EXTENDED HEALTH VISIBILITY IN THE HOSPITAL ENVIRONMENT

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Abstract: Wireless sensor networks can help healthcare providers enhance patient monitoring and communication capabilities. This paper describes the present state of the development of a vital signal monitoring network applied to the hospital environment. The proposed network is based on non-obstructive sensors able to communicate through a low power wireless sensor network based on the ZigBee protocol. This network enables continuous patient monitoring, creating entirely new mechanisms for providing healthcare under a plethora of cases (e.g. post-op, continuous care, and chronic diseases). The main advantages of this system include increased patient mobility, faster detection of potential problems, real-time feedback to caregivers and patients, and faster response to emergency situations.

1 INTRODUCTION

We have specified a system that facilitates vital signals gathering in a hospital environment that resembles the basic configuration analyzed in (Cypher, Chevrollier, Montavont, & Golmie, 2006) with some improvements. We have added a mechanism to send messages back from the hospital's monitoring system to the patient. With this system we want to introduce the concept of "extended health visibility", where non-critical patients can be continuously and unobtrusively monitored while simultaneously being informed about their condition and receive messages from the hospital caregivers (e.g., a doctor appointment, a reminder to take their medicine, or a visitor arrival notice). Through this system, instead of collecting vital signals only a few times along the day, hospitals will be able to maintain continuous patient records which will provide better emergency condition detection and response, enhanced diagnosis capabilities, and promote, among the patients, a better appreciation of the care being provided.

Despite the evident benefits that can result from the adoption of wireless technologies, there are still many concerns that limit the widespread application and challenge researchers to devise potential solutions. It is essential to satisfy demanding requirements in terms of quality of service such as sustainable throughput, bounded delay and reliable packet delivery. At the same time, it is necessary to guarantee that the power consumption of the sensor nodes is small, since they are powered by batteries, in order to increase their autonomy. Another difficulty arises from the fact that some sensors must be sampled quite often, generating a large amount of data and, consequently, requiring the network to operate under high load, which is not common in typical wireless sensor network scenarios. Several strategies are been used to overcome those problems and they include the use of techniques to compact data and the efficient use of the communications channel.

In order to adequately introduce and describe our solution, we present a quick review of related work. The scenario envisioned in (O'Donoughue, Kulkarni, & Marzella, 2006) differs from ours because the developed system aims at transmitting vital signals from in-patients in a very restricted area, an intensive care unit. In our case, patient mobility poses another challenge. It will be necessary to provide means of efficiently collecting the signals throughout the hospital's targeted areas without losing information.

Two different scenarios are also considered in other related works. In case of mass casualty, overwhelming quantities of patients need to be monitored and triaged. AID-N is a real-time patient monitoring system that integrates vital signs and location sensors, ad-hoc networking, electronic patient records, and Web portal technology to allow remote monitoring of patient status (Tia, Greenspan, Welsh, Juang, & Alm, 2005). CodeBlue also considers critical care environments (Lorincz et al., 2004). It is a common protocol and software framework which allows wireless monitoring and tracking of patients and healthcare professionals. Our work shares the basic concerns of systems planned to operate in those scenarios, namely device discovery, naming, routing and security. Nevertheless, we are not concerned with data prioritization but in assuring the reliability of the data transmission.

Telediagnosis and teleconsulting are considered in the AMBULANCE project (Pavlopoulos, Kyriacou, Berler, & Koutsouris, 1998). A portable device, carried inside an ambulance, allows telediagnosis, long distance support and teleconsultation by specialized physicians. It allows the transmission of vital signals and still images of the patient from the incident place to the hospital. While AMBULANCE uses GSM, a system primarily designed to handle voice communications, we have chosen to use ZigBee (ZigBee.Alliance, 2007), an emerging wireless sensor network (WSN) protocol primarily conceived to be applied in low traffic scenarios.

In the next section, we present some tests results considering the electrocardiogram data acquisition and its wireless transmission. The conclusions and future work will be presented in the last section.

2 EXTENDED HEALTH VISIBILITY

Gathering current patient medical data promptly and accurately is vital to proper health care. Continuous monitoring offers the capability of identifying and responding to events as they occur, possibly preventing a dangerous condition, instead of simply allowing its diagnosis after the danger has taken place.

