BER Performance of IR-UWB Signal Based WBANs with BPPM

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Abstract—The basic requirement of Wireless Body Area Network (WBAN) is to send physiological signals acquired from implantable or wearable sensor nodes to a remote location. Low-power consumption is required for WBANs since most medical sensor nodes are battery operated. Impulse Radio-Ultra Wideband (IR-UWB) is a suitable wireless technology for the use in WBAN applications due to its inherent properties such as low power consumption, high data rate capability, low complexity hardware implementation, and small form factor. In this paper, the sensor nodes use two mechanisms to ensure that the transmit power is managed effectively. Firstly, the maximum allowable Full Bandwidth (FBW) transmit power is evaluated. Secondly, the number of Pulse Per Bit (PPB) can be dynamically changed according to the Bit Error Rate (BER) required value by using Binary Pulse Position Modulation (BPPM) scheme. These mechanisms enable the sensor nodes to operate at optimum power consumption and dynamic BER while maintaining a reliable data communication link.

Keywords - BER, BPPM, IR-UWB, WBAN.

I. INTRODUCTION

WBAN is a networking concept that has evolved with the idea of monitoring vital signals from low power and miniaturized in-body or on-body sensors. In a WBAN, data collected from the sensor nodes are transferred to a remote node via a wireless medium, where the data is forwarded to a higher layer application to be interpreted [1].

The human body is a medium that poses numerous wireless transmission challenges. Unlike air, the body is composed of varied components that are not predictable and will change as the patient ages, gains or loses weight, or even changes in posture. Recent works suggested that for wireless communication inside the human body, the tissue medium acts as a channel through which the information is sent as electromagnetic (EM) radio frequency (RF). So in WBAN, information is transmitted as electromagnetic (EM) radio frequency (RF) waves [2].

Medical sensors involved in WBAN communication are battery operated. Hence, they should consume low power. This paper presents IR-UWB as a suitable wireless technology to achieve high data rates while keeping power consumption and form factors small. Thus, the unique capabilities and potential applications of IR-UWB system have already drawn a huge interest over the world.

This paper studies the effects of varying the number of PPB in the performance of IR-UWB system. Such effects are evaluated in terms of the BER for a BPPM scheme, which is the most popular form of modulation used for IR-UWB signal. The dynamic PPB scheme ensures that sensor nodes always transmit data with acceptable BER value.

The paper is organized as follows: Section II studies an IR-UWB communication system. Section III discusses a simple BPPM technique which is used as the modulation scheme for the IR-UWB transmission. Section IV describes the implemented network in the simulation. Section V describes the transmission power optimization and BER analysis for multiple PPB and shows the results. Finally, section VI concludes the paper.

II. OVERVIEW of IR-UWB SYSTEM

IR-UWB is a novel wireless short-range technology. According to Federal Communications Commission (FCC), IR-UWB communications operate in 0–960 MHz and the 3.1–10.6 GHz bands. IR-UWB signals have a fractional bandwidth larger than 0.2 or at least 500 MHz. Since IR-UWB systems use ultra-wide bandwidth, the transmission rate of IR-UWB systems can go up to 20 Mbps. In the same time, the emission power of IR-UWB must be kept below ~41.25 dBm/MHz. As a result, IR-UWB devices can enjoy a much longer operating time with a battery. On the other hand, low power transmission of signal limits the communication range (usually 0.1–2 m) [3].

Out of the existing wireless physical layer technologies, Wireless Local Area Network (WLAN) standard is rarely used in WBAN applications because of its large power consumption. Zigbee, Bluetooth, and WLAN operate in the 2.4 GHz unlicensed Industrial, Scientific and Medical (ISM) band; hence create interference issues to each other. Medical Implant Communication Services (MICS) band can only be used for low data rate WBAN applications due to its limited bandwidth capabilities.
It can be concluded that the IR-UWB presents some unique benefits over other wireless technologies in the design of WBAN sensor nodes including the low power requirements, high data rate capability, small form factor, and uncomplicated circuit design. In terms of interference rejection, IR-UWB spectrum provides a large bandwidth; hence, a sub-band of IR-UWB can be selected for a particular application such that the interference from other bands is minimized [4].

