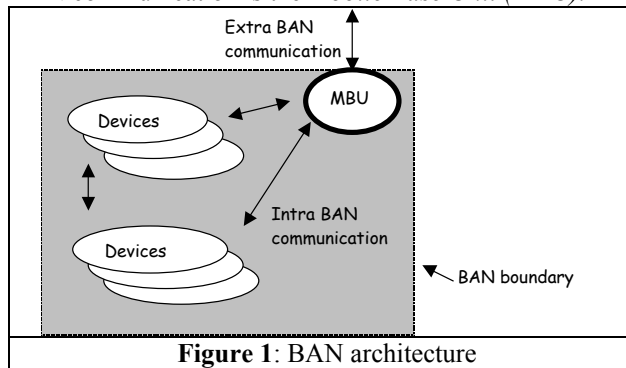


Figure 1: BAN architecture

Figure 1 shows the architecture of a BAN. Sensors and actuators establish an ad-hoc network and use the MBU to communicate outside the BAN. The MBU can be any device with sufficient processing power able to manage the BAN and provide extra-BAN communication services.

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. This signal is then amplified, conditioned, digitised 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, digitisation 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. Thus, synchronization between sensors may be needed.

Figure 2 shows the functional architecture of the service platform. The dotted square boxes indicate the physical location where parts of the service platform will be executing. The rounded boxes represent the functional layers of the architecture.

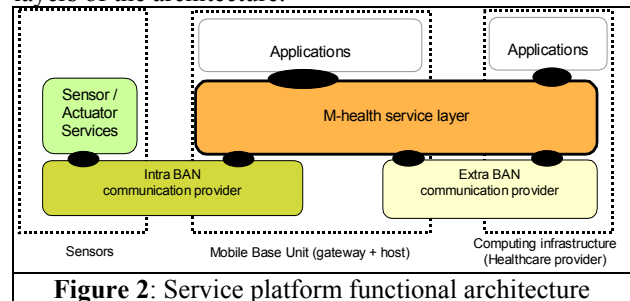


Figure 2: Service platform functional architecture

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 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.

The BAN has been implemented using both front-end and self-supporting sensors, both using Bluetooth for intra-BAN communication. Electrodes, movement sensor, pulse oximeter and alarm button are examples of sensing devices that can be attached to the front-end. Sensor data is processed by a sensor front-end before being transmitted to the MBU. A range of front-ends can be associated with an MBU, enabling customisation of the BAN. Although the MBU used in the MobiHealth trials is based on the HP iPAQ platform, porting to UMTS programmable telephones is currently under way.

The MBU was implemented on an iPAQ H3870. This device has built-in Bluetooth capabilities and can be extended with a GPRS extension jacket. The UMTS



Figure 3 : GPRS system and UMTS system

version uses a Nokia UMTS telephone connected to the MBU via Bluetooth. Figure 3 shows on the left the GPRS system with sensors, and on the right the UMTS system (without the sensors).

The BANip [3] has been implemented using Java 2 Micro Edition (J2ME) 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.



Figure 4: MBU display
Respiration



Figure 5: MBU display
Plethysmogram

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.

Vital Signals

The MobiHealth trials required the measurement of six different signals and namely: ECG, Pulse Oximetry, Temperature, Marking, Respiration and Motion/activity. In addition a number of derived signals was produced like heart rate, EMG etc.

The signals were visualized on the MBU (figures 4 and 5) and were send life to the health care organization, where they were presented to the medical personnel (figure 6).

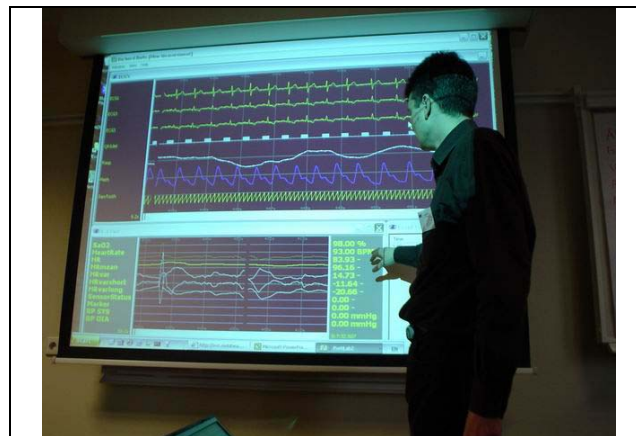


Figure 6: MobiHealth PortiLab end-user application

The MobiHealth Trials

The overall goal of the MobiHealth project was to test the ability of 2.5 and 3G infrastructures to support value added healthcare services. For this a number of trials were organized, spanning four European countries and covering a range of conditions like pregnancy, trauma, cardiology, rheumatoid arthritis and respiratory insufficiency. In the trials we used 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 (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 was specialized by addition of the appropriate sensors and application software. The trials in Netherlands, Spain and Sweden used both UMTS and GPRS networks

Trial 1 - Germany : Telemonitoring of patients with cardiac arrhythmia

The target group in this trial are patients with ventricular arrhythmia who are undergoing drug therapy. In patients suffering from arrhythmia, ECG measurements have to be taken regularly to monitor the efficacy of drug therapy. The patient is able to transmit ECG and blood pressure via GPRS from home or elsewhere to the health call centre, where the vital signs are monitored by a cardiologist. This way irregular patterns can be detected quickly and appropriate intervention can be initiated.

