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Communication Platform for Biosensor-based Sleep Management Applications

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Abstract—**This paper presents the architecture of a complete communications platform for biosensor-based applications in the domain of sleep disorders. It covers from the direct communication with the sensors themselves to the most remote application modules. It has been divided into three levels: BAN (Body Area Network), LAN (Local Area Network) and WAN (Wide Area Network), and it uses wireless communications at all levels of the architecture.**

I. Introduction

HUMAN beings need to sleep. Sleep is not a matter of choice; it is essential and inevitable [1]. Today's "24 hour society" seems to pressure many individuals to sacrifice sleep in favor of other activities, without realizing the negative effects this has on their health and ability to perform a wide range of tasks.

Sleep disorders have a high prevalence in the general population: insomnia (10-20% of adults), sleep apnea syndromes (4-6%). They are responsible for high costs of diagnosis and treatment modalities [2]. Diagnosis is usually done in sleep laboratories at the expense of cost in personnel and long waiting list. Remote monitoring could be an alternative to laboratory diagnosis, to decrease the burden of cost and long waiting lists, which is not well satisfied with the current health care system and commercially available equipment [2].

At the same time, extended research is conducted in the field of fatigue monitoring for different situations such as critical operators in industrial contexts and car drivers, but few integrated systems have been developed to monitor and alert the user in case fatigue is detected and are mainly based on user active feedback on his/her state, through requests at specific time-oriented intervals.

Facing this reality, the European Union has funded the integrated project SENSATION under the thematic area "Micro and Nano Systems" of the IST (Information Society Technologies) program [3].

SENSATION aims to achieve unobtrusive, cost-effective, real-time monitoring, detection and prediction of human physiological state in relation to wakefulness, fatigue and stress anytime, everywhere and for everybody. In this context, it aims to explore a wide range of micro and nano biosensor technologies, as well as to develop innovative applications in the medical (for distance monitoring of patients with sleep-related disorders) and industrial (for fatigue and sleepiness prediction systems) fields.

Communications play a crucial role in the project, since they provide the means for the correct integration of the whole system in order to achieve seamless and wireless transmission of all sensor data.

This paper is focused on the presentation of the complete communication platform, which wirelessly integrates the sensors with the applications in the body, local and wide area networks.

II. Materials and Methods

In SENSATION project, a heterogeneous set of biosensors are being developed to be used by an equally heterogeneous set of applications. This heterogeneity, leads to the necessity of conceiving a communications platform based on the following premises:

--A limited number of flexible interfaces: the interfaces between sensors/applications and the communication platform must be limited in number for system consistency, but flexible enough to be compatible with a great range of very different sensors and applications. Possibility of customization: the platform must be designed in a modular way, composed of a set of independent modules able to be adapted to different scenarios and needs.

--Use of communications standards when possible at all levels of the platform.

One of the most innovative aspects of the communication

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platform and the key to succeed in the implementation of a comfortable and unobtrusive system is the use of wireless communications in each level of the architecture, from the sensors output to the most remote applications modules [4].

Due to the nature of the data and the applications handled by the platform, special security measures compliant with the current European regulation are taken.

III. Results

The design of the communication platform has been divided into three levels, as shown in Fig. 1: The Body Area Network (BAN), the Local Area Network (LAN) and the Wide Area Network (WAN), in order to deal with the different areas in which the data are handled.

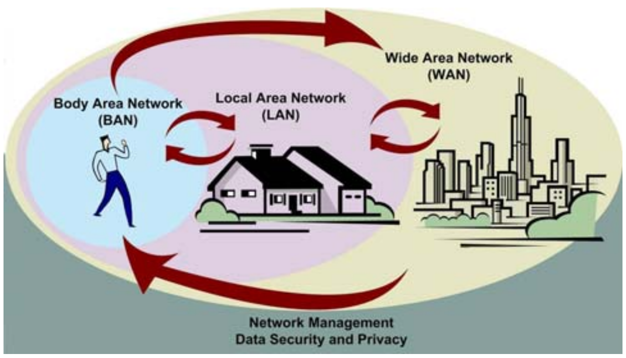

Fig. 1. The three levels of the communication platform: BAN, LAN and WAN.

The BAN aims at the communication between the sensors and a central device that receives the data from them. This central device has been called the Personal Data Processing Unit (PDPU) and performs the data analysis, provides the required feedback ti the user and manages the communication.

