RESURE
Wireless Sensor Network for Health–Care Monitoring

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Abstract: This work presents a sensor system to monitoring a patient vital signs remotely. The proposed sensor network architecture is based on IEEE 802.15.4 PAN technology with start topology. An experimental set-up was implemented including the development of some biological sensors. In the implementation stage we use Xbee modules, the remote sensors was configured as RFD devices and the network coordinator as FFD device. As central device a smart phone was used. From the results, we conclude that the IEEE 802.15.4 technology is appropriate for medical WPAN sensor network implementation.

1 INTRODUCTION

The World Health Organization (WHO) estimates that by the year 2025, more than 1,000 million people will be older than 60 years (WHO, 2004), in other words, the average age of the world-wide population is increasing. Normally, the aging comes accompanied by non-transmissible chronic diseases, such as cardiovascular disease and others that need a continuous monitoring. This scenario presents many challenges to modern societies; one of them is the design of sensor systems that can continuously record physiological variables, from these variables the health of the people can be inferred (Woodward and Rasid, 2003).

Nowadays, the technological advances in microelectronics and instrumentation ease the development of sophisticated, small size, low power consumption and relative low cost monitoring systems. In addition, the WPAN technology allows easy and fast interconnection of different kind of elements, i.e. earpieces for mobile phones, video, camera, audio reproducer, computers, etc. Therefore, the new technologies offer the possibility of transmitting physiological signs for processing or visualization devices (PCs, PDAs, screen, etc.) or to processing center without limiting the patient mobility (Rodríguez, J. et al., 2005). Due to medical and economical reasons, shorter periods of inpatient stay are desirable. Patients' monitoring at home environments is one of the most attractive areas for WPAN applications (Karl and Willig, 2005), because this technology can enable seamless connectivity in hospital and home environment. A WPAN central device can be implemented as a wristwatch or a small belt-worn box.The device could be able to communicate with the hospital monitoring system using the home network access points via wireless indoor communication systems like WLAN, DECT or Bluetooth. WPAN monitoring is also adequate for patients with chronic diseases such as diabetes, asthma and cardiovascular diseases. The employing of WPAN in the patient' home is useful for rehabilitation and post operational care. A central WPAN device with modules for accessing global wireless networks like GSM or UMTS can provide potentially worldwide mobility for WPAN users (Istepanian, R. et al., 2001). Summarizing, we can say that quality of life can be significantly improved.

2 REQUERIMENTS OF A MEDICAL SENSOR NETWORKS

A medical sensor network design greatly depends on the application and deployment environment. A sensor network designed for ad hoc deployment in an emergency site has very different requirements than one deployed permanently in a hospital. For example, the latter can make use of fixed, wall powered gateway nodes, which provide access to a wired network infrastructure. In general, we can identify seve-

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ral characteristics that nearly all medical sensor networks should have (Shnayder, V. et al., 2005).

- **Scalability**: is the capability of a system to increase performance when new nodes are added.
- **Wearable Sensor Networks (WSN)**:Medical applications require very small, lightweight, and wearable sensors. Power consumption in a WSN is important since most or all devices must be battery powered. Replacing or recharging in short intervals will be impractical, so power consumption is of significant concern.
- **Reliable communications**:In medical settings, a great emphasis is placed on data availability, although intermittent packet loss due to interference may be acceptable. However, persistent packet loss would be a problem. Depending on the used sensors, sampling rates may vary between 1 to 1000 Hz or more, placing heavy demands on the wireless channel.
- **Device mobility**:Both patients and caregivers are mobile, requiring that the communication layer adapt rapidly to changes in link quality. For example, if a multihop routing protocol is in use, it should quickly find new routes when a doctor moves from room to room during his rounds.
- **Security**:The security in wireless networks is always of great importance. In sensor networks, it is especially important to have integrity and authentication. Integrity means that data should not be altered or destroyed in its way from the sender to the receiver and the authentication should ensure the identity of the sender and the receiver.
- **Association**:The service used to establish a device's membership in a WPAN. How a WPAN adds a new node is of interest in this kind of networks. As well as how one sensor is associated with the correct output at the central monitor side.
- **Cost**:To be able to compete in the international market it is essential that the components be at the lowest possible price. This is most important when the product shall be mass-produced.

3 SHORT RANGE WIRELESS TECHNOLOGIES

Based on the above mentioned requirements of medical WPAN systems, following the technical characteristics of some wireless technologies are presented, which according to the bibliographical review and our criteria, can be used to design a medical WPAN.

