A Scalable Wireless Body Area Sensor Network for Health-Care Monitoring

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Abstract

We propose a framework for real-time monitoring of wireless biosensors. This will be a scalable platform that requires minimum human interaction during setup and monitoring. The main components include: (i) biosensor/transceiver pairs, (ii) smart hardware modules to automatically setup the body area network, (iii) data delivery mechanism to an internet sever, and (iv) automatic data collection, profiling and monitoring. Such system can increase the quality of life and can significantly lower the health-care cost for everyone in general and elderlies and those with disabilities in particular. To prove the concept, an experimental platform is implemented that uses off-the-shelf components to monitor Electrocardiograph.

Keywords: Biosensors, Body Area Network, ECG Monitoring, Plug-and-Play Systems.

I. Introduction

A. Motivation

According to Department of Health and Human Services, in 2007, about one in every seven, or 14.3% of the population is an older American [1]. The older population (65+) will continue to grow significantly in the future. Our work aims at inexpensive pervasive monitoring of people as they continue their daily routines.

Recent developments in wireless, radio frequency identification (RFID), biosensors and networking have provided incentives for researchers to use them in health care systems. Specifically, utilizing technology in the care of elderly people has attracted a lot of attention due to its potential in increasing the quality of life and reducing the cost. While many research works are reported in the literature and some commercial products and services are offered, the state of the art is still far from maturity. Specifically, platforms that are fully-wireless, can provide high-rate data processing and are scalable to remote monitoring of large population are highly in demand. This has altogether formed the main motivation for this work.

B. Prior work

Biosensors and body area networks (BAN) are expected to be used in many applications including health care, sport and entertainment. Among those, the health care applications require a series of miniature biosensors, a data transmission media (e.g. wired or wireless) and a collection/processing node. While one can build an experimental platform easily using the current technologies, there are many challenges to make it robust, secure and scalable. These challenges include the size/power consumption of sensor-transmitter, the data rate, the scalability in terms of number of biosensors and also number of patients. Today's Bluetooth and Zigbee radios have provided experimental platforms for researchers for their investigations. However, they cannot be used in low-power applications in which less than $100\mu W$ power consumption is expected [2].

For experimentation in this work, we use the heart monitoring application. Coronary heart disease is the single largest cause of death in US and one in every five deaths are attributed to it alone [3]. An estimated 60 billions dollars are spent each year for the treatment and prevention of heart attacks. Due to the advancements in pathological research and related technologies; the number of deaths due to heart disease has decreased in the last decade. Still the fact remains that it is the world's number one killer. Most of these deaths are caused by cardiac arrhythmias resulting in sudden death (deaths occurring within one hour after the first symptoms were felt by the patient). Ventricular Fibrillation, usually caused by Ventricular Tachycardia, is the most severe and life threatening arrhythmias which stops the pumping action altogether and if normal rhythm is not restored within three to five minutes, causes the patient to suffer brain and heart damage and die. Implantable Cardioverter-Defibrillator (ICD) devices are put inside the body to constantly monitor heart rhythm and quickly detect any abnormality and administer the therapy when needed. Since this is an invasive technique requiring surgery with potential complications and associated high cost; it is only a recommended solution for high risk patients. For most of the potential heart disease patients, abnormal cardiovascular symptoms such as chest pain, faints and shortness of breath can be detected before the occurrence of the fatal cardiac arrhythmia. Therefore it is important to have an effective measurement and reporting system to avoid deaths caused by heart attacks by providing immediate medical help. Several wireless Electrocardiograph (ECG) monitoring systems have been proposed [4], [5], [8], [9]. These systems use 802.15.4 (Zigbee) [4], [8], [9] or Bluetooth [5] as the radio interface for the ECG sensors to communicate with a hand held device. Neither radio interface was originally designed for real-time, high-speed, low-power continuous data transfer applications. To address some of these limitations, we propose a flexible experimental platform for designing wireless biosensor monitoring.

C. Main Contribution and Paper Organization

The main contribution of this paper is in offering an inexpensive, yet flexible and scalable, wireless platform to deliver, train and monitor data provided by biosensors. For the proof of concept, we have implemented a preliminary ECG monitoring system using off-the-shelf components. Additional requirements to achieve a full-fledge biosensor system for remote monitoring will be carefully highlighted. A large number of applications, particularly in health care sector, can benefit from such platform because it is expected to significantly lower the cost. From the perspective of a user, this is a plug-and-play gadget that can be setup quickly by a non-professional and the pervasive monitoring becomes possible without interruption in patient's daily routines. We have offered a few technical innovations including efficient signal conditioning, ubiquitous connection to internet and a powerful back-end software that performs data acquisition, profiling, reasoning and decision making.

