J2ME and smart phones as platform for a Bluetooth Body Area Network for Patient-telemonitoring

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Abstract— A prototype of a system based on a Bluetooth Body Area Network (BAN) for continuous and wireless telemonitoring of patients' biosignals is presented. Smart phones and Java (J2ME) have been selected as platform to build a central node in patients' BAN. A *midlet* running in the smart phone compiles information about patient's location and health status. The *midlet* encrypts and retransmits it to the server through 802.11 or GPRS/UMTS. Besides when an alerting condition is detected, the *midlet* generates a MMS and a SMS to be sent to patients' relatives and to physician, respectively. Additionally, the system provides to physicians the possibility of configuring BAN's parameters remotely, from a PC or even a smart phone.

I. INTRODUCTION

The paradigm of present medical monitoring systems is the definition of a W-PAN (*Wireless Personal Area Networks*) or W-BAN (*Wireless Body Area Networks*). The PAN (or BAN) must integrate a set of wearable wireless devices capable of sensing and transmitting biosignals. In most cases, the PAN/BAN is coordinated by a node which in turn may retransmit the signals to a remote central monitoring unit [1]. Thus, the general architecture of a PAN/BAN considers three components:

- A medical sensor network (which can be completed with movement and positioning sensors), equipped with a low power, short range wireless interface.
- A central coordinator node that communicates with sensors and, simultaneously, acts as an Internet gateway to other networks (GSM/GPRS/UMTS or WLAN) in order to transmit sensors biosignals (or medical alarms) and to receive control information.
- A central node in charge of storing the sensors signals, detecting alarms and sending the patients' information (e.g: via Internet, SMS, e-mail, etc) to the medical staff.

Optionally, the medical staff may receive the information from the patient in a handheld (PDA, phone, etc.) specifically designed or programmed for this purpose.

This article presents an architecture that defines a monitoring network of Bluetooth biosensors connected to a commercial 3G cell phone with a WLAN interface. The main goal of this architecture is to evaluate in the future the performance of smart phones when used as the gateway/master in a PAN of Bluetooth medical sensors.

The paper is structured as follows: Section 2 introduces related work. Section 3 describes the general structure of the prototype. Section 4 comments in detail the implementation. Finally section 5 presents some conclusions and project's current status.

II. STATE OF THE ART ON MEDICAL WIRELESS PANS

The first projects that introduced the concept of Personal Area networks (PAN) employed proprietary systems for wireless transmissions. However, the present tendency in the field of medical PANs is the utilisation of standards for the PAN communications. The use of standards notably reduces the development cost while easing the deployment of telemedicine systems and product interoperability.

In case of requiring to reduce as much as possible the sensor consumption (a basic aspect when dealing with implanted sensors), Zigbee/802.15.4 based transmission may be the best choice. However, if battery restrictions are not so exigent, Bluetooth (BT) is the most utilised technology to interconnect PAN sensors with the monitoring system. The main advantages of BT are the small size, reduced cost and low power consumption of the BT radio modules, the BT technique of frequency hopping (which increases security in radio transmissions), the capability of BT to conform ad hoc networks, and specially the present penetration of BT in the market when designing solutions for short range transmission. Additionally the bandwidth supported by BT (up to 1 Mb/s) is enough to convey any real time biosignal.

Diverse prototypes of BT sensors have been developed for different biosignals, including ECG, glucometers, tensiometers, pulse-oximeters and even stethoscopes. In fact, several vendors (Corscience, Nonin Medical, A&D Medical, etc.) have launched numerous wireless biosensors with Bluetooth interfaces. These commercial Bluetooth terminals permit a straightforward integration of general purpose devices (PDAs, embedded PCs, Mobile Phones, etc) in the design of the PAN/BAN networks. So, the system can benefit from the computing power of these devices just by simply integrating Bluetooth communications through conventional programming libraries. This increases the versatility and capability of reconfiguration of the network, reducing its deployment time and its final cost.

Different networking architectures have been proposed in the literature to solve the problem of medical telemonitoring.