IR-UWB transmitter uses simple short discrete pulses in order to transmit data. The IR-UWB pulse generation technique is shown in figure 1. IR-UWB pulses are generated by passing a square wave signal and its time-delayed version through an XOR gate. Buffer with 3 V supply voltage is used to introduce delay level to the signal. The data bit generated by the microcontroller is modulated by the IR-UWB pulse stream using a BPPM before entering the Low Pass Filter (LPF). Employing LPF in order to filter out the 0–1 GHz section of the IR-UWB pulse spectrum. This portion of the spectrum is the highest power compared to the rest of the spectrum. Filtered spectrum is then shifted using a mixer and a Voltage Controlled Oscillator (VCO) operating at 4 GHz. A band pass filter is used at the output of the mixer in order to contain the IR-UWB signals within the 3.5–4.5 GHz band. This technique offers the highest power efficiency for an IR-UWB transmitter. An IR-UWB signal with a bandwidth of 1 GHz centered at 4 GHz, pulse width of 2 ns and Pulse Repetitive Frequency (PRF) of 100 MHz is shown in figure 2. PRF affects the number of spectral lines and their amplitudes that lie within a certain bandwidth. A higher PRF system tends to create a lesser number of spectral lines that are higher in amplitude.

![Fig. 1. IR-UWB pulse generation technique](image1)

![Fig. 2. IR-UWB pulse stream](image2)

### III. IR-UWB PULSE POSITION MODULATION SCHEME

IR-UWB systems transmit short pulses to transmit data. Pulsed nature of IR-UWB transmitters enables the use of simplest modulation schemes such as BPPM. BPPM scheme enables less complex hardware systems implementing IR-UWB communication systems and reduces the power consumption significantly. Also, it provides the best performance in terms of modulation efficiency and spectral performance. It is therefore more suitable for battery-operated WBAN applications.

BPPM scheme uses the position of a pulse in two time slots to represent the value of an information bit, i.e. presence of a pulse in the first time slot indicates a ‘1’ and that in the second time slot indicates a ‘0’. In other words, a binary communication system can be established with a forward or backward shift of the pulse in time. When demodulating a BPPM signal, an IR-UWB receiver compares the energy of the received signal in the two-time slots. If the energy in the first time slot is larger than that in the second time slot, a ‘1’ is received; otherwise, a ‘0’ is received. As shown in figure 3. Thus, the key parameter in pulse position modulation is the time delay of each pulse [5]. Analytically, the signal can be represented as:

\[
S_i(t) = p(t - \tau_i)...
\]

(1)

Where \(p(t)\) is waveform at unmodulated nominal position, \(\tau_i\) is time shift for \(i\)th modulation state [6].
SIMULATION MODEL A WBAN used in the simulation is arranged such that the coordinator is placed at the center while the patients with the sensor nodes are placed around the coordinator preserving the Line-Of-Sight (LOS).

In this network, sensor nodes directly communicate with the coordinator using IR-UWB communication. Coordinator node acts as the central controlling device of the proposed WBAN system. It is responsible for organizing and controlling the communication with multiple sensor nodes while maintaining an acceptable level of BER.

All the nodes are contained in a 10 m * 10 m (average hospital room area) MATLAB simulation environment. Each sensor node is placed at an averaged distance of 2 m from the coordinator node. Considering a realistic hospital scenario, a maximum of five patients are assumed to enter the room during the simulation time. It should be noted that the BER increases significantly as the number of sensor nodes increases. In order to maintain an acceptable BER value, the maximum number of sensor nodes has to be limited to four for a single patient. Figure 4 depicts the simulated network topology.

IV. TRANSMISSION POWER OPTIMIZATION

The transmit power consumption of sensor nodes used in the simulation is determined by two limiting factors. Firstly, the maximum allowable FBW transmit power, which depends on the duty cycle of the pulse transmission, determines the maximum limit of the energy per UWB pulse. Secondly, the number of PPB value determines the number of UWB pulses sent within the bit transmission slot, which determines the energy consumption within the transmission slot. However, these two factors are discussed in detail in this section. Figure 5 depicts the use of 2 and 3 PPB schemes for sending data bits.
A. Transmission Power Limitations

According to the FCC regulations, an IR-UWB signal is a power limited by measured Full Bandwidth (FBW) peak power of 0 dBm (1 mW) and measured average power density of -41.25 dBm/MHz (75 nW/MHz) [7]. The measurement of the average and peak power can be calculated easily using a spectrum analyzer in practice. For the average power measurement, the resolution bandwidth is 1 MHz with an integration time of 1 ms. A resolution bandwidth of between 1 and 50 MHz can be used for the measurement of the peak power. The peak limit is dependent on the resolution bandwidth and varies according to [8]:

$$\text{Peak power} = 20 \log \left( \frac{\text{resolution bandwidth}}{50} \right) \text{ dBm}$$  \hspace{1cm} (2)