This paper is organized as follow. Section II describes the main elements, their functionalities and the system architecture. Section III discusses the software modules and the key optimization algorithms that are involved. In Section IV, we present our implementation using the off-the-shelf components for ECG monitoring. Finally, concluding remarks are in Section V.

II. System Architecture

The architectural block diagram of our system is pictured in Figure 1. Each biosensor will include a short-range transceiver that transfers data in a secure channel to a small BAN gateway. The gateway, in turn, would process data and resends it through a secure channel to a wireless modem/router for internet delivery. Each main unit is briefly explained next.

- **Biosensor-Transceiver Pair**: Wide range of biosensors can be found in the market. Examples are sensors for heart rate, temperature, falling, bending, etc. [6][7]. Each sensor needs to be paired and packaged with a miniature low-power transceiver. As a matter of practicality, it would be much easier to use if the sensor-transceiver pair is packaged as a patch.
- **Gateway**: The gateway, would be responsible for data collection, processing and overall BAN network management. Having enough memory and processing power (a mid-size microprocessor) is inevitable. The gateway also include two types of wireless communication: (i) a receiver to get data from biosensors and (ii) a wireless Ethernet adapter to communicate with the standard wireless router/switch.
- **Monitoring Server**: A monitoring server runs a powerful back-end software to collect, analyze, profile and make decisions. It is well understood that bio metrics of each individual are very much unique. Thus, for effective processing a personalized profile should be "learned" automatically by the server. This is a crucial step to minimize (and even achieves zero-level of) *false positive* (i.e. raising alarm for non-critical situations) and *false negative* (i.e. missing a critical, perhaps life-threatening situation). To do so, a combination of innovative learning and reasoning algorithms are required to interpret data properly during monitoring.

III. Software Modules

Figure 2 pictures the main modules running on the back-end software. A brief explanation of the main modules follows.

- **Setup**: Initial signal setup interface checks for the reception of wireless signals, network setup and resolves various difficulties that may arise. Additionally, this module makes sure that the BAN and wireless networks are alive and handshake properly.
- **Registration**: Patient's information is fed in this module and stored in the server. This module includes a graphical user interface (GUI) that simplifies data entry and retrieval. Additionally, the module keeps track of patient's biosensor data and records all information needed. If any critical situation occurs, the system behaves based on the patient's pre-defined data and requests (e.g. notifying the relatives) and the severity of the situation (e.g. notifying a hospital).
- **Monitoring & Reasoning**: It keeps track of the patient's health status and depending on his health status, a decision regarding the patient's treatment is made. This is by far the most important module of system as making decisions through logical reasoning using limited number of biosensors (e.g. ECG, blood pressure/Oxygen/Glucose) is quite challenging. In general, this is done by building a dynamic model (historical profile) for each individual and use learning/reasoning algorithms to evaluate and grade the severity of each and every significant changes. More importantly, this module will be responsible to set off the alarm while achieving almost-zero false positive and false negative.
- **Value Added Services**: This module provides extra information such as geographical location of patients and close hospitals, availability of doctors in region, weather, etc. Such services may be desirable for certain group of patients with special needs or requests.
- **Report**: It is responsible for communicating (exchange messages) with the outside components, e.g. producing/sending an alarm or a report to a health-care provider.

IV. ECG Monitoring – A Case Study

A. Block Diagram

To prove the concept and understand the challenges, we focused on an experimental platform for ECG monitoring. We acknowledge that various ECG monitoring devices (e.g. belts, wrist-watches, etc.) are commercially available in the market. However, our intention was to design a platform as an experimental vehicle to show the concept, evaluate its scalability and effectiveness of various hardware and software components. ECG monitoring requires relatively large volume of data, synchronization, dealing with noise, various types of signal conditioning and processing. Our platform not only does

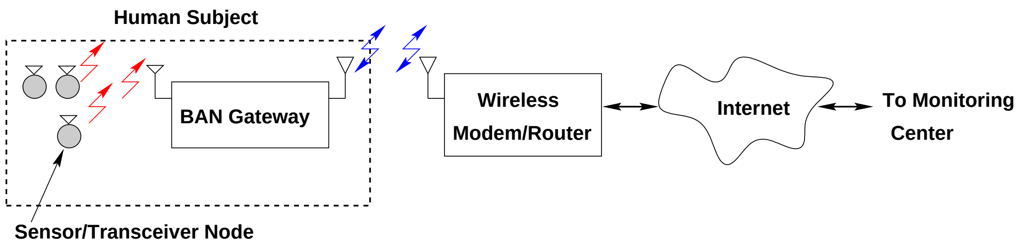

Figure 1. Architectural block diagram of our system.

