Performance Analysis of UWB Body Sensor Networks for Medical Applications

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Abstract. Wireless sensor networks can be employed in medical healthcare in many tasks such as, monitoring vital signs, controlling medical equipment, patient positioning, and in addition for non-medical service such as entertainment, psychophysiological detection of deception[1]. Ultra-Wideband (UWB) radio is a revolutionary, power-limited, and rapidly evolving technology, which employs short pulses with ultra low power for communication and ranging. Compared to narrow systems, UWB systems have several advantages, such as fading robustness, low power consumption and low cost transceiver implementation. In this paper we evaluate an UWB-based body sensor networks communication with respect to signal propagation around a human body. The performance such as, node location, AWGN (Additive white Gaussian noise), ISI (Inter-Symbol Interference) effects on the BER (bit error rate) were evaluated.

Keywords: ultra-wideband, body sensor networks, wban, IEEE 802.15.6.

1 Introduction

As the population ages and the risk of chronic disease increases, the cost of healthcare will rise. The employment of new technologies for medical healthcare could reduce the cost and improve the efficiency of treatment. By the summer of 2005, the initiative of marrying information technology to medicine seemed clear, and the media was heralding what some called "the e-health" revolution. Wireless technology capabilities are growing at a fantastic rate. There appears to be no limit to what technology might accomplish, given infinite resources [1].

In order to improve the efficiency, a strong demands for introducing wireless technology in medical healthcare. This proposal comes from various parties such as medical societies as well as communications technology (ICT) industries. This caused the emergence of body sensor networks (BSN), where a set of communicating devices are located around the human body.

BSN is a collection of low powered biosensor devices known as "motes" (or "nodes"). In principle, each node is an integration of embedded microprocessors,

[1] Popularly referred to as a lie detector.

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a radio transceiver with limited amount of data storage. The recent development of high performance microprocessor and novel sensing materials has stimulated great interest in the development of smart sensors physical, chemical or biological sensors combined with integrated circuits [2], [3]. These sensors could be located on the body as tiny intelligent patches, integrated into clothing, or implanted below the skin or muscles.

The introduction of wireless connections to exchanges sensor's data could provide a great flexibility for both, patient and medical staff. This propriety will contribute to allow more mobility for the patient and more facility for the doctors during his intervention (i.e., surgical operations). So, this will be more comfortable to the patients as well as medical personnel in comparison to conventional wired sensors.

The collected data could also be stored for further analysis. It could be utilized directly in a more effective way by the medical personnel. By using a computer or personal digital assistant (PDA), although outside hospital, the medical staff could be capable to monitor the patient regardless of his position as long as the he was connected to the network.

To harmonize with the strong demands from both medical healthcare societies and ICT industries, a standardization committee referred to as IEEE 802.15.6 was formally set up in December 2007 [4].

The objective of IEEE 802.15.6 is to define new physical (PHY) and media access control (MAC) layers for WBAN (and even BSN). This could be used to develop a low cost, ultra low power and highly reliable wireless network. These functionalities are controlled primarily by PHY and MAC layers in conjunction with the application layers.

Ultra wideband (UWB) technology has emerged as a solution for the wireless interface between medical sensors in future healthcare systems [5]. Therefore, UWB has been proposed to be used into WBAN in the IEEE 802.15.6 task group [4].

In this paper, we focus on the UWB signalization at BSN's physical layer. We'll assume that once the vital signs data are collected, they will be modulated and transmitted through multipath channel. At the receiver node a non-coherent detection with low complexity scheme has been used. By the link budget calculations, we show that although the performance is not pleasing, the transmission requirement of the low-rate BSN can be satisfied which means that the proposed scheme can be used to realize low-rate BSN with very low complexity. The rest of the paper is organized as follows. In Section II, we give an overview the wireless healthcare system. The system architecture is formally described in Section III. The system description is presented in Section IV. Simulation results are included in Section V. Finally, we conclude the paper in Section VI.

2 Related Work

The advances in wireless sensor networking have opened up new opportunities in healthcare systems [6]. The future will see the integration of the abundance of existing specialized medical technology with pervasive and ubiquitous wireless networks. They will coexist with the installed infrastructure, augmenting data collections with real-time response.

