IMPLEMENTATION ISSUES FOR WIRELESS MEDICAL DEVICES

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ABSTRACT

Recent technological advances in sensors, low-power integrated circuits, and wireless communications have enabled the design of low-cost, miniature, lightweight, and intelligent physiological sensor nodes. Being capable of sensing, processing, and communicating one or more vital signs, these nodes can be seamlessly integrated into wireless personal or body area networks (WPANs or WBANs) for health monitoring. These networks promise to revolutionize health care by allowing inexpensive, non-invasive, continuous, ambulatory health monitoring with almost real-time updates of medical records via the Internet. Though a number of ongoing research efforts are focusing on various technical, economic, and social issues, many technical hurdles still need to be resolved in order to have flexible, reliable, secure, and power-efficient WBANs suitable for medical applications. This paper discusses implementation issues and describes the authors' prototype sensor network for health monitoring that utilizes off-the-shelf 802.15.4 compliant network nodes. The paper presents performance analysis for different health care equipment for 6LoWPANbased wireless network**.**

I. INTRODUCTION

An emerging application for wireless sensor networks involves its use in medical care. In a hospital or clinic, outfitting every patient with tiny, wearable wireless vital sign sensors would allow doctors, nurses and other caregivers to continuously monitor the status of their patients. In an emergency or disaster scenario, the same technology would enable medics to more effectively care for large numbers of casualties. First responders could receive immediate notifications on any changes in patient status, such as respiratory failure or cardiac arrest. Wireless sensors could augment or replace existing wired telemetry systems for many specific clinical applications, such as physical rehabilitation or long-term ambulatory monitoring.

This paper reviews and extends the work we presented in [1 and 2]. Before brining all medical devices in to the described architecture [1], we carried out performance measurement with respect to different vital parameters. Many constraints imposed by diverse applications and different case studies make the choice of a singular wireless technology indeed challenging. Therefore, it is expected that many wireless technologies with variety of devices have to be used in order to support different application requirements.

In this paper, we focus primarily on low-rate medical applications deployed in different environment while considering the emerging low-rate wireless personal area network technology as specified in the IEEE 802.15.4 standard [3] with implementation of 6LowPAN [4] for cable replacement and short range connectivity. To experience the required technologies CC 2420 single chip 2.4 GHz [15], IEEE 802.15.4 compliant and ZigBee™ ready radio frequency transceiver [16] are currently being deployed. We try to analysis the performance issues of different medical wireless devices including wireless electrocardiography (ECG), breathing rate (BR), skin resistance (SR), and body temperature (BT) sensors. For this purpose, we carried experiment with different parameters including packet length, time of arrival, round trip time with different distance values.

Most likely multiple wireless technologies will be used simultaneously in the same area at hospital. As the radios share the same frequency spectrum, the interference levels between them are matter of concern in such unforgiving environments. Thus, after evaluating technologies independently, we investigate performance behavior of the devices whether they can coexist by quantifying the impact of any potential interference.

The following discussion is based on the ideas and work carried out by the WILHO [20] Consortium in Oulu region in Finland. Besides the Centre for Wireless Communications (CWC), the other key contributors for the research comprise the *Intelligent Sensor Group* (*ISG*) at the Computer Engineering Laboratory and the *Optoelectronics and Measurement* Techniques Laboratory *(OEM)* at the University of Oulu and *Oulu University Hospital* (*OUH*). In addition to the academic contributors, the consortium in Oulu region has two SME's: *ODL Health Ltd.* (*ODL*) and *Whealth Ltd*. All these parties have formed the WILHO Consortium to improve the utilization of wireless technologies in hospitals and promote the concept globally.

II. REQUIREMENTS FOR WIRELESS MEDICAL SENSORS

The requirements for a medical sensor network design depend greatly on the specific application and deployment environment. A sensor network designed for *ad hoc* deployment in an emergency situation has very different requirements than the one deployed permanently in a hospital. In general, we can identify several characteristics that nearly all medical sensor networks would share.

Wearability: To achieve non-invasive and unobtrusive continuous health monitoring, wireless medical sensors

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should be lightweight and small. The size and weight of sensors are predominantly determined by the size and weight of batteries. However, battery's capacity is directly proportional to its size [5]. We can expect that further technology advances in miniaturization of integrated circuits and batteries will help designers to improve medical sensor wearability and the user's level of comfort.