The AMON Project [2] implemented a portable device capable of measuring several biosignals simultaneously

(SPO2, ECG, blood pressure, temperature and patient movements). The developed equipment processes the signals and, in case of alert, communicates with the medical center by means of the cellular network. However, as it is difficult to integrate multiple biosensors in a single device, today most medical telemetry systems include some kind of 'wearable piconet' of independent wireless sensors. In most cases, the architecture consists of a 'multiplexing' PAN node which collects the biosignals from one or more biosensors. Once the signals are received, the node directly shows them on an embedded display or it retransmits them to a central node through WiFi, GPRS or UMTS.

In the works [3] and [4] an ECG signal is transmitted via BT to a PALM device and a smart phone, respectively. These devices in turn forward the signal to a server through GPRS. A similar system for ECG monitoring, presented in [5], adds to the GPRS transmitted flow the compressed information from a GPS. Analogously, the architecture in [1] allows a wearable unit (PDA or cell phone) to receive via BT the signals from a ECG but also from a pulse monitor and a tensiometer. In [6] a pulsioximeter and a tensiometer are integrated in the same device which transmits the signals to a mobile phone via BT. A J2ME programmed application in the phone allows to process the signals and detect medical alarms. In that case, a SMS is sent to the medical staff. The architecture in [7] also includes a mobile wearable equipment which acts as a gateway between the BT sensors and a GPRS/UMTS connected central unit. The particularity of the system is the utilisation of XML for the configuration of the sensors.

Authors in [8] develop a piconet of BT smart sensors. The sensors can be programmed by a control node which is remotely accessed by GPRS/UMTS. In the piconet of wearable sensors presented in [5], the control node is situated in a cell phone or PDA with Wifi, GPRS and UMTS interfaces.

In the system described in [9], the piconet is substituted by a set of wired sensors connected to a microprocessor board. The board includes a BT module to intercommunicate with the hospital through a GPRS mobile phone. In the reception unit medical staff can receive the information in a PDA. To ease the interoperability among different vendors, in [10] BT biosensors are accessed by using BT Serial Port Profile. The work in [11] introduces a PAN architecture comprising ECG, pulsioximeter, humidity and temperature sensors controlled by a wearable data logger. By using BT the logger connects to an Internet-attached base station which stores the signals in a distributed data base.

Authors in [12] suggest that the main goal of a telemonitoring system is to transmit medical alarms. As these systems are aimed at patients and elder people who spend most time at home, the work proposes the use of not-wearable BT access points that will be responsible for retransmitting the signals to a central unit in a hospital.

From these experiences, we can detect the growing use of

'general purpose' devices (mainly PDAs or Cell Phones) to build the PAN gateway between the sensors and the remote control node. So, the implementation of this gateway node can be performed without introducing any new hardware and just reconfiguring a familiar element in the everyday life of the patients. In this sense, to develop the software in the phones (or PDAs), initial architectures utilised C or C++, which permitted an optimised design for real time processing and a better interaction with the operative system (e.g.: Symbian). However, since the apparition of J2ME (Java version for mobile devices), the portability of Java is notably stimulating its adoption in the field of medical BANs.

III. SYSTEM DESCRIPTION

The profile of the target user is a patient who needs continuous monitoring. The patient usually resides in his own home or in a shared environment with other patients or users, i.e. a care unit or a residence for elder people. This scenario will be referred as a "controlled environment". Besides, health status must not be an obstacle to leave the controlled environment to go for a walk, for example. In this case the patient will be in an "outdoor scenario". The purpose is to carry out a smart tracking of patients to achieve the following advantages: a) to avoid patients to have to stay on bed and connected by cable to a medical monitor, b) to increase the patient's mobility and comfort level, c) to allow remote monitoring in outdoor spaces, d) To reduce the number of periodical check-ups.

The system is intended to provide the next functions: 1) Monitoring of the health parameters in order to detect an emergency 2) Recording of the outdoor location of patient, 3) To provide medical assistance in case of emergency.

Regardless of the patient's environment, there are three basic parts or components in the system: 1) An iBAN (intelligent BAN) worn by the patient to be remotely monitored, 2) A Central Control Server (CCS), located in the controlled environment, 3) A Mobile Control Monitoring Unit (MCMU) carried by the physicians.