Thus far, increasing number of research groups around the world has been created. For example, the performance of an IEEE802.15.4/Zigbee MAC based WBAN operating in different patient monitoring environment has been analyzed [7].

The authors in [8] have been presented an UWB transmitter implementation for WBAN application. The pulse generator has been implemented in a digital 0.18 μm CMOS technology, showing the potential of UWB in the realization of a low-cost radio interface for the WBAN sensor nodes.

While the authors in [9] summarized the design issues for the physical layer proposals with the category of narrowband and UWB signals for IEEE 802.15.6. In [10] Keong et al. have been presented a single channel real-time wireless electrocardiograph monitoring system, which has been implemented using low data rate UWB impulse radio method, aligned with the direction of IEEE802.15.6.

In [11], the authors proposed a system design and realization of a wireless EEG (electro-encephalograms) and ECG (electrocardiograms) sensor network focusing on issues such as time synchronization, bandwidth, and power constraints constituent of WBANs. The authors have been used and evaluated via simulation a WSN composed of three transmitting nodes.

However, only few works have been seriously done around the physical layer limitation for UWB-based medical sensor networks. For example, the authors in [12] presents architecture of a healthcare wireless network that exploits the capabilities of ultra wideband technology for medical sensing and in-body tracking and imaging. However, the authors don't investigate thoroughly on sensor node transmission capability.

In our knowledge, only one study has been done on the implementation of a UWB transmission system around the body. A simple performance evaluation of coherent RAKE receiver in a BAN has been done in [13]. However, the authors don't take into account the real transmission system, which including body propagation channel and ISI effects.

In fact, the physical layer performance and how should UWB be exploited to provide a good transmission is crucial task for the design of global transmission system. Hence, it will be useful to see the physical layer performance. Based on these results, we can exploit the UWB characteristics to design more optimum transmission system.

3 Proposed Wireless Biomedical Sensor Networks Architecture

The main goal of this paper is to investigate on UWB transmission. We investigate on BSN architecture for smart healthcare that possesses the following proprieties:

– Real-time and long-term remote monitoring;
– Tiny sensor with very low complexity;
– Can be integrated with existing medical practices and technology;

For the first query, the large bandwidth of UWB signal is the low electromagnetic radiation. The Federal Communications Commission (FCC) has authorized UWB communications between 3.1 GHz and 10.6 GHz. Although the regulations on UWB radiation define a power spectral density (PSD) limit of -41dBm/MHz, the low radiation has little influence on the environment and safe for human body, even in the short distance [14].

Among the most important advantages of UWB technology are the low system complexity and the low cost. UWB systems can be made nearly "all-digital", with minimal radio frequency (RF) or micro wave electronics. The low component count leads to reduced cost, and smaller chip sizes invariably lead to low-cost systems.

The simplest UWB-based node could be assumed to be a pulse generator, a timing circuit, and an antenna [15]. Other important advantage of UWB resides in the possibility to significantly reduce the power consumption of the radio front-end by switching off the transmitter during the relatively long silence periods between UWB pulses. Therefore, low UWB transmission allows to the node a longer battery life.

It has been shown that the effect of multiuser interference (MUI) on system performance is generally less detrimental in UWB networks than in narrow band networks [16]. Also, the UWB transmission offers good penetrating properties that could be applied to medical applications. In addition, by using UWB signalization, the nodes could be able to allow transmission even under very bad channel conditions.

One patient is equipped with several sensors monitoring different parameters. A Body Sensor Network is made up of one or more body area networks and a base station. When the information has been gathered in the sensor network it is forwarded to this base station. The information is then received at a relay station and passed on through a backbone network. In the end, the information can be viewed at terminals or monitoring stations that are connected to the network. This system has the potential of making remote monitoring and immediate diagnostics a reality [2], [17], [18].

