Cell-based Sensor Network for Complex Monitoring at Home of Patients with Chronic Diseases

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Abstract— **In order to improve the quality of life for the elderly or people with chronic disease, the paper proposes a smart cell-based sensor network for home monitoring. The cell is considered to be a small sensor network which is situated into the patient's house. It is composed of mobile and fixed sensors, disposed on five sensor groups. Each group is actually a network of dedicated sensors: ambient sensor network, body sensor network, emergency sensor network, visual sensor network and sensor network dedicated to on request - physiological parameters monitoring. Sensor networks cooperate with each other within the cell to increase the efficiency of monitoring, to decrease energy consumption and radiation level. Adaptive rates of acquisition and communication are used. Some experimental results are presented in the last section.**

***Index Terms*—sensor network, multilevel network, hybrid cells, motion monitoring, ambient sensors, body sensors, accelerometers**

I. INTRODUCTION

HOME care for the elderly and chronic disease persons becomes an economic and social necessity. According to the US Bureau of the Census, the number of old people (65–84 years old) is predicted to double from 35 million to 70 million by 2025 [2]. This trend shows that the world elderly population will double from 375 million in 1990 to 761 million in 2025. Furthermore, overall healthcare expenditure in the US was $1.8 trillion in 2004, and this number is projected to be triple by 2020, or 20% of the US Gross Domestic Product (GDP) [3]. Therefore, the monitoring solutions at home for elderly or people with chronic diseases became of increasing interest.

The latest discoveries in wireless communications, intelligent low power sensors and integrated circuits made possible the creation of Wireless Body Area Networks (WBAN), which can be defined as a collection of low power, miniaturized, lightweight wireless sensor nodes that monitor the human body functions and the ambient environment. Today, WBANs have a lot of innovative and interesting applications in different domains, such as healthcare, entertainment or military [1].

Because of demonstrated need and market demand, WBAN research has concentrated on healthcare applications, addressing the weaknesses of traditional patient data collection, such as imprecision (qualitative observation) and under sampling (infrequent assessment). In contrast, WBANs can continuously capture quantitative data from a variety of sensors for longer periods. By addressing challenges such as the energy-fidelity tradeoff, WBANs will enable telehealth applications (medicine beyond the confines of hospitals and clinics) and, because of their human-centricity, will facilitate highly personalized and individual care. WBANs integrated with higher-level infrastructure will likely excel in healthcare scenarios, serving the interests of multiple stakeholders. In addition to delay-insensitive applications such as longitudinal assessment, WBANs that can offer real-time sensing, processing, and control will augment and preserve body functions and human life. WBAN researchers are already working to improve deep brain stimulation, heart regulation, drug delivery or prosthetic actuation. BASN technology will also help protect those exposed to potentially life-threatening environments, such as soldiers, first responders, and deep-sea and space explorers. Finally, WBANs are well positioned to benefit from the intersection of two formerly disparate application areas. Physiological and bio-kinetic sensing applications are increasing as athletes and fitness enthusiasts seek to improve human performance, while gaming systems are pushing their envelope by integrating more sophisticated interfaces based on human movement. With the crossing of these markets, WBANs are well positioned to deliver the biofeedback and interactivity necessary for next-generation fitness and entertainment applications.

An early prototype of a mobile health service platform that was based on Body Area Networks is MobiHealth [4].

An Internet based topology is proposed in [5] for the remote home monitoring applications that use a broker server, managed by a service provider. The security risks from the home PC are transferred to the broker server and removed, as the broker server is located between the remote monitoring devices and the patient's house.

The sleep quality is very important for the quality of life, as it is stated in [6]. Therefore, specific parameters are monitored, like pattern of heart rate variability (derived from ECG), breathing parameters, snoring parameters and body motion index referenced to the presence of delta waves (EEG).

The most important requirements of the developer for an e-health application are size and power consumption, as considered in [7]. Also, in [8], a thorough comprehensive study of the energy conservation challenges in wireless sensor

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networks is carried out. The need for effective utilization of limited power resources is also emphasized, which becomes pre-eminent to the Wireless Sensor Networks.