Reliable Communication: Reliable communication in wireless hospital area network (WHAN) is of utmost importance for medical applications. The communication requirements of different medical sensors vary with required sampling rates from less than 1 Hz to 1000 Hz [6]. One approach to improve reliability is to move beyond telemetry by performing on-sensor signal processing. For example, instead of transferring raw data from an ECG sensor, we can perform feature extraction on the sensor, and transfer only information about single event. In addition to reducing heavy demands for the communication channel, the reduced communication requirements save total energy expenditures, and consequently increase battery life. A careful trade-off between communication and computation is crucial in optimal system design.

Device mobility: Both patients and caregivers could be mobile. This requires that the communication layer adapts rapidly to the changes in a link quality. For example, if a multihop routing protocol is used, it should quickly find new routes when a doctor moves from room to room during rounds. Handovers between different access points need to be carried out.

Interoperability: Wireless medical sensors should allow users to easily assemble a robust wireless hospital area network (WHAN), depending on the user's state of health. Standards that specify interoperability of wireless medical sensors will promote vendor competition and eventually result in more affordable systems.

III. Wireless Technology and Medical Applications

In this section, we describe two potential wireless technology candidates for medical applications and give a brief overview of the characteristics and requirements of these applications.

IEEE 802.15.4: IEEE 802.15.4 [3] is a proposed standard addressing the needs of low-rate wireless personal area networks (LRWPAN) with the focus on enabling wireless sensor networks. The standard is characterized by maintaining a high level of simplicity, allowing for low-cost and low-power implementations thus enabling applications, impractical for previous WPANs, in the fields of industrial, agricultural, vehicular, residential and medical sensors and actuators.

Various wireless technologies, such as IEEE 802.11 WLAN family [17] already exist for military and medical applications, to be used in Internet access and file sharing. However as time and technology progress, so does the infiltration of wireless into other areas and medical applications [7]. Cable replacement for removing tethering devices and flexible configuration for mobile units appear to be good reasons for applying wireless technologies to medical applications. We examine the stability of new low rate IEEE Std. 802.15.4-2003 [3] and its suitability to low rate medical applications. The IEEE Std. 802.15.4 [3] describes very low rate wireless technology that is designed for communication among wireless devices within a short range using very low power (most likely battery operated).

Recently, applications could not make use of current wireless technologies or they use proprietary solutions (in most cases unidirectional) [8]. The 802.15.4a is a recent revision of the standard IEEE 802.15.4; in particular it specifies a new different optional physical (PHY) layer for ultra wideband (UWB) [19] frequencies: 3-5 GHz, 6-10 GHz and less than 1GHz. The principle interest of this alternative PHY is in providing communications and high precision ranging/location capability (1 meter accuracy and better), high aggregate throughput ultra low power, adding scalability to data rates, longer range and lower cost.

6LoWPAN framework: The IPv6-over-IEEE 802.15.4 [9] document specifies the IPv6 headers carrying over IEEE 802.15.4 network with the help of a LoWPAN adaptation layer which locates between the MAC layer and the network layer (compressed IPv6) as depicted in Fig. 1. The LoWPAN adaptation layer must be provided to comply with IPv6 requirements of minimum maximum transmission unit (MTU). However, it is expected that most of IEEE 802.15.4 applications will not use large packets. Small application payloads in conjunction with proper header compression will produce packets that fit within a single IEEE 802.15.4 frame [9].

The justification for this LoWPAN adaptation layer is not just for IPv6 compliance, as it is quite likely that the packet sizes produced by certain application exchanges, such as configuration or provisioning may require a small number of fragments. The LoWPAN network is characterized by low-powered, low bit-rate, low cost and short ranged transmission [9]. Thus, all multicast nodes defined in neighbor discovery [10] is not often desirable in the LoWPAN network. IEEE 802.15.4 does not have multicast support, however, it supports broadcast. Broadcast messages could be used in some cases to represent all-node multicast messages, but periodic broadcast messages should be minimized in the LoWPAN network in order to conserve energy.

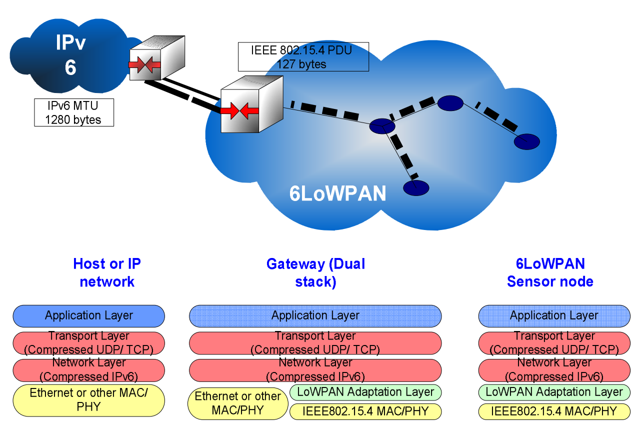

Figure 1: 6LoWPAN frame work.