Sensors are heterogeneous, and all integrate into the human body. The number and the type of biosensors vary from one patient to another depending on the state of the patient. The most common types of biosensors are EEG "Electroencephalography" to measure the electrical activity produced by the brain, ECG "Electrocardiogram" to record the electrical activity of the heart over time, EMG "Electromyography" to evaluate physiologic properties of muscles, Blood pressure, heart rate, glucose monitor, SpO2 "Oxymeter" to measure of oxygen saturation in blood, and to measure temperature of the body [19], [20].

As shown in the Table 1, according to the characteristics of physiological measurements or type of application services which can be real-time or non real-time with high or low rate.

Table 1. Service Classification of Physiological Measurements

Type of Service	Data rate	Latency	Class of Service
ECG	High	Low	Real-time high rate
EEG, EOG, EMG	Low	Low	Real-time low rate
Blood pressure, body temperature, heart rate, glucose monitor	Low	High	Non real-time low rate
Medical image, X-ray, MRI	High	High	Non real-time high rate

4 System Description

In order to evaluate the characteristics of UWB communication for use in a BSN, we have planned scenario where a patient has been equipped with four sensor nodes. These nodes are mounted around his body (Fig. 1). Each node is implemented with different medical sensor ECG, SpO2, body temperature, and blood pressure. The task and the position of each sensor are summarized in Table 2.

Table 2. Sensor information and location

	Sensor	Distance (m)	Position
Node 1	ECG	0.25	Front
Node 2	Blood Pressure	0.35	Side
Node 3	SpO2	0.42	Side
Node 4	Temperature	0.50	Back

The collected data will be transmitted to a base station which has been mounted on the front of the patient. This base station can either store, or transfer the data to the remote hospital server and the related services. This could be accomplished by using a mobile phone, a PDA or Internet. The global schema of patient's monitoring is presented shown in Figure 1.

4.1 Body Channel Model

A basic step required for a communication system simulation is to get precise models of all the elements involved in the system. This includes, of course, the radio channel, as the physical mean of transport for the wireless signal.

Several WBAN channel model has been measured and analyzed, ones of them has been described in [21]. The work done by Fort and al. [21] takes into account both, the propagation of the signal around the body, and the reflections at the nearest scatters in the room. Because this model has been recommended as an improvement of previous BAN models, and has been recognized by the committee for the emerging 802.15.6 standard [22]. So, this channel has been used to evaluate the performance of UWB systems around body. The channel impulse response has been represented by

$$h(t) = X \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l} \delta \left(t - T_l - \tau_{k,l} \right) \tag{1}$$

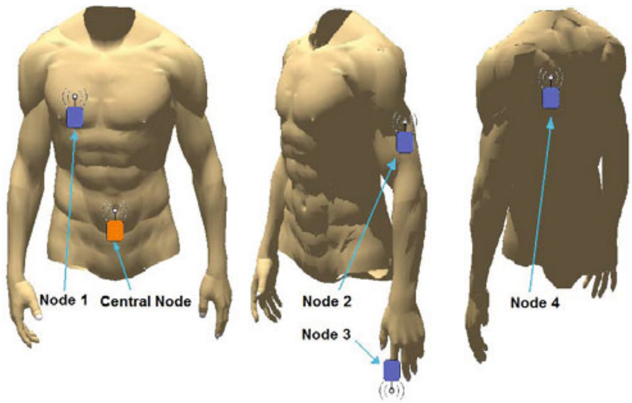

Fig. 1. The global schema of patient's monitoring. The illustration of the nodes and the central node (receiver) locations on the body.

- $\alpha_{k,l}$ are the multipath gain coefficients;
- T_l is the delay of the l^{th} cluster;
- $\tau_{k,l}$ is the delay of the k^{th} multipath component relative to the l^{th} cluster arrival time T_l;
- X represents the log-normal shadowing.

In calculating the path loss, the distance between the transmitter and receiver has been measured along the surface of the body rather than along a strict straight line as the waves travel along the body rather than passing through it. The PL in dB as function of the distance is given by:

$$PL(d) = PL_0 + 10.n \log_{10} \frac{d}{d_0} \tag{2}$$

where

- $PL(d)$ represents the received power at a distance d, computed relative to a reference distance d_0.
- PL_0 is the interception point and is usually calculated based on the mid-band frequency.
- n is path loss exponent.