Many international and national projects were in the domain of sensor networks dedicated to real-time monitoring of patients diagnosed with chronic diseases, in home-care. For example,

- CHIRON [9] (ARTEMIS ETP project, started in 2010) proposes an integrated framework designed for efficient, patient-centric healthcare management,
- ERISC [10] ("4th Program – Partnership in Key Areas", 2008-2011) had the objective to develop a solution for an e-health system for real-time monitoring for patients diagnosed with cardiovascular risk, in home-care and
- TELEASIS [11] implemented between 2008-2010, proposed the development of a model for medical and social tele-assistance, efficient from the cost point of view, as well as of information and communication technologies.

Integrating the body sensors with the existing ambient monitoring network in order to provide a complete view of the monitored parameters is one of the issues discussed in this paper. Providing a localization system and a basic algorithm for event identification is also part of our strategy to fulfill all possible user requests. Caregivers also value information about the quality of air inside the living area. Many false health problems are usually related to the lack of oxygen or high levels of CO or CO_2.

II. THE ARCHITECTURE OF THE MULTILEVEL NETWORK

The proposed architecture (Fig.1) of the network is based on three hierarchical levels: i) basic level or **Level 1**, which includes the wireless sensor networks (Fig. 2), composed of the sensor nodes of the indoor WSNs (also called primary networks), ii) intermediate level or **Level 2**, of the associations of sensor networks, which form local cells, referred to as femtocells (FC) and iii) top level or **Level 3**, the decision level whose nodes are cells (FC1,…, FCn), along with the management node (NMN) and the decision nodes corresponding to the global functions (objectives) of the global network. NMN collects data from the cells, analyzes the message type and send them towards the decision nodes DN (hospital, police, firemen, social assistance, building manager, relatives). The communication with the cells and decision nodes is performed through the Internet or GSM. It detects and communicates potential failures in the system. Also, it communicates the actions and recommendations of the decision factors towards the users associated to the cells. If a parameter value is out of normal limits, an alert is triggered and, then, the corresponding information and alarm are sent to the specific intervention factor (current physician, hospital, police, fire department, social assistant, kindred etc.).

Monitoring will be performed in indoor, geographically distributed environments by using various integration technologies related to data processing and communication. The foreseen result is a multilayer sensor network with support for multiple standards of radio communication. Flexibility issues, interference reduction, energy and electromagnetic radiation reduction as well as the increase of data transmission reliability will be addressed by integrating digital signal processor inside the network nodes, at any level, and combining the wireless communication infrastructures with the radio over fiber ones.

The cell (Fig. 2) is considered to be a small sensor network which is situated into the patient's house. It contains all the primary sensor networks used to establish the main tasks of acquiring information from the patients and their environment (the home). It is composed of mobile and fixed sensors, disposed on five sensor groups. Each group is actually a network of dedicated sensors: ambient sensor network (ASN), body sensor network (BSN), emergency sensor network (ESN), visual sensor network (VSN) and sensor network dedicated to on request - physiological parameters monitoring (sensors that can't be permanently attached to the monitored human subject) (DSN). The primary network has intelligent sensor nodes (NI), meaning they can determine: the shortest routing path, information sampling rate from the sensors, energy supply status, communication speed, node ID recognition; also, they can process the data acquired by the sensors. Each cell has several NIs grouped into functional networks (ASN, BSN, ESN, VSN and DSN) and a femtocell management node (FMN). The primary network integrates composing sensor nodes and assures the transmission of the collected data towards the femtocell management node by means of ASN nodes (Fig.3).

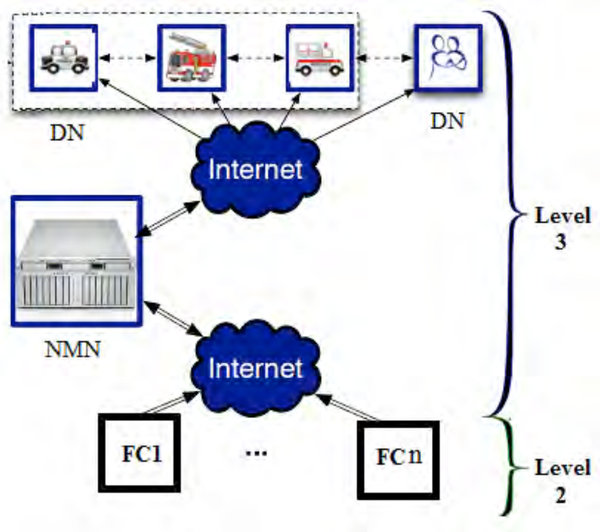

Fig.1. Proposed Global Network Architecture.