2.1 The Envisioned Solution

The envisioned system is not intended to eliminate current existing devices or routines but to improve patients monitoring capabilities. Under this assumption, it is not intended, for instance, to replace wire-based continuous monitoring devices from intensive care units. Urgency, observation, ward and recovery from procedures that require local anesthesia or sedation are possible scenarios.

The system in development is based on a ZigBee ad-hoc wireless sensor network with routers and gateways distributed all over the hospital spaces intended for monitored patients. This network will be responsible for receiving data from sensor units and transmitting this information to the main application running in the nurses' station through a ZigBee to Wi-Fi gateway. The data sent to the main application will be processed and will become available, through a web portal, to registered healthcare providers carrying a portable device (e.g., a Personal Digital Assistant, PDA), as depicted in Figure 1, where only one ZigBee network is shown.

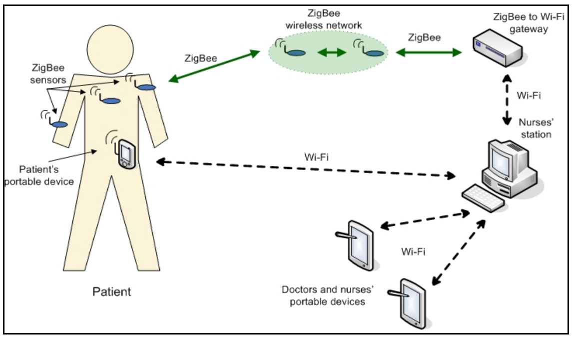

Figure 1: Envisioned system architecture.

Five vital signals will be monitored: cardiac rate, electrocardiogram (ECG), arterial pressure, pulse oximetry and temperature. Medical sensors will be designed to be minimally obtrusive.

The main application will analyze patient data and, based on thresholds defined by the physician, generate alerts to healthcare providers if a critical condition occurs. Furthermore, it will be possible to alter threshold values individually. Additionally, portable devices will allow healthcare providers to remotely access patient information and change monitoring configurations at any time. In the patient perspective, the system will be able to provide a mechanism for communication between patients and the nurses' station. Nurses will be able to send messages to patients and to receive assistance requests.

2.2 Current Project Status

ZigBee is a wireless network standard which resulted from the collaborative efforts of a consortium of companies known as the ZigBee Alliance. IEEE 802.15.4 (IEEE, 2003) is a standard defined by the IEEE for low-rate, wireless personal area networks which specifies the physical (PHY) and the medium access control (MAC) layer used by ZigBee. The specification for the physical layer defines a low-power spread spectrum radio operating at 2.4 GHz with a bit rate of 250 kbps. There are also PHY specifications for 915 MHz and 868 MHz that operate at lower data rates.

Even though ECG data rates are relatively high compared with data rates generated by other sensors, they are well below the bit rate of a ZigBee network operating at 2.4 GHz, so it is expected that ZigBee will be able to carry the generated traffic using its CSMA/CA protocol, provided that high traffic loads are avoided, in order to limit the percentage of packets lost due to collisions. ZigBee was chosen because it allows the construction of networks composed by a large number of nodes that can cover large areas through the use of multihop communication, in contrast, for example, with Bluetooth, which supports only seven end nodes per piconet in a short-range star topology. Additionally, ZigBee is a standard based protocol that operates on a license-free ISM band and provides low-cost, low-power and small form factor modules.

The ZigBee network developed is based on JN5139 modules manufactured by Jennic (Jennic, 2008). Basic network functionalities have already been tested using several end devices that continuously send simulated ECG data in a star network topology.

2.2.1 The Wireless Network for ECG Monitoring

The ECG application was chosen as the first one to be assessed because it is the most demanding one. The network operates in the 2.4 GHz band and the access to the radio channel is gained using the unslotted CSMA/CA. The chosen sample rate is the same used by commercial monitoring ECG equipments, 120 Hz (Fulford-Jones, Gu-Yeon, & Welsh, 2004).