The typical value of n varies between 5 and 6. This means that the pulse propagation around the body is very demanding due to the high attenuation of the signal. Due to space limit, the channel parameters have not presented in this paper, however they can be found in a [21].

4.2 Transmitter and Receiver Architectures

Channels encountered by UWB communication systems are highly dispersive in nature and so the channel estimation is a very challenging task. Designing a

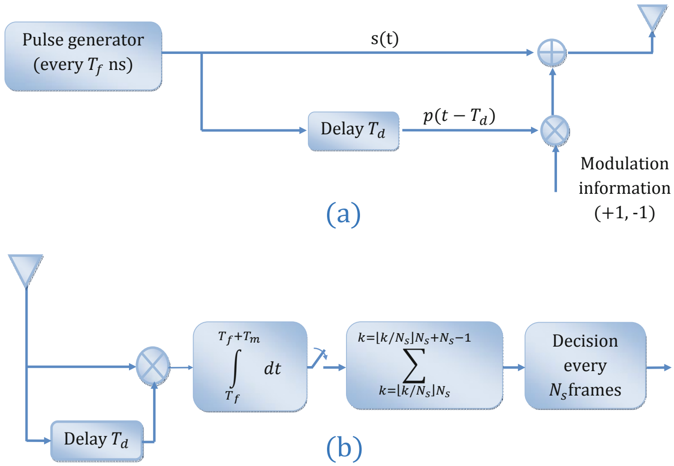

Fig. 2. Illustration of the non-coherent TR system, transmitter (a), receiver (b)

receiver that generates reference locally at the receiver, estimates the channel, and captures enough energy for data detection is a difficult and costly process. But instead of locally generating the reference signal, it can be transmitted along with the information data. Such a system is known as Transmitted Reference (TR) system. TR is a correlation receiver system; thus a TR system does not require channel estimation and has weak dependence on distortion.

Compared to coherent receiver (i.e. RAKE), the TR receiver is very attractive. The block diagram of a TR transmitter and receiver are presented in Figure 2.

As shown in the Figure 2 (a); the transmitter of a TR system comprises of a pulse generator, a delay line, and an antenna unit. Figure 2 (b) shows the simple receiver structure. The receiver comprises of a delay line and a correlator to demodulate the signal, and an addition unit to add over N_s pluses so that enough energy is captured to estimate the information bit.

Assuming a single-user UWB system with antipodal modulation (binary pulse amplitude modulation), a typical transmitted reference frame is given by For TR the transmitted signal is modeled as:

$$s_{tr}(t) = \sum_k p(t - kT_f) + b \lfloor k/N_s \rfloor p(t - kT_f - T_d) \qquad (3)$$

where

- k is the frame index;
- T_f is the frame time;
- T_d is the delay between reference and modulated pulse;

– N_s is the number of successive times the frame is repeated to achieve adequate bit energy required for detection;
– b_l are the channel symbols with values ± 1, generated randomly having equal probability of occurrence.

For a single user case when operating in a multi path channel with multi path delay spread time T_m,to avoid inter symbol interference (ISI) problem a TR frame is designed such that $T_f \geq 2T_d \geq 2T_m$.

5 Results and Discussion

To evaluate the performance of the UWB-TR receiver for use in medical application, a bit error rate (BER) calculation has been calculated. Since the transmitted data bit was known in advance, using the UWB receiver, the information bit was detected. The detected and the transmitted bits were compared.

5.1 Performance of the TR Receiver Node in the Absence of ISI

Figure 3 shows the variation BER by increasing the energy bit per noise (E_b/N_0). The black, green, red, and blue curves correspond to the BER of the Node 1 to 4, respectively. When only one node was transmitting, at the receive node, the signal was effected by multi path channel and corrupted by the AWGN.

The performance of the four nodes when ISI is avoided are shown in Figure 3. As was expected, the performance for the Node 4 is about 6 dB worse than the Node 1. The corresponding E_b/N_0 requirement is about 24 dB for the Node 4 if the target BER performance is set as 10^{-2}. This is due mainly to the NLOS configuration of the Node 4.