The iBAN prototype is based on Bluetooth technology. Currently the iBAN comprises a commercial a pulsioximeter, a GPS device and an *Intelligent Node* (IN). The IN integrates two wireless communications interfaces, 802.11 and Bluetooth, as well as a connection to the cellular network. Bluetooth is the technology used for communications between the sensors and the IN, which plays the master role in the piconet. Wifi and/or GPRS/UMTS are employed to send information from the IN to the CCS and to the MCMU.

A. Interaction Patient iBAN - Central Control Server

An application in the IN manages the Bluetooth piconet and the CCS connections. When it is automatically started, the following steps are carried out: (1) inquiry procedure, (2) services search, (3) connection establishment with the

pulsioximeter and GPS device, (4) pulsioximeter configuration and (5) server connection and user registration.

As the IN receives data from iBAN nodes, it stores them during a period which can be remotely configured. Then, the IN sends the data to the server through the 802.11 interface in case that the user is in a controlled environment and there is an available Wifi access point. In other case, the data will be transmitted through GPRS/UMTS.

The Bluetooth connections are kept active as long as the devices are in the coverage area of the IN. Thus, as soon as an event occurs, the IN can notify it to the server. This is performed at the cost of an increase in power consumption.

The data rate depends on the mode operation of the BAN:

1. *Default Mode (mode 1)*: The pulsioximeter sends 3 bytes/s. The information from GPS is also received and stored in the IN, but it is not retransmitted to the CCS.

Verbose Mode (mode 2): This operation mode has to be remotely enabled from the CCS server or the MCMU. In this case the pulsioximeter sends a rate of 375 bytes/s (75 samples/second). Both the SPO2 signals and the GPS information is delivered to the CCS. If the verbose mode is activated and the GPS device does not provide valid data, the latest stored GPS location is recovered and transmitted.

Additionally, in both modes, the information received from the pulsioximeter is processed in order to verify that the oxygen saturation and the heart rate are not out of the security range established for the patient. If the IN detects a value lower or greater than a predefined threshold, a SMS will be sent to the MCMU (a cell phone carried by a physician and/or by a predetermined list of patient's relatives). The thresholds can be set up by the physician from the server or from his own MCMU. Moreover, the CCS periodically requests the Intelligent Node to switch temporarily to verbose mode in order to check battery status. This is necessary because the chosen commercial pulsioximeter only includes this indicator under this mode.

B. Interaction Monitoring Unit –Central Control Server

When a MCMU receives a SMS alert from a patient, the physicians should start the J2ME monitoring application, which allows to select a patient and the sensor data to display. In order to get the requested data, a *midlet* establishes a TCP connection with the CCS. Through this connection, the CCS retransmits the frames received from the iBAN in quasi-real time. The transmission is not stopped until the physician selects the corresponding option.

Additionally, the application provides the possibility of configuring the operation mode, the threshold values used to detect an emergency or even the transmission period. In order to guarantee the reliability these configuration commands are sent through a TCP connection.

IV. SYSTEM IMPLEMENTATION

The next devices have been incorporated in the iBAN

prototype: a smart phone (Nokia 9500, N93, and E61 models were alternatively employed), as the platform for the intelligent node, a Bluetooth pulsioximeter, from Nonin Medical, and a Bluetooth GPS receiver with SifStarIII chipset. For the Mobile Control and Monitoring Unit (MCMU) a smart phone has been also utilised.

A. Intelligent Node and Monitoring Unit

A J2ME application has been implemented for the IN. The *midlet* uses the following Application Program Interfaces (APIs): *Bluetooth API* JSR-82 for managing BT, *Location API* JSR-179 to get data from GPS with more reliability; *Wireless Messaging API* JSR-205 for sending SMSs and MMSs; *File Connection API* JSR-75 to record patient's information into the file system residing on the mobile device or on an external memory card. Additionally, *Security and Trust Services API* (JSR-177) was employed to guarantee the privacy of the medical data. To encrypt the transmissions to the CCS, a symmetric Data Encryption Standard algorithm with a prefixed key was utilised. The screenshot in fig. 1a shows the pulsioximeter parameters during an execution in Nokia N93.