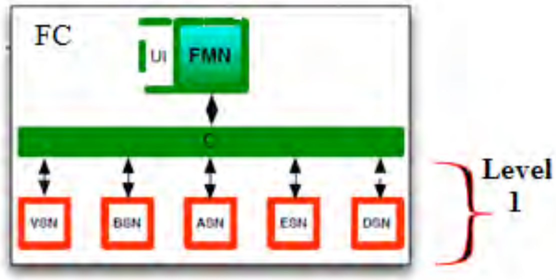

Fig. 2. Hybrid Cell Configuration.

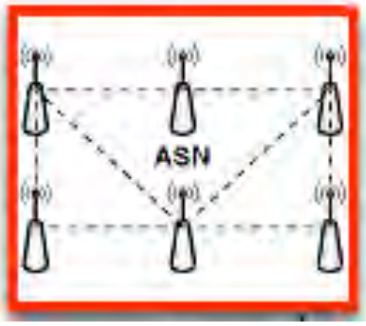

Fig.3. ASN Nodes as Routers.

Giving the various possibilities of collecting data, energy supplying, communication and mobility, the cell has multiple hybrid characteristics as follows:

- some components collect information related to physiological parameters (BSN, DSN and VSN – partially), other component collects information related to the indoor environment (ASN) and others collect information related to potential immediate danger (ESN, VSN);
- some components are powered by batteries and have a very low energy consumption (BSN); other components are powered by the energy network and have backup batteries (ESN);
- some components have wireless communications (BSN); other have combined communications: wireless and RoF (Radio over Fiber);
- some networks are mobile networks (BSN, DSN) and some are fixed networks (ASN, ESN).

Flexibility issues, interference reduction, energy and electromagnetic radiation reduction as well as the increase of data transmission reliability will be addressed by integrating digital signal processor inside the network nodes, at any level, and combining the wireless communication infrastructures with the radio over fiber ones.

The communication between the cells and the network management node and the communication between NMN and decision factors, like hospital, police, fire station or relatives, (DN) are based on internet.

In the paper two important primary networks, namely BSN and ASN, are investigated.

The BSN, which is attached to the patient, monitories the following parameters: blood pressure, heart rate, body temperature, stress, body position and activity (especially fall detection or total inactivity), snoring and apnea.

When designing the BSN architecture, the following characteristics have to be referred:

► Radiation level needs to be compatible with prolonged human usage (sensors are placed on the patient's body, therefore, low radiation is needed);

► Monitoring modules need to be small in order to be easily tolerable by the patient over fairly long periods of time;

- Monitoring modules need to be small in order to be easily tolerable by the patient over fairly long periods of time;

- The BSN needs to connect to the management node of the femtocell using wireless communication over very short distances (for example, ZigBee);
- Energy consumption is critical (the battery powered sensors need to stay functional for longer periods of time without recharging in order to interfere with the patient's activities as little as possible). Therefore the network needs constant battery recharging.

The ASN contains only fixed nodes which communicate each other wireless (20m-30m) or through optical fiber support (obstacles like walls). The monitored parameters are the following: ambient temperature, ambient light, pressure, humidity, CO2 concentration, fall detection and patient position inside the femtocell. In addition, ASN nodes act as a local gate and router for other small networks (BSN) with the aim to send acquired and processed data to the cell gateway. Each ASN node has an ID which is used in two purposes: a) to correctly interpret the data from environment and b) to locating the person (with BSN) inside the house, also through the medium of an attenuation factor. Thus, the patient can be accurately localized using an attenuation map.

The location of the environmental sensors, in a fixed and dedicated topology, into patient's house is presented in Fig. 4.

Fig. 4. Ambient Sensor Placement.

III. DATA PROCESSING

Inside the global network, three types of data processing are performed: primary processing, intermediate processing and high level processing. Data processing is performed in real time.

Primary processing, like analog to digital conversion, noise rejection and segmentation, is performed by the nodes of the primary networks. Local average and median filters into small windows are used to reject the noise, especially at data acquired from accelerometers.

