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MOBIHEALTH : AMBULANT PATIENT MONITORING OVER PUBLIC WIRELESS NETWORKS

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Abstract: 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[1,2] has developed a generic Body Area Network (BAN) for healthcare and an m-health service platform. Biosignals measured by sensors connected to the BAN are transmitted to the remote healthcare location over public wireless networks (GPRS/UMTS). The project results 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 haver been 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.

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 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. This is 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).

[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.

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.

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).

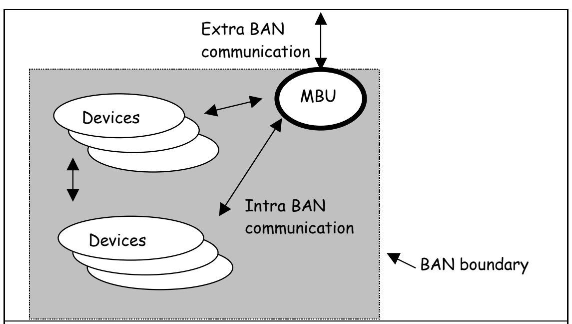

Fig. 1 –BAN architecture

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 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.

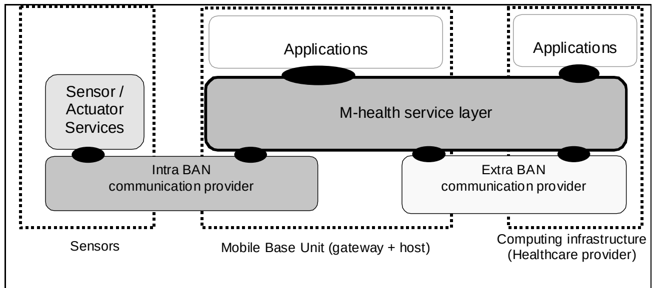

Fig. 2: Service platform functional architecture

Fig. 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. 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 supported and self-supporting sensors. Fig. 3 shows the self-supporting EISlab sensor (left) [4] and a TMSI front-end (right). Both approaches use Bluetooth for intra-BAN communication. Electrodes, a movement

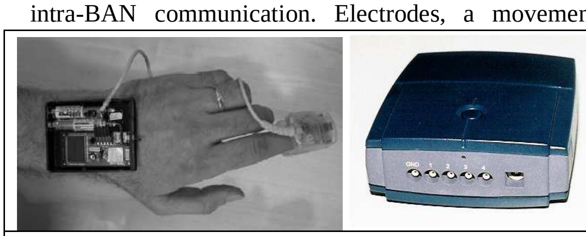

Fig. 3: Self supporting sensor and front-end, ECG sensors

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 a sensor 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 (Fig. 4: iPAQ H3870 acts as MBU platform, showing pulse plethysmogramme).

The BANip [3] 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.

The MobiHealth Trials

The overall goal of the MobiHealth project is to test the ability of 2.5 and 3G infrastructures to support value added 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, rheumatoid arthritis and respiratory insufficiency and make 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 (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.

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. The intention is that irregular patterns will 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. The trial uses both GPRS and UMTS networks.

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. The trial uses both GPRS and UMTS networks.

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.

Conclusions

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.

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, 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 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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