The objective of the LAN is to communicate different PDPUs in order to provide a collaborative network where a local application can take advantage of the interaction among them.

Finally, the WAN aims at communicating data to applications that cross the 'local' boundaries in a distributed system.

The scenario presented in Fig. 2 illustrates the role of each of these three levels in an ambulatory monitoring application. It represents a patient diagnosed with insomnia undertaking a new method on evaluation of insomnia treatment.

The patient wears a set of wearable biosensors that measure signals that are relevant for the required application. They are wirelessly connected with a portable device similar to a mobile phone, which receives and stores the data acquired by the biosensors, and is capable of performing some simple data analysis. The conjunction of the portable device and the sensors worn by the patient constitutes the BAN.

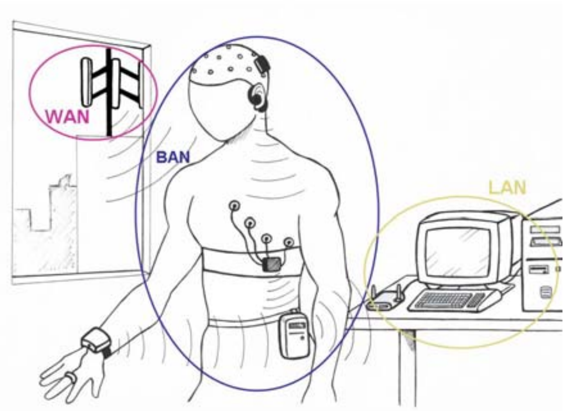

Fig. 2. Example of an ambulatory monitoring application.

At some point, the patient transfers the recorded data to a home-located desktop computer. There, a previously-installed application performs a more thoughtful data analysis and provides the patient with some advices automatically extracted from the data. The patient's home is considered as the LAN in this specific application.

The WAN in this case refers to a monitoring centre located in the patient's hospital. The recorded data are transferred here from the patient's desktop computer or even from the portable device through a GPRS connection. At the monitoring center, the data are received and stored in a database, and the patent's doctor can analyze it to see if any significant problem has taken place.

In next paragraphs, a technical description of the platform is presented.

A. BAN (Body Area Network)

The BAN can be considered as the first "level" of the communication platform. It aims at transmitting the information acquired by the wearable sensors away from the user. The BAN is composed of two main modules:

--Sensor Communication Module (SCM): it is a small device attached to the sensor that allows wireless communication with the central device. It is responsible for the management of the wireless transmission of the data acquired by the sensor.

--Personal Data Processing Unit (PDPU): it is a portable device, similar to a PDA in shape and size, which receives the data coming from all the sensors connected to it (through the corresponding SCM). It is responsible for the coordination of the communication within the BAN. In addition, this device is capable of performing some data processing, allows user interaction and manages the communication of sensors with eventual external modules of the application in which they are being used.

The wireless communication protocol used in the link between sensors (SCMs) and PDPUs has been developed using a IEEE 802.15.4 transceiver at the Physical and MAC levels, and an own Network level protocol based on and compatible with Zigbee. The choice of ZigBee as the basis for the development of this protocol has been mainly motivated by its efficient power consumption, which is lower than other possible options such as Bluetooth [5] [6].

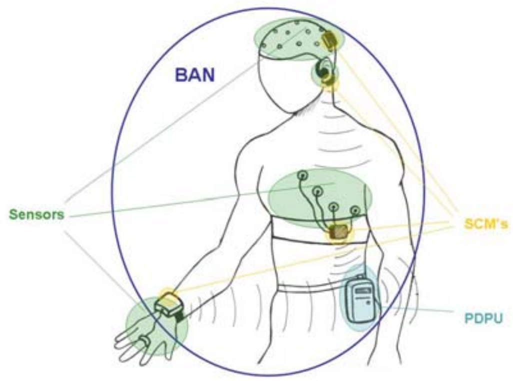

Fig. 3. BAN modules.

All the data received from the sensors through the SCM in the PDPU are synchronized using a beacon-based communication system, an important requisite for some applications.

The PDPU can be connected with external networks through USB, Wi-Fi (IEEE 802.11g) or GPRS. This is the foundation for the communication with the LAN and WAN.