The data processing at intermediate level (data compression through features) is performed by FMN. The data processing at high level (recognition of the condition and interpretation of patient's problems) is performed partially by FMN and partially by NMN. Thus, data processing is performed both distributed and by fusion. Therefore, the whole network is not flooded by useless data from all cells. In [12] the authors presented a method to establish an adaptive acquisition rate for a parameter V, based on the parameter derivative and according to the last harvested data into the safety interval [V_{min}, V_{max}]: when the harvested data is very close to the interval center value $V = \frac{1}{2}\left(V_{max} - V_{min}\right)$ and the derivative is low, the rate of parameter acquisition is low.

IV. EXPERIMENTAL RESULTS

Experimental data that was collected from body sensor networks is first illustrated. Two body sensor nodes: Node 1 and Node 2, are placed on the subject's body. Node one is placed on a belt on the left hip while node 2 is placed just above the right knee. Nodes are uniquely identified within a local network through their ID. In a global addresing space, the local ID is prefixed with the network and femtocell identification numbers. The main component of the nodes that we use consists of the Freescale MMA7376 accelerometer [13]. The arguments for this component are low power operation, high sensitivity at 800 mV/g for the 1.5g range and built-in signal conditioning with low pass filter. Common applications include 3D gaming, pedometers, navigation, robotics and associated embedded devices. Within our scenario both the range and the sampling rate are user selectable through the user interface of the body sensor network.

In order to obtain comparable values in relation to the patient's reference coordinate system, the orientation of the accelerometer board has to be brought on par with a global reference. Therefore, we express movement in directly evaluable terms of front-backward, left-right and up-down as global axis coordinates, whereas these directions correspond to the following axes of the two body nodes:

- Front-backward movement: X axis Node 1, Z axis Node 2;
- Left-right movement: Z axis Node 1, X axis Node 2;
- Up-down movement: Y axis Node 1, Y axis Node 2.

Figures 6 to 8 plot the collected results. Axis are shifted according to the list above. Data is collected during normal home activities among which standing, sitting and slow movement from one place to another. Depending on the body posture, the acceleration values are either strongly correlated or almost not at all. Time or frequency methods can be applied to the raw data in order to extract necessary information. In the time domain we reffer mainly to: thresholding, peak detection, transition detection and statistical indicators for the raw series. Frequency methods, like the discrete fourier transform (DFT), can be useful for example to evaluate the step frequency of the patient, as a useful measure of its activity levels and overall well-being. Figure 6 highlights best a succession of postures during sitting and standing along with slow movement between the static positions.

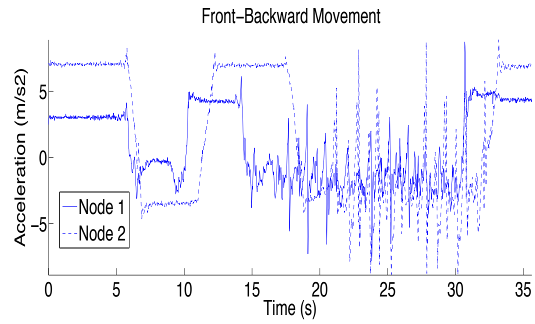

Fig. 6. Patient Movement – Global X axis

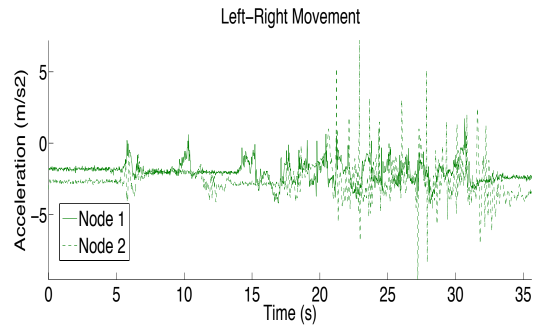

Fig. 7. Patient Movement – Global Y axis

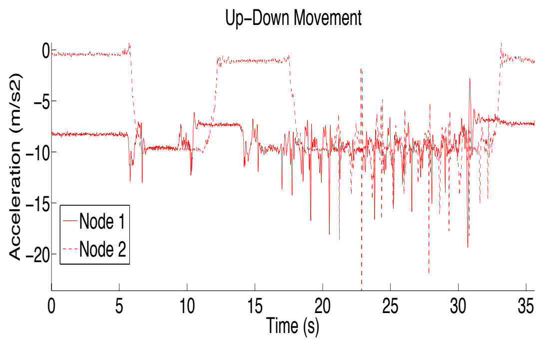

Fig. 8. Patient Movement – Global Z axis

The second test consists of short and medium term monitoring of indoor parameters in a typical home. For this we use an ambiental sensor networks kit which offers the possibility of acquiring temperature, humidity, light and barometric pressure.