Application requirements: In this section, we describe the nature of some medical applications and their requirements that have life or death implications when data is lost, corrupted, or delayed. This is unlike in most other environments where the requirements are mainly financial based. As part of the framework evaluation, the IEEE 1073 group[1] has defined a number of potential medical applications and usage cases. Each medical application is defined in terms of data rate (raw data needed to be transported), end-to-end latency (potential packetization and transmission delay), and expected coverage area (radio distance between two communicating devices).

An example of a medical application is electrocardiogram (ECG) monitoring. It uses a star topology where multiple sensors communicate with a data unique collector.

An ECG is an electrical method to investigate heart diseases. It can identify abnormalities in the heart's electrical conduction system. The data stream from the digitized analog signal could be sent to a control monitor that is available on either a nurse's personal digital assistant (PDA) or a nurse's personal computer (PC). As part of an ECG system, a personal worn device (PWD) defined by the IEEE 1073 group (i.e., a wireless electrode) generates 4 kbps of data. The latency introduced by the packetization of the samples and the transmission delay should be below 500 ms.

IV. MEDICAL DEVICES

In patient wards crave for non-invasive, easy to use, monitoring equipment that are capable of keeping track of the most important vital parameters. These parameters are ECG with 3 electrodes, heart and respiration rates, oxygen saturation, non-invasive blood pressure (NIBP) and body temperature. Frequency ranges, sensors and bit rates of the most commonly measured signals have been presented in [11]. Total data rate for one patient is between 24 kb/s and 78 kb/s depending on the amount of the ECG-electrodes [11].

ExG Amplifier Board: In our measurements we use U53 *"ExG"* amplifier board is used [12]. The ExG biopotential amplifier board uses the IMEC ExG amplifier ASIC. The ASIC control signals are connected to the micro.2420 [12] board through the bus. The board has also two additional analog inputs, temperature sensor input and an input for a piezoelectric breathing rate belt. The temperature sensor input is intended for use with a negative temperature coefficient (NTC) type sensor with a nominal resistance of 10kΩ. The breathing rate sensor needs external biasing with two resistors. The power for the ExG board and for the micro.2420 board is supplied by two alkaline batteries that are connected to the power input. The nominal input voltage is 3.0V while maximum safe input voltage is approximately 3.6V [12]. The board also provides an approximately 1.2V output for the patient bias electrodes. The ExG amplifier board is shown in Fig. 2.

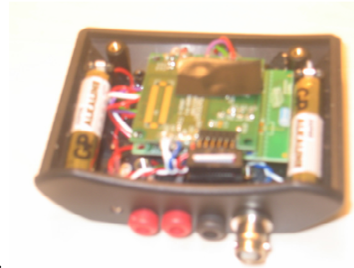

Figure 2: ExG amplifier board

Skin Resistance Board: U532 skin resistance *"Eda"* board [10] is used in the measurements. The board has two additional analog inputs, temperature sensor input and an input for a piezoelectric breathing rate belt. The temperature sensor input is intended for use with an NTC type sensor with a nominal resistance of 10 kΩ. The breathing rate sensor needs external biasing with two resistors. Skin resistance board is shown in Fig. 3.

Figure 3: Skin resistance board

V. MEASUREMENTS RESULTS

During our research, lots of experiments were carried out to discover some of the characteristics of medical wireless sensor network. We present measurement results to evaluate the performance of a low-rate WPAN. In the measured system, the MAC and PHY layers are based on IEEE 802.15.4 (low rate WPAN) with adaptation layer of 6LoWPAN [13]. In general, we find that performance results vary according to the network configuration, distance and packet length. We measure different results for different medical devices in the presence of WLAN.

NanoStack: In the measurements every node has been programmed with NanoStack [12]. NanoStack supports the IP 6LoWPAN wireless sensor networking solution for very limited low-power wireless devices. The architecture is made up of the NanoStack protocol solution for embedded wireless nodes along with drivers and tools for accessing wireless nodes from a PC.