3.1 IEEE 802.15.1 / Bluetooth

The IEEE 802.15.1 standard is derived from the Bluetooth specification (version 1.1). In fact, the IEEE standard has added two clauses to the existing specification; WPAN architecture overview and Service Access Points (SAPs). In other words, the 802.15.1 standard presents a wireless personal area network that utilizes the Bluetooth wireless technology. A PAN is defined as a computer network used for communication among computer devices close to one person. The Bluetooth WPAN operates in the unlicensed 2.4 GHz industrial, scientific and medical (ISM) band. The Bluetooth 1.0 data rates include an asymmetric data rate of 721 kbit/s while permitting 57.6 kbit/s in the return direction; and a symmetric data rate of 432.6 kbit/s (IEEE Standard, 2002).

3.2 IEEE 802.15.4 /Low-Rate WPAN

IEEE 802.15.4 is a standard defined for low-rate (LR) WPANs. A LRWPAN is a simple, low cost communication network that allows wireless connectivity in applications with limited power and relaxed throughput requirements. The main objectives of a LR-WPAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life (IEEE Standard, 2003). Like all IEEE 802 standards, the IEEE 802.15.4 standard encompasses only those layers up to and including portions of the data link layer (DLL). I.e. the standard 802.15.4 defines only the PHY and the medium access layers (MAC). In particular, it defines two PHYs representing three license-free frequency bands that include sixteen channels at 2.4 GHz, ten channels at 902 to 928 MHz, and one channel at 868 to 870 MHz. The maximum data rates for each band are 250 kbps, 40 kbps and 20 kbps, respectively. A WPAN consists of several components; the most basic is the device. There are two different device types, which can participate in an LR-WPAN; a full-function device (FFD) and a reduced-function device (RFD). A FFD can talk to RFDs or other FFDs, while an RFD can talk only to an FFD. An RFD is intended for applications that are extremely simple, such as light switches or passive infrared sensors; they do not have the need to send large amounts of data and may only be associated with a single FFD at a time. Because of that, the RFD can be implemented using minimal hardware resources (Thraning, 2005).

Table 1: Comparison of short–range low power wireless technologies.

	Bluetooth	802.15.4	ZigBee
Data rate(Mbit/s)	1	0.250	0.250
Range(m)	10-100	10-100	10-100
Power supply	Medium	Very low	Low
Security	High	Medium	High
Scalability	7	255	255
Cost	Medium	Very low	Low

3.3 Zigbee

ZigBee was created to address a specific market need for an industrial standard to support automation and remote control applications. The ZigBee Alliance decided to use the IEEE 802.15.4 standard as the Physical layer and Media Access Control sub-layer, while the ZigBee Alliance defines the upper layers. The ZigBee network layer supports multiple network topologies including star, cluster tree, and mesh. The application layer consists of the application support layer (APS), the ZigBee device object (ZDO) and the manufacturer-defined application objects. The APS is responsible for maintaining tables for binding and forwarding messages between bound devices. A binding is the ability to match two devices together based on their services and their needs. The binding include the device discovery, which is the procedure to discover other devices that are operating in the same area (ZigBee Alliance, 2005).

The different IEEE 802.15 standards were designed with different purposes. Bluetooth was designed to replace cabling connections between devices, while 802.15.4 and ZigBee for network sensor targeted to home automation. Therefore, none of them was specifically designed to be used in medical sensor network.

4 PROPOSED ARCHITECTURE FOR THE SENSOR SYSTEM

In the absent of a specific standard, in this work we propose the use of the IEEE 802.15.4 and Zigbee standard as the more adequate solution for medical WPAN sensor networks. Most Bluetooth modules are not appropriate because its power requirement is high for battery-operated devices that cannot be charged or changed regularly. It is also restricted by its scalability capacity; it can only have seven active nodes in one network. 802.15.4 and ZigBee looks like a perfect fit, except for its low data rate. This technology presents low power requirement because the nodes are in sleep mode most of the time.

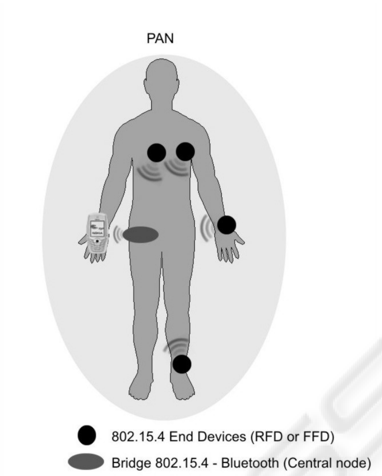

Figure 1: Proposed network architecture for biological signs monitoring.