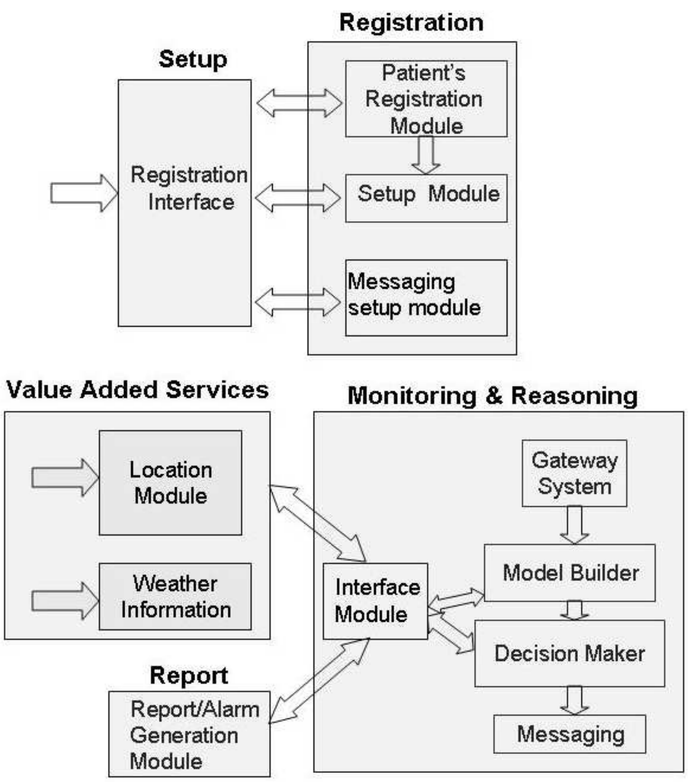

Figure 2. The flowchart of health monitoring system.

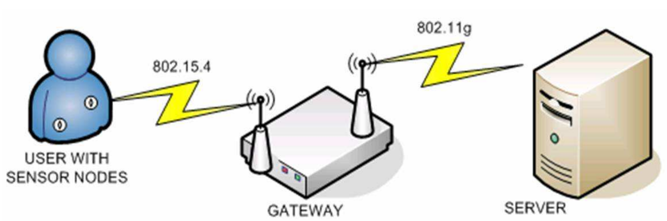

Figure 3. Experimental platform for ECG monitoring.

all of these but also hooks the patient to the internet for real-time remote monitoring. In this platform, we use all off-the-shelf products to show the concept. The block diagram of our system is pictured in Figure 3. Due to lack of space, we will not explain the technical details. Instead, the main configuration of the preliminary system and the challenges ahead will be highlighted.

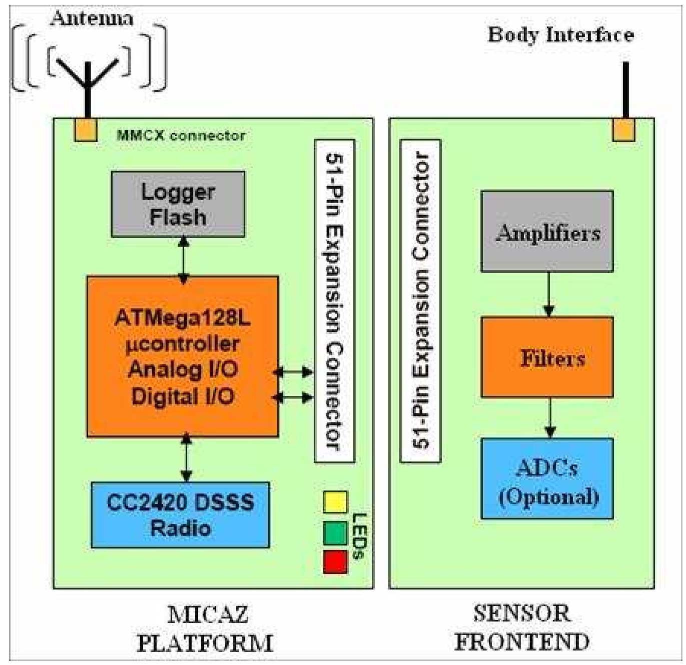

Figure 4. Sensor Node.