The control and monitoring application for the MCMU also has been developed as a *midlet*. When an alert is detected, the application, making use of API JSR-205 (*Wireless Messaging API 2.0*), sends a MMS and a SMS to the MCMU. To get the phone numbers the API JSR-75 (*File Connection and PIM API*) has been employed. The generated MMS contains a text with the patient identifier and the values of the sensed health parameter, a patient's photograph and a sound clip with a message from the patient (to describe a sensation or any indication of disease). The three MMS's components are integrated in a SMIL (Synchronized Multimedia Integration Language) presentation, which is reproduced when the MMS is opened. The figure 1.b shows a SMIL presentation in the Nokia N70 phone.

Fig. 1.a) Screenshot of the *midlet* b) SMIL presentation in the MMS

The MMS sent by the Intelligent Node are received as any ordinary MMS (directly in the input message box of the cell phone). A *midlet* that receives and processes a SMS automatically has been developed for the MCMU. By the use of Push Registry Utility, provided by MIDP 2.0, the

midlet is notified about the SMS reception in a specific port. So, the program is started without requiring any operation from the user. The *midlet* shows the SMS text, reproduces the sound and provokes the cell phone to vibrate until the user reads the message (see an example in figure 2).

Fig.2. Screenshot of the SMS reception *midlet*

B. Central Control Server (CCS)

The CCS is an Apache web server implemented as two *servlets* under Tomcat. The first one carries out two main functions: (1) it manages the connection requests from patients to be monitored, processing medical data, (2) it provides access to the IN capabilities through a web interface with embedded applets. The second CCS *servlet* serves access requests from the MCMUs and retransmit data from the IN to the MCMU through a TCP connection.

The communication between the CSS and patient iBAN can be established with two protocols: (a) *HTTP*: data are sent in a HTTP request. If the server has to send a command, it will use a HTTP response. (b) *TCP-UDP*: configuration commands (and their responses) are transmitted through TCP, whereas the patient data are sent over UDP.

Aiming at providing an easy access to physicians, two access mechanisms are included in the architecture:

1. *Web interface*: The physician can access the system from any point with Internet access, using a navigator with RMI (*Remote Method Invocation*) support by means of a *Java Applet (J Applet)*. This *JApplet* is structured in two main components: (a) A *Configuration Interface*, to manage the iBAN configuration and operation mode, and (b) A *Data Display*, to show the health parameters and location information. The *Configuration Interface* component communicates with the CSS by the RMI. The *Data Display* subsystem also uses RMI to get, in real-time, the parameters extracted from the sensor frames decoded in the CCS.
2. *Mobile Unit*: The control and monitoring *midlet* are installed in the MCMU. The physician only has to start the *midlet*, which will establish a TCP connection with the CCS to receive the encrypted frames from the IN. The figure 3 shows a screenshot of a received plethysmogram.

V. EVALUATION AND CONCLUSIONS

The utilization of smart phones as the central node in a medical PAN takes advantage of the user familiarity with mobile devices. However, the main restriction from usability perspective is that the monitoring application carries out tasks considered by operating system as risky for security.

Therefore acknowledgements are requested to user before continuing certain actions. This drawback could be avoided by means of a validated certificate. On the other hand, the J2ME implementation for monitoring applications is advantageous since its portability is greater than Symbian. Nonetheless, problems detected in the *midlet* heavily depend on the model of the employed smart phone. The phone Nokia 9500 generates Symbian errors during the BT connection establishment. It has been checked that these errors also happen with other applications that use the SPP profile. However, the establishment works successfully in Nokia N93 and Nokia N70 models. In Nokia N93 the *midlet* may freeze during the search of a WiFi access point. Symbian errors also take place in Nokia 9500 when a Bluetooth connection is dropped and the application tries to recover it. Finally, it has been verified with Nokia N93 that the application continues running when the cover is closed, in contrast with other experiences [7].

Fig. 3. Snapshot of the Reception *midlet* for data display

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