By using ZigBee mesh topology supports (Thraning, 2005) there is no need of a master node in the WPAN, in this configuration every node/sensor can communicate directly and each node acts as a router. This way a data flow from one node can take multiple routes to its destination, making it very resilient; if a node drops out the flow, it is redirected through other nodes. A routing algorithm is used to ensure that the data takes the fastest possible route.

A drawback of mesh networking is synchronization. Two or more data flows that need to be time synchronized at the receiver may take different routes, resulting in different time delays. If this delay is greater than what is possible to buffer, data lost occur. To overcome the above mentioned problem, in this work we propose the use of IEEE 802.15.4 technology with a star network topology. With respect to power consumption, this technology has suitable characteristics for medical WPAN application since it was originally developed to have low power consumption; i.e. ideally a node should work for months or years without batteries changes. In addition, the standard was developed for the communication between sensors, which reduces its complexity, allowing lower implementation costs than Bluetooth technologies.

5 EXPERIMENTAL SET-UP

In order to validate the proposed network an experimental set-up was implemented, including the development of some biological sensors. Figure 1 presents the proposed network architecture. In the proposed topology the sensors are RFD devices which communicate to a central node, configured as FFD.

5.1 Hardware Components

There are many chips or modules manufacturers' following this standard, including Texas Instruments, Maxstream, FreeScale, among others. In this work, we select an OEM module from Maxstream Company, the XBee. This module has a 100 meters range for outdoor and 30 meters indoor, with a 1 mW of power in antenna, consuming 45 mA in transmission and 50 mA in reception modes. The XBee module uses the MC13193 transceiver chip working in the 2,4GHz frequency band and a MC9S08GB60 microcontroller, both from Freescale. In addition, the microcontroller has 8-channel analog to digital converter with 10 bits resolution and an UART interface (Digi International, 2006).

The WPAN central device is a mobile phone (Nokia 6620), which collects and processes the sensors signals, transmitting them to a central monitoring system through the mobile phone network using SMS and MMS protocols. Due to the novelty of IEEE 802.15.4 technology, the mobile phone does not support this standard, reason why we implemented an IEEE 802.15.4-to-Bluetooth bridge for integrate the phone to the sensor network. The Nokia 6620 was selected because it has Bluetooth interface and runs Symbian operating system, which allows the development of applications in C++ or Java programming languages.

In addition, a cardiac pulse sensor was implemented. Actually, we are developing others biological sensors such as ECG and pulse oximeter.The cardiac pulse sensor is implemented using a piezoelectric transducer that obtains the blood pressure pulse waveform across an artery. The SDT1-028KD PVDF piezoelectric transducer from MSI (Measurement Specialties, 2006) was selected.

The analog circuit for transducer signal conditioning consists basically of a differential charge amplifier which uses three op-amps in the classic instrumentation amplifiers configuration. The differential topology reduces line-noise pickup, which is a problem with high-gain circuits. Besides, an active guard has been used to compensate unbalances in the transducer terminals and a shield around the transducer behaves like a Faraday cage, connected to the active guard. The next amplifiers and filters stages are implemented as single ended devices. In the Figure 2 a simplified schematic of the charge amplifier is shown. The small pulses of charges are integrated and converted to differential voltages pulses at the output of the first stage. The second stage is a differential–to–single–ended amplifier. The gain of the differential stage is given by the ratio between C1 and C2, where C2 corresponds to the equivalent capacitance of piezofilm (Maxim Inc., 2002). The circuit has a good performance, with an S/N ratio of approximately 40 dB.

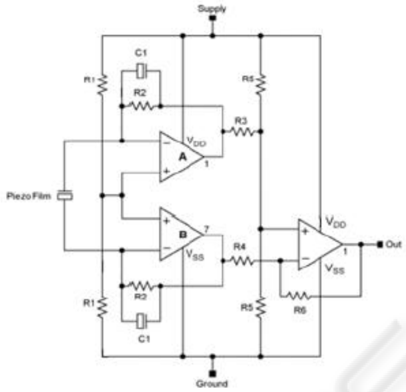

Figure 2: Charge amplifier schematic for the PVDF transducer.

Figure 3: Photo of the sensor node and the smart phone used as the central device.

Figure 3 is a photo of the designed sensor node. It can be seen the Xbee OEM module, the analog signal conditioning circuit for the PVDF transducer and the smart phone used as the central device.