Figure 9 presents circadian variations of the ambient temperature parameter for a network of three nodes placed in different rooms of the home. Differences between the measured values reflect temperature differentials between the rooms e.g. kitchen, living room, dormitory. Nodes have small size so that they can be installed efficiently inside the living space as to optimize sensing and communication coverage, and, at the same time, be concealed within the interior design as not to be noticeable to the user. Similarly, Figure 10 shows the ambient humidity variation during the same observation period. A configuration interface allows the system operator to observe the battery status of the nodes and either reduce the sampling and communication rate when an intervention is not possible, or decide the replacement of the batteries.

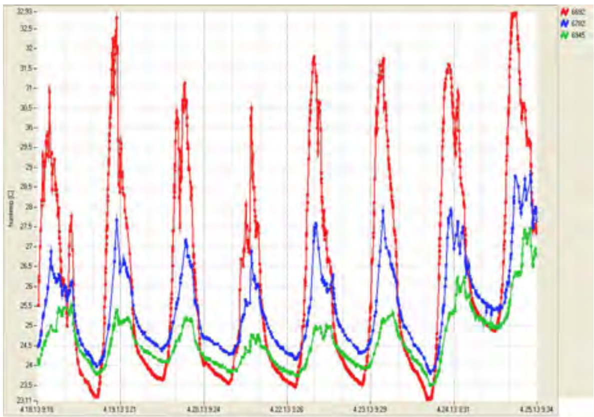

Fig. 9. Temperature Parameter monitored by 3 Nodes.

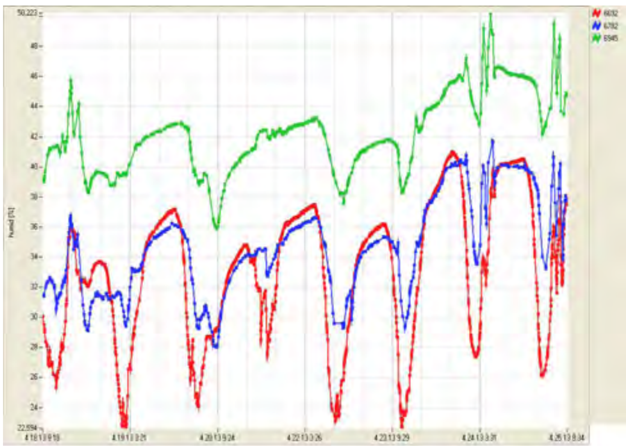

Fig. 9. Humidity Parameter monitored by 3 Nodes.

The deployed infrastructure merges both star and mesh topologies in order to achieve flexibility. The main trade-off consists in balancing high throughput for fast varying parameters and long autonomous battery operation by aggressive duty cycling of the nodes. An important advantage of the mesh configuration is that through the routing facility embedded in the nodes we can extend the indoor coverage of the network by densily deploying additional nodes. The test scenario in this paper is fully functional and the hierarchical approach of the femtocell based design is scalable to suit a rage of deployment cases.

V. CONCLUSIONS

The proposed architecture consists of a hybrid sensor network capable of monitoring human activities and environmental parameters in an indoor environment. This paper focuses on two of the most important components, the body sensor network and the ambient sensor network. The first experiment is designed to determine the possibility of identifying certain human activities by employing two accelerometers as part of the BSN. The second experiment is focused on the ASN, underlining its architectural features that help it act as a robust multihop self configuring monitoring system. The tests demonstrated that the proposed monitoring system can be implemented as a home monitoring system for elderly or disabled.

Future implementations will also include health sensors and will focus on achieving a user friendly approach for continuous health parameters monitoring. This is achieved by dedicated applications implemented on mobile devices that the patient is comfortable with, such as smartphones or tablets. An interesing approach is also to invesitgate self-powered body sensor nodes [14] for collection of acceleration data, which can mitigate the problem of battery . Movement patterns have to be studied first in a pilot deployment as to insure that enough energy is generated for reliable autonomous operation.

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