B. Experimental Results

We have used all off-the-shelf components to implement this experimental platform for pervasive wireless ECG monitoring. Our system consists of three main devices:

1) **Sensor Nodes**: Each sensor node, shown in Figure 4, consists of a commercial ECG electrode patch, an analog front-end and a Micaz board [10].
2) **Gateway Node**: The gateway node, shown in Figure 5, consists of: (i) Micaz based board, (ii) Altera FPGA [11] board for various signal processing and (iii) an 802.11 module for wireless connection.
3) **Server**: The server carries the proper storage, database and application softwares. It is intended to be highly available (i.e. 24/7) and be scalable for monitoring a large number of patients. The server runs real-time analysis of sensor's data, provides user access to the database at various levels (e.g. patients, relatives, physicians, etc.) and generates alarm in case of emergencies.

Figure 6 show the ECG signal before and after processings. The top curve is the noisy signal picked up by sensors. This signal is amplified, converted to digital on the Micaz board and quantized at a sampling frequency of 200 Hz. The Micaz board then transmits this data (i.e. 20 samples per packet and

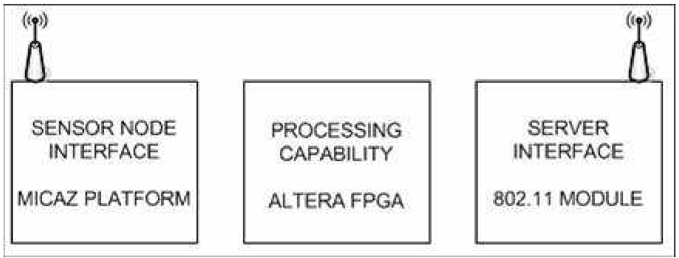

Figure 5. Gateway.

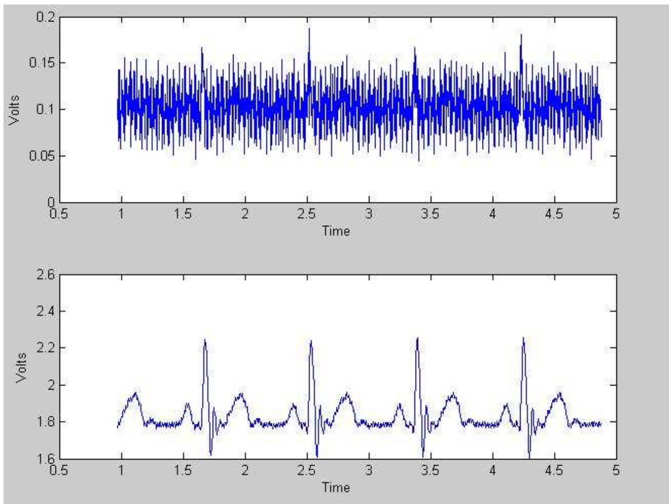

Figure 6. ECG signals: read by sensors (top curve) and recovered after transmission and processing (bottom curve).

10 packets per second) to the gateway where the signal is further processed in the FPGA.

The gateway further conditions the signal by eliminating the hum noise using notch filter and band-limit it to 0.5 Hz to 100 Hz. The band-pass filter also provides a gain of 16 in two cascaded stages. The processed signal is then sent to the server using TCP/IP connection for analysis and storage. All required signal processing is accomplished using softwares running in the gateway and the server. The final result is shown in the bottom curve in Figure 6.

C. Challenges Ahead

The preliminary ECG monitoring platform has taught us many valuable lessons that highlighted our direction toward a full-fledge system. We hope to address these challenges in near future.

- **Sensor Node**: (a) Miniaturization of this node (to reduce the cost and enhance its wearability), (b) effective noise removal (to improve bit error rate and indirectly data rate and reliability); and (c) dynamic/programmable power management (to fit in various environments/cases) are the main tasks.
- **Gateway Node**: The key challenegs here include: (i) Customizing the two transceivers (to reduce cost and power), (ii) a customized network protocol for sensor identification and communication, (iii) an encryption unit for security of transmitted data; and (iv) memory mangement for store-and-forward operation as well as for backup possibility.
- **Server**: The three vital tasks here are: (a) Minimizing the probabilities of false positive and false negative (e.g. below 0.01), (b) an intelligent context learning methodology that automatically profiles and monitors massive data collected for large number of individuals and sensors; and (c) a multi-level hierarchical graphical user interface allowing patient, doctor and selected individuals (e.g. relatives) see part of the information and exchange data for comfort, monitoring, diagnosis and urgent/non-urgent response action.

V. Conclusions

Non-invasive wireless monitoring of biosensors is highly in demand for various applications. In particular, such system can significantly improve the quality of life and reduce the health care cost especially for elderlies and people with various disabilities. In this paper, we have discussed a simple yet flexible and scalable framework of a scalable wireless biosensor system tuned for real-time remote monitoring. The accuracy, power consumption and cost of our platform, built using off-the-shelf components for ECG monitoring, are quite promising. Our future plan is to customize the hardware and software to fit system within real world environment.

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