NanoStack is executed as a single task in the FreeRTOS[2] environment. This allows reduced memory usage and provides an effective way for flow control. Protocol modules are always executed sequentially. Stack usage analysis is also simplified, as the protocol modules do not use direct function calls between each other.

[1] http://www.ieee1073.org

[2] http://www.freertos.org/

The main stack loop is responsible for module handler execution. Buffers move along a single buffer queue, which ensures that the user application is not blocked during a protocol stack operation. NanoStack can flexibly hold a large variety of protocol elements which are configured together into stacks. A protocol stack can include everything from Zigbee™ and TCP/IP [18] to traditional wired controller area network (CAN).

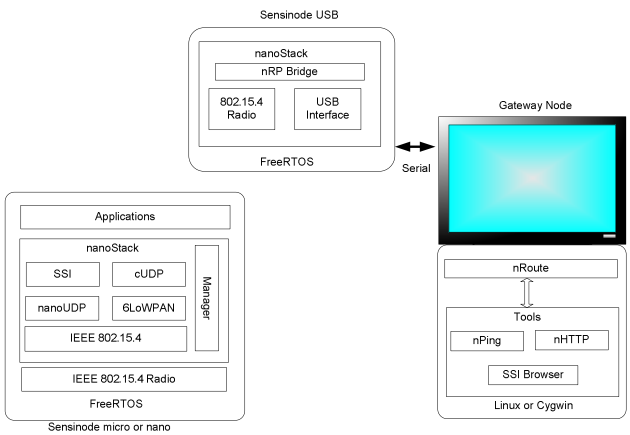

Figure 4: The internal components of the NanoStack arch.

Anything that can be accessed through a socket-style interface can be implemented in NanoStack. NanoStack include the following protocol elements: included in Nanostack are IEEE 802.15.4, network manager, NanoUDP and 6LoWPAN. The NanoStack architecture has been shown in Fig. 4.

Scenario – I

We use ExG board to simply check the performance of the packets in the network. We measure packet arrival times for different packets sizes. Different number of samples has been added in the packet to increase its size. Each sample has 2 bytes size. The averaged arrival time versus packet length measurement were carried out using 500 packets. As seen from figure 3, the effect of increasing of packet length substantially increases the packet arrival time when the sampling rate is 200Hz.

It is observed that with maximum packet size, the arrival time is under 190msec. We change the ExG board configuration so that it can read both values from ADC, i.e electrocardiography (ECG) and breathing rate (BR). It has been noticed that the packet arrival time lies between 200 ms to 300 ms when packet size varies from 62 bytes to 127 bytes. The results are shown in the Fig. 5.

To illustrate the simultaneous use of the two wireless medical devices, we repeat the previous procedure for the skin resistance (SR) and body temperature (BT) sensors with the sampling rate of 50 Hz. We plot the arrival times versus packet length for both devices, ExG and Eda broad. Fig. 6 shows the impact of packet length on arrival time for both ExG and Eda boards. It is observed that both sampling rate and packet length have impact on the packet arrival time in 6LoWPAN network. With the maximum packet length from Eda and ExG boards, with sampling rate of 50 and 200Hz, respectively, it is observed that the difference between packets arrival times for Eda is almost double of ExG device, which implies that the sampling rate and packet size both have impact on the arrival time.

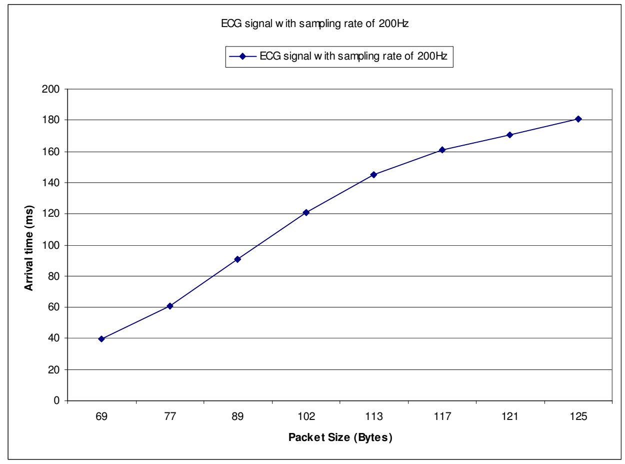

Figure 4: Effect of packet size on arrival time.