5.2 Software Modules

On the Nokia 6620, both Java and C language can be used for applications development. While both languages are capable of connecting to the Bluetooth stack and communicate via GPRS, SMS or MMS; Java applications are halted if the user receives an incoming call or loads another Java application. Writing code in C language allows our program to continue capturing data from the sensor network in the background regardless of the task the mobile phone is doing on the foreground. The used development environment was the Carbide V1.0 with the Nokia Series 60 SDK 2nd Edition. This platform integrates a phone simulator for debugging purpose. Compiled

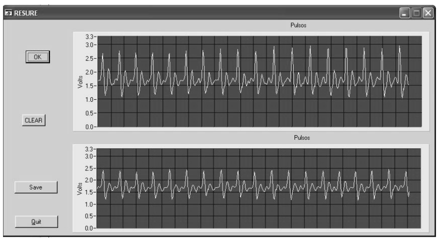

Figure 4: Measurements taken by two cardiac pulse sensors located on two different positions of the neck.

code was packaged into a Symbian .SIS installation file and downloaded to the phone via Bluetooth.

The Figure 4 shows some measurements taken by two cardiac pulse sensors located on two different positions in the neck. The signals are displayed on the screen of a test program developed using LabWindows environment. It can be observed that the shapes of the cardiac pulses are well defined and the signals have good signal–to–noise ratio. If analyzed by a physician, these waveforms could give information about the arteries' state.

6 NETWORK PERFORMANCE ANALYSIS

In order to validate the proposed network architecture performance, we implement two cardiac pulse sensors. From this test bench, we obtain some network parameters and acquired two pressure signals simultaneously from two different positions of the body.

Following, some results are presented:

- **Security**: The 802.15.4 Default Security protocol offers AES encryption with a 128-bit key. However, the use of this feature causes a packet overhead reducing the available bandwidth. That's why, the AES encryption is disable in the carried out experiments.
- **Battery lifetime**: With a 2400 mAh battery and a transmitter consumption of 45 mA with duty cycle of 100% we have a lifetime of 2400 mAh/45mA, approximately 53 hours. The calculation assumption of 100 % duty cycle is not realistic; it could be a lot less in this kind of networks. The question is how often do the sensors need to transmit? To achieve best possible effective data rate it is important to use the largest packet size possible. The Maxstream module can send up to 106 bytes per packet with a maximum 92 bytes payload. Each sample has 10 bit resolution, this means that 46 samples fit in each packet. The sensor, with 500 Hz sampling rate, takes a sample every 2 ms (1/500 Hz). If the sensor does not transmit until the packet is full (46 samples), the sensor transmits every 46*2 ms = 92 ms. Transmitting 106 bytes at 250 kbit/s takes 3.36 ms, to wake up the transmitter from sleep mode takes 2 ms and to access the channel 10 ms. An ACK frame of 11 bytes which takes 0.35 ms to be transmitted. Summarizing, the radio activity time is 2 ms + 10 ms + 3.36 ms + 0.35 ms =15.71ms. Considering that the radio can sleep when it is not in use and if no error occurs, the transmitter is in use during 15.71ms per each 92 ms which gives a 17% duty cycle. Beacon frames from the coordinator, for time synchronization, is not take into account. With the above considerations, the battery lifetime is approximately 2400mAh / (45mAh*0.17) = 313.72 hours. This is an optimistic result; actual battery lifetime will likely be somewhat below this. Also, note that sleep mode current is not taken into account; it is approximately 50 uA and his impact on the battery life will be minimal.
- **Scalability**: With a 500 sampling per second rate and a 10 bit resolution, 5000 bits needs to be transferred each second. Each packet in the network has 14 bytes overhead and 92 bytes payload. The required data rate to transmit 5000 bits per second is ((500/46)*106)*8 9.2 kbits/s; a very low data rate considering the 250 kbits/s bandwidth available between each sensor and the PAN coordinator. Theoretically, up to 25 nodes can be added to the network, but this is not a true number because of the IEEE 802.15.4 medium access control mechanism.

From the above analysis we can conclude that the IEEE 802.15.4 standard is appropriate for medical WPAN sensor network.

7 CONCLUSIONS

In this work a wireless sensor network for medical applications is proposed based on IEEE 802.15.4 standard. To validate the proposal a prototype, composed by two wireless blood pressure sensors, was build.

From the theoretical analysis and experimental tests, we can conclude that the IEEE 802.15.4 standard is appropriate for medical WPAN sensor network with respect to the following performance parameters: battery lifetime, scalability and security.

Actually, we are working on the development of other sensors, specifically an ECG and a oximeter sensors, which will be added as nodes in the WPAN sensors network. Also, we are working on a program for the mobile device that will analyze the different signals in order to obtain useful information to be presented to the user.

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