Trial 2 - The Netherlands : Integrated homecare for women with high-risk pregnancies

The trial will use the MobiHealth BAN to support integrated homecare for women with high-risk pregnancies. Women with high-risk pregnancies are

often admitted to the hospital for longer periods of time because of possible pregnancy-related complications. Homecare with continuous monitoring is desirable and can postpone hospitalisation and reduce costs, as well as offering more security for the mother and unborn child. In this trial, patients are monitored from home using the MobiHealth BAN and the (maternal and foetal) biosignals are transmitted to the hospital.

Trial 3 - The Netherlands : Tele trauma team

MobiHealth BANs will be used in trauma care both for patients and for health professionals (ambulance paramedics). The trauma patient BAN will measure vital signs which will be transmitted from the scene to the members of the trauma team located at the hospital. The paramedics wear trauma team BANs which incorporate an audio system and a wireless communication link to the hospital. The purpose of this trial is to evaluate whether use of mobile communications can improve quality of care and decrease lag-time between the accident and the intervention.

Trial 4 – Spain: Support of home-based healthcare services

This trial involves use of GPRS for supporting remote assistance and home-based care for elderly and chronically ill patients suffering from co-morbidities including COPD. The MobiHealth nurse-BAN will be used to perform patient measurements during nurse home visits and the MobiHealth patient-BAN will be used for continuous monitoring during patient rehabilitation at home, or even outdoors. Parameters to be measured are oxygen saturation, ECG, spirometry, temperature, glucose and blood pressure.

Trial 5 - Spain : Outdoor patient rehabilitation

The patients involved in this trial are chronic respiratory patients who are expected to benefit from rehabilitation programs to improve their functional status. The study aims to check the feasibility of remotely supervised outdoor training programs based on control of walking speed enabled by use of the MobiHealth BAN. The physiotherapist will receive online information on the patient's exercise performance and will provide feedback and advice. It is expected that by enabling patients to perform physical training in their own local settings, the benefits, in terms of cost and social acceptance, can be significant. Parameters to be measured are pulse oximetry, ECG and mobility with audio communication between patient and remote supervising physiotherapist.

Trial 6 - Sweden : Lighthouse alarm and locator trial

The target group involved in the trials are patients at the Lighthouse care resource centre and also clients living at

home, but with the common characteristic that all have an alarm system located in their room at the Lighthouse Centre or in their home. The current system does not allow the patient any freedom related to mobility and forces the patient to be trapped at home or in their room at the Centre. By replacing the fixed alarm system with the mobile MobiHealth system the patient can move freely anywhere. In addition, positioning and vital signs are monitored.

Trial 7 - Sweden : Physical activity and impediments to activity for women with RA

Trial subjects will be women with Rheumatoid Arthritis. The use of the BAN together with the mobile communications will enable collection of a completely new kind of research data which will enhance the understanding of the difficulties and limitations which these patients face. The objective is to offer solutions that will make their lives easier. Parameters measured include heart rate, activity level, walking distance and stride length.

Trial 8 - Sweden : Monitoring of vital parameters in patients with respiratory insufficiency

The group of patients involved in the trial suffer from respiratory insufficiency due to chronic pulmonary diseases. These people need to be under constant medical supervision in case they suffer an aggravation of their condition. Besides needing regular check-ups, they are also dependent on oxygen therapy at home, which means oxygen delivery and close supervision. The use of the MobiHealth BANs is designed to enable the early detection of this group of diseases but also to support homecare for diagnosed patients by detecting situations where the patient requires intervention. Parameters measured are pulse rate, oxygen saturation and signals from a motion sensor (accelerometer).

Trial 9 – Sweden : Home care and remote consultation for recently released patients in a rural area

Home care services and the possibility of monitoring health conditions at a distance are changing the way of providing care in different situations. If suitable, home-based services are provided and patients do not need to be in hospital, for example they are recovering from an intervention. By investing in home care, hospitals have been able to significantly reduce pressure on beds and on staff time dedicated to the kind of patients named above. This trial tests transmission of clinical patient data by means of portable GPRS/UMTS equipment to a physician or a registered district nurse (RDN) from patients living in a rural, low population density area. .

Evaluation

The target of the trials was to evaluate both the user acceptance of the system and services and the UMTS network performance. For the user evaluation questionnaires were used for both the patients and the medical personnel. For the network performance, we conducted both passive and active measurements for the UMTS networks in Netherlands, Spain and Sweden.