2.2.2 Power Consumption Estimation and Measurement

Power consumption is an important issue. It is desirable that end devices consume the least possible power to allow for continuous operation for long periods without batteries replacement. To estimate the battery lifetime, we must consider that the CPU is always active because frequent ADC measurements are required. During these periods, the module consumption is equal to 9.21 mA. In reception and transmission modes the current consumption reaches 37mA (Jennic, 2007).

The module reads the ECG sensor thirty times, once every T_S = 8.33 ms (which is the inverse of the sampling rate, 120 Hz) using an internal 12-bit resolution ADC, and then, every 250 ms, sends a data packet with the measurements. One module cycle is depicted in Figure 2, where current consumption values are shown for each activity: ADC reading (ADC), backoff (BP), clear channel access (CCA), data transmission (T_{DF}), acknowledgment waiting (t_{ack}) and acknowledgment reception (T_{ACK}).

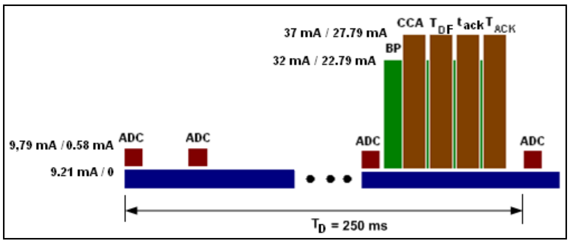

Figure 2: Module current estimation.

Taking those operation parameters into consideration, it is possible to determine that the average current over the 250 ms period is equal to 9.84 mA. The total operating time considering the module is powered by two AAA 1200 mAh batteries is approximately 122 hours or 5 days.

The current drained by the module as a function of time was measured to confirm the power consumption estimation using a data acquisition board driven by a MATLAB program. In Figure 3 it is possible to observe the current variation over a period of approximately 300 ms where ADC sensor readings and backoff, CCA, data frame transmission, t_{ACK} and acknowledge reception are shown.

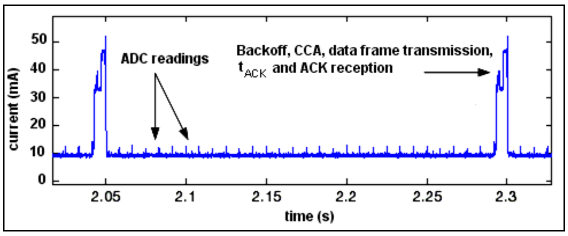

Figure 3: Module current measurement.

2.2.3 Network Operation Tests

We have tested the packet error rate by considering just one end device transmitting a 2-byte payload data frame to the coordinator. Five runs were executed involving the transmission of a total of 40,000 packets at different intervals. No packet was lost in any run but we have observed packets retransmissions during the longer tests probably due to interference from Wi-Fi traffic. The number of packets that required retransmission in each run is shown on Table 1. The results confirm the satisfactory coexistence between ZigBee and Wi-Fi networks.

Table 1: Transmission test results.

Interval between packets	***Number of retransmitted packets in each run***				
	1	**2**	**3**	**4**	**5**
100 ms	6	5	6	0	0
20 ms	1	0	0	0	0
10 ms	0	0	0	0	0
5 ms	0	0	0	0	0

A second test was performed using five ZigBee modules to simulate a small ZigBee star network. Four modules were used as end devices to gather and transmit ECG signals using the unslotted CSMA/CA mode. Every 250 ms a 45-byte payload data packet was sent to the fifth module, which was programmed to perform as the network coordinator. It also checks if any data packet from any end device is lost and reports it. Ten runs involving the transmission of at least 2400 packets by all four end devices were executed. No packet was lost in any run, which can be considered a promising result.

3 CONCLUSIONS

Wireless sensor networks promise ubiquitous vital signal monitoring that might completely transform the way health care is provided.

We have proposed a system that facilitates vital signal gathering in a hospital environment for what we call *extended health visibility*. Instead of collecting vital signals only a few times along the day, healthcare professionals will have access to continuous patient records which will provide several improvements compared to current capabilities. Power consumption estimation and measurements, as well as network performance test results were discussed. These preliminary results seem to validate the potential applicability of the proposed system for the intended application.

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