These measured power limitations can be converted to maximum allowable FBW transmit power limits using (3) [9]:

$$P_{\text{peak}} \leq 7.5 \times 10^{-8} \left( \frac{B_p}{R} \right)^2 \times \frac{1}{5} \text{ W}$$ \hspace{1cm} (3)

Where $P_{\text{peak}}$ is the actual maximum transmit power of the IR-UWB signal, $B_p = 1/\tau$, $\tau$ is the pulse width, $R$ is the PRF and $\delta$ is the duty cycle of pulse transmission slot based on a measurement duration of 1 ms. For the simulated system, a pulsewidth of 2 ns is used. Hence $B_p$ in (3) is equal to 0.5 GHz for the IR-UWB signals used in the simulations. Figure 6 shows the variation of maximum allowable FBW transmit power values with the duty cycle ($\delta$) for a sensor node that generates IR-UWB signals with a PRF of 100 MHz and a pulsewidth of 2 ns. According to figure 6, the duty cycle of the IR-UWB signal should be kept within 10% in order to transmit at a maximum allowable power of 0.0186 mW (-17.3 dBm), which complies with the FCC limitations.

B. BER Analysis of Multiple PPB Scheme

BER stands for bit error rate. It is the number of bit errors divided by the total number of bits transmitted during a studied time interval. It is usually used as a performance measurement in digital communications. The bit errors in a WBAN environment mainly occur due to multipath interference and random fading of the IR-UWB signal that originates from reflection from various surfaces and different absorption characteristics of objects, such as various body surfaces and indoor equipment [10].
Since the power required to transmit a databit is equal to the summation of the power of a number of pulses sent to represent that data bit, a considerable power saving can be achieved if the allocation of the number of PPB can be dynamically changed according to the BER required value at the receiver end.

Assume that two identical sets of data are transmitted using the same transmit power and same separation distance in a realistic WBAN environment that is susceptible to multipath interference and random fading with one data set transmitted using a higher PPB value and the other with a lower PPB value. The transmit signal with higher PPB results in a lower BER than a lower PPB transmission for the same separation distance in a realistic environment with fading and multipath interference.

Probability of error for single pulse detection of the receiver with BPPM modulations scheme can be derived from [11]:

\[ P_e = Q \left( \frac{\left( \frac{E_p}{N_0} \right)^{1/2}}{2} \right) \]  \hspace{1cm} (4)

Where \( P_e \) is the probability of error, \( B \) is the signal bandwidth of 1 GHz, \( T_s \) is the integration period which is equal to the pulse width of 2 ns for the simulation, \( E_p \) is the received signal energy during the 2 ns integration period and \( Q \) represents the Q function.

When multiple PPB is sent, it is assumed that a bit is erroneous when more than half the pulses sent per that bit are erroneous. If \( N \) pulses are sent per bit, probability that a bit being erroneous can be obtained by:

\[ P_{e\text{bit}} = 1 - \sum_{i=1}^{[N/2]} \binom{N}{i} p^i (1 - p)^{N-i} \]  \hspace{1cm} (5)

Where \( p = P_e \), \( \binom{N}{i} = \frac{N!}{i!(N-i)!} \) and \( [N/2] \) is the inferior integer part of \( N/2 \). Modulation curves showing BER for different number of PPB are obtained based on (5) and presented in figure 7. It should be noted that the BER is plotted against pulse \( E_p/N_0 \) in this figure. Bit energy can be obtained by the summation of pulse energies that represent the bit. The results in figure 7 show that for the same \( E_p/N_0 \), sending more number of PPB results in lower BER.

From the above result, we can conclude that the number of PPB can be dynamically changed in order to control the BER value. For best system performance, the optimum BER value is \( 10^{-4} \) for all sensor nodes, because a good throughput can be obtained with this value.

VI. CONCLUSION

In this paper, the performance of IR-UWB system based WBAN was studied. A simple BPPM technique is used as the modulation scheme for the IR-UWB transmission. The FBW transmit power and PPB mechanisms are analyzed. These mechanisms lead to dynamic BER and power control at the sensor nodes, which helps to improve the reliability of communication and power efficiency of sensor nodes under dynamic channel conditions. It can be concluded that the duty cycle of the IR-UWB signal should be kept within 10% in order to transmit at a maximum allowable power of 0.0186 mW. Furthermore, when sending more number of PPB results in lower BER.
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