A non-trivial issue that has been faced up is the connection of the sensors to the SCM. Taking into account the wide range of sensors that are supported by the platform (lista), it has been necessary to define a common sensor interface that allows the SCM to be attached to sensors and compatible with both analog and digital sensors.

All modules that compose the SCM and the PDPU are off-the-shelf, with the exception of an ASIC (Application-Specific Integrated Circuit) that has been developed to optimize the connection with the analog sensors to the SCM.

B. LAN (Local Area Network) and WAN (Wide Area Network)

The LAN provides connectivity in a local environment. Its objective is to communicate different PDPUs with other devices (PCs, PDAs, etc.) in order to make a collaborative network available where local applications can take advantage of the interaction among them.

The rationale of the WAN is to communicate data for applications that exceed the "local" boundaries in a distributed system. The WAN represents an important and innovative added value to the current state of the art on sleepiness and fatigue monitoring systems [7].

The internal architecture of the LAN and the WAN are quite similar, although their implementations are very different due to the different requirements and characteristics of each of them.

SIP (Session Initiation Protocol) is used to establish connections in the LAN and the WAN. This protocol, widely used in VoIP applications, is perfectly suitable for the requirements of the proposed communication platform [8], due to the following characteristics:

--It is independent of the protocols used above or below it.

--It provides the capabilities to: determine the location of the target end point, determine the availability of the target end, establish a session between the originating and target end, and handle the transfer and termination of sessions.

In order to abstract the pure communication issues to upper layers, the LAN and the WAN have a module which has been called Workflow Management Module. It acts as an intelligent routing and it is in charge of:

--managing the data flow among local applications, PDPUs and remote applications;

--maintaining a repository with the running applications, the available PDPUs, sensors and their mapping;

--managing the QoS (Quality of Service) of the different messages to be sent in order to guarantee a proper service provision.

It is developed as a FSA (Finite State Automaton), in which each application has its specific states' diagram, and interactions are managed following its schema.

The system includes a QoS management module in order to deal with messages having different time constraints. It is based on a priority management system where each outgoing/ingoing message has an associated priority level and they are consumed attending to their priority.

As it was mentioned before, wireless communications are provided in all the different areas of the platform. The protocols used to communicate the PDPU with the LAN are Bluetooth (Serial Port Profile) and Wi-Fi, depending on the specific implementation. Access to the WAN is provided through the Internet, using GSM as access network.

IV. Discussion

One of the objectives of SENSATION project is to develop new medical diagnosis and treatment applications, using new sensors, databases and knowledge for a wide range of sleep disorders, as well as to enhance the sleep quality of all people. The key point to succeed in such an ambitious objective is to achieve the interconnection of biosensors and applications through an embedded connectivity at the body, local and wider area and their integration in multi-sensorial systems through innovative signal processing and computational intelligence algorithms for data fusion, data management and power consumption minimization.

The design of the presented communication platform allows its use in a great variety of scenarios, thanks to the three-level architecture (BAN, LAN, WAN) and the modularity of its development. The platform offers a set of common interfaces both to applications and sensors, allowing its easy integration in different implementations.

The use of wireless communications avoids the use of cables in applications where comfort and minimalintrusiveness is required. Although wireless technology requires a bigger effort in design than the use of cables at the BAN Level, advantages are innumerable. The use of wires for transmitting the information acquired by the sensors worn by monitored users impedes the performance of daily tasks, making the applications obtrusive and uncomfortable.

Nevertheless, there exist a number of issues that has presented some problems in the development of the platform. One of them is the fact of dealing with a great number of very different sensors, and the consequent difficulty in defining a limited set of common interfaces. Batteries continue to be a great limitation in power consumption and size in every portable system, and security issues also present some limitations to the development of the communication platform.

V. Conclusions

The design of a complete communication platform covering from sensors to remote applications allows the shift from the nano to the macro scale, and provides the basis for the construction of nano and microsensor-based real-life applications.

The main innovation of the presented work is the introduction of a technological framework and modular system for hypo-vigilance monitoring and management for cross-sector applications, based on micro and nano sensor technology. This will create the critical mass for a yet not existing or weak market to introduce this type of systems in Europe in a variety of applications fields. The innovative modular cross-sector approach provides the pre-requisites for the technological break-through, by combining the different sub-systems to target at a variety of products.

The Wireless BAN is a key development for projects like SENSATION, where applications are framed in scenarios in which monitored users are going to carry out daily activities.

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