The results of the user evaluation indicate that users see a clear need for such a mobile system, and have high expectations. However, the prototype delivered was evaluated as a final product and of course some users were disappointed. What was interesting was that users (medical personnel and patients) that had good technical support were satisfied with the service and system and a good level of confidence of the services was finally achieved. Nevertheless in spite this initial disappointment, by the end of the project all users agreed that a stable product would be very useful.

A first analysis of the network performance evaluation data collected during the trials, provide us with interesting 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 e-health services can be introduced in the market. Some of the most important are the restricted available data bandwidth for uplinks, delay variation, delays in transmission and handovers.

Delay variation

During the trials we observed that the uplink delay variation (jitter) was in some cases very high due to bearer switching and error recovery (figure 6). 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 a future

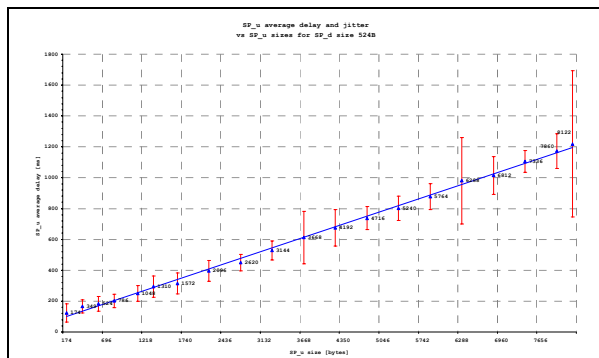


Figure 6: Delay and jitter (scale 0 to 1800 ms) for different packet sizes (from 174 to 8022 bytes)

IPv6 environment where a far better QoS is anticipated. Further fine-tuning of the network will be required.

Handovers

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. Further analysis is needed to identify and resolve this problem.

During the trials we had the opportunity to test GPRS-UMTS hard handover using dual mode terminals on a pre-commercial UMTS network. 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.

Clearly, the hard handover delay will need to be resolved but in addition, information about the hard handover policy (when, what bandwidth will be next available etc) should be made 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 below the “dream” 2 Mbps, the operators do not yet support this bandwidth. Nevertheless, we measured a steady bandwidth for downlink of 384 Kbps (net: 270Kbps due to overhead), and 64 Kbps (net: 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).

Clock drift

Our system was incorporating a number of stand-alone devices (Portable PC, PDAs etc) interconnected via bluetooth. Each device had its own internal clock and for the performance evaluation we time-stamped the packets and data at different points. However, the internal clocks of the different devices were drifting to the point where the measured delays were unrealistic. The drift was most probably due to environmental changes, like rise of the room temperature when the heating was turned on, which in its turn was rising the temperature of the devices, causing the clock to drift. In addition, the regular automatic clock re-synchronization functions were forcing the clock to advance (by 50ms or more) creating

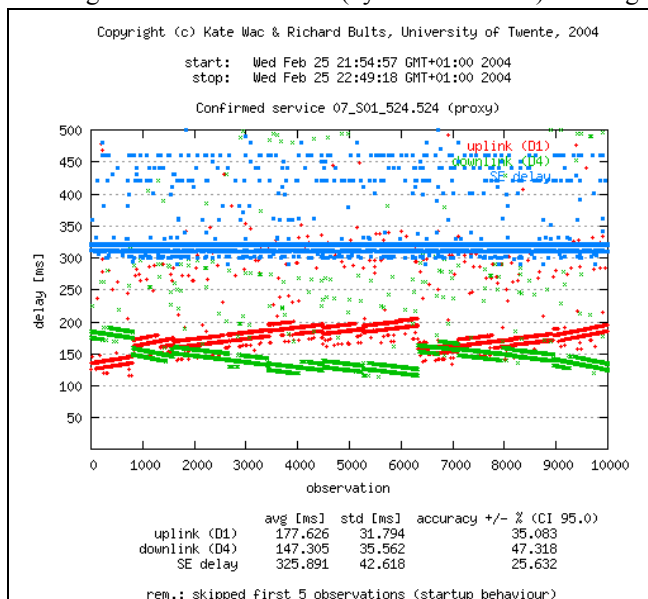


Figure 7: Clock drift influence on the measured delay over a period of 1 hour (uplink, downlink and total delay)

artefacts and destroying the measurements (Figure 7).

To resolve this problem we stabilized the environmental conditions (no heating) and took care to re-synchronize the clocks more often. Nevertheless, the clock drift remains an important problem in the design of applications requiring high precision of timing between interconnected devices.

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 needs to be conducted.

Directions

Although our formal work in the MobiHealth project was 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, commercial companies and patients, as well as the products that become available in the market every day encourages us to proceed in the creation of a company that will promote and commercialise the MobiHealth services and platform. We expect that by end 2005 to have a first version of a commercial service and system available to interested users in different European countries.

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