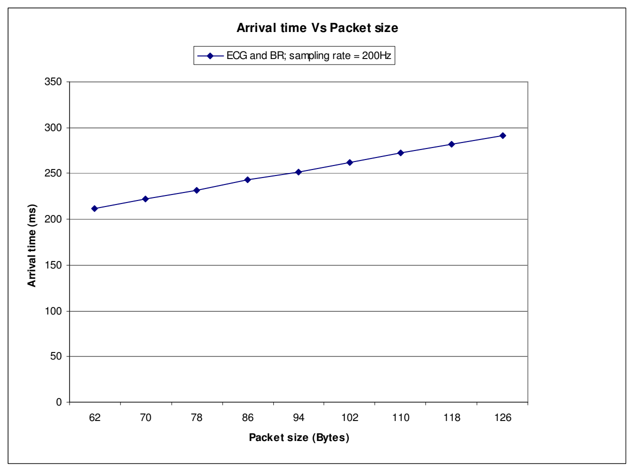

Figure 5: Effect of packet length on arrival time.

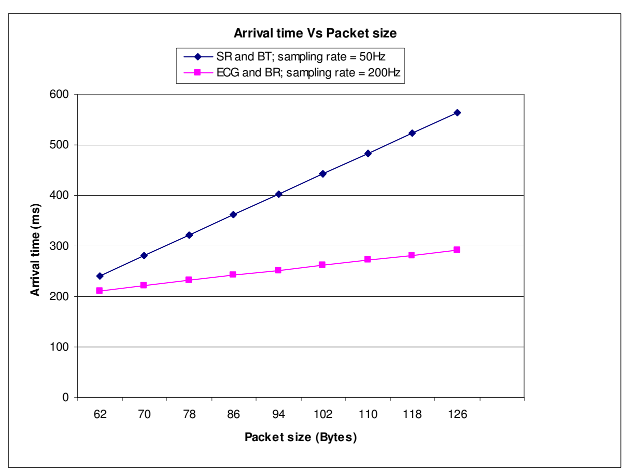

Figure 6: Effect of packet length on arrival time.

Scenario – II

To measure the round trip time for packets we use nRoute protocol (nRP) [12]. The nRoute protocol is used in a communication between a node and a PC over the serial port. The protocol allows data transfer and radio configuration. In each measurement, we sent 50 packets over the network (one packet/sec) and calculate the average round trip time for each packet. The procedure is repeated for different distances from 1 m to 5 m. Fig. 6 shows that with the increase of packet length, the average round trip time (RTT) increases; on the other hand, there is no prominent effect for packet averaged round trip time. From the result shown in Fig. 6 it is cleared that the distance variation is independent of the round trip time.

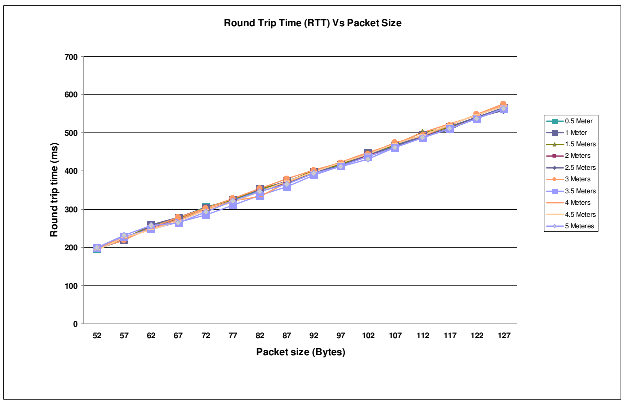

Figure 7: Effect of distance and packet size on RTT

VI. CONCLUSIONS AND FUTURE WORK

In this paper we investigate the use of the IEEE 802.15.4 standard based wireless technology applied in medical applications supporting multiple devices with different data rates. Our results show that 6LoWPAN adaptation layer with IEEE 802.15.4 technology is unable to meet the very strict application requirements, under assumptions chosen in this paper and thus, their usage in a healthcare environment may requires careful configuration design and even enhancements for existing protocols. Measurements with different assumptions (packet size and distance) will help us to quantify the tradeoff between packet loss, latency and overhead.

Since most wireless network based devices are battery operated, power limitation is one of the major challenges for system developers. Sometimes they have to guarantee that the device will work for a year or two without changing the battery [14]. This includes devices such as heart pacemakers [14]. The developers have to design better scheduling algorithms and power management schemes to deal with these power issues. Also we know that wireless channels are slower than their wired counterparts. Developing applications and devices that can deal with traffic congestion and other performance issues is a major challenge.

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