5.2 Performance of the TR Receiver Node in the Presence of ISI

Figure 4 shows the performance of a the receiver for all nodes when $T_f \leq 2(T_d + T_p)$ so that ISI occurs. In this case each pulse will overlap and interfere with other pulses. As is known, a main drawback of a TR system is the noisy template used for detection. In the presence of ISI, the template that was already noisy suffers from the overlapping of the earlier transmitted pulses via multipath, thereby limiting the performance of the system.

As compared to the others nodes, the impact of the ISI for the Node 1 is not that severe. This is because the bit information was concentrated in the first multipath component. So, the ISI does not pose any problem in cases where the pulse was placed in one of the first clusters. However, the received signal detection for the Node 4 is problematic when the effect of ISI was considered. For example, when the SNR = 15 dB, the BER is 0.05 for node 1, while this value increase to 0.35 for Node 4.

To keep a good performance against ISI noise, and in order to be able to achieve a satisfactory performance for Node 4, it is necessary to use multiple pulses per bit. It has been seen that the increase the number of pulses can reduce the BER without increasing transmitter power.

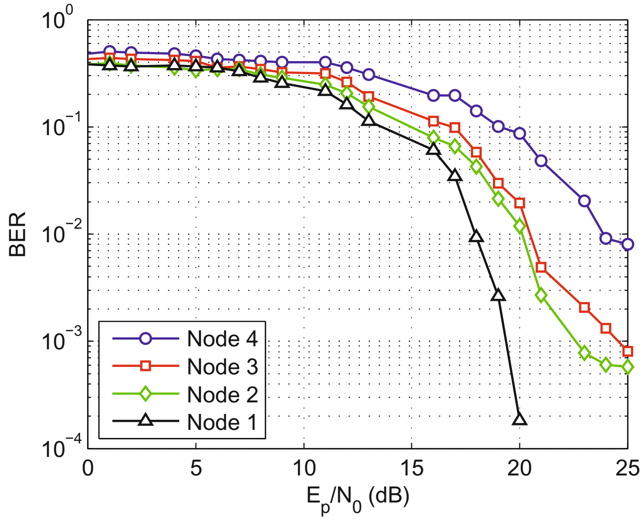

Fig. 3. Performance of the TR receiver node in absence of ISI vs. E_p/N_0

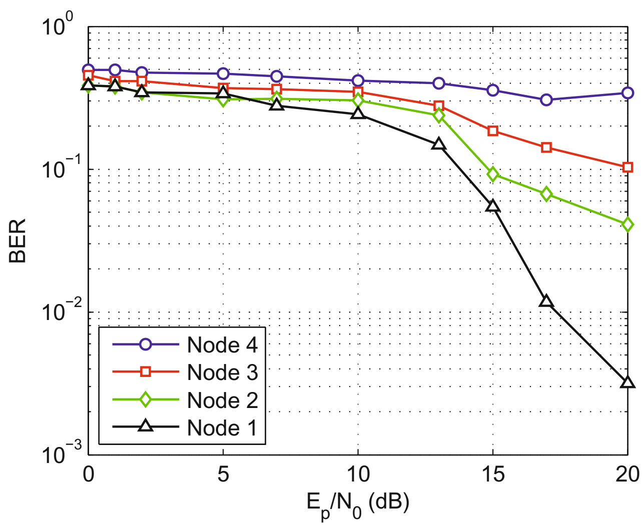

Fig. 4. Performance of TR receiver in presence of ISI

6 Conclusion

The UWB technology has the potential to enable low-power consumption, high data rate communications within short distance and other characteristics that make it an ideal candidate for wireless body area networks. The objective of this paper was to analyze the performance of using UWB signalization for medical application. We evaluate the feasibility of BSN architecture based on sub-optimal communication. Based on non-coherent Transmitted Reference receiver, and for peer-to-peer communication, BER has been evaluated for two scenarios. Single user case has been addressed in this paper. Hence, for the future works, the performance of the receivers in multiuser scenario, when all nodes are transmitting in the same time, should be studied.

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