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Ultra Wideband Transceiver Design for Compact and Implantable Medical Devices

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***Abstract*— Wireless health monitoring systems are becoming increasingly important with the development of new medical systems that require increased mobility and faster data rates. Ultra wideband (UWB) communication is becoming one of the most prevailing technologies that can accommodate some of the most critical requirements of a medical communication system. Since UWB has limited range capabilities due to the low signal power constrain by the spectral mask, performance could be impaired dramatically due to the interference that may exist in a medical environment such as an operating room. In this paper, we investigate a UWB communication system with simple Hadamard coding at the transmitter and energy detection at the receiver. The resulting system can be extremely compact and energy-efficient, making it suitable for implantable devices. We show simulation and analysis results with the proposed system in this paper.**

***Index Terms*— Wireless health, Ultra wideband radio, Noncoherent detection and Hadamard coding.**

I. Introduction

There are several medical applications that can be implemented using the new wireless technologies. Many medical conditions can benefit from the optimization of safe wireless communication systems. An example is monitoring the condition of a patient remotely, which may entail large amounts of data that may need to be transmitted in real time while maintaining information accuracy and precision. Other medical devices such as implantable devices and other applications such as chronic disease management, wellness and preventative medicine and telemedicine may benefit from the concepts presented in this paper.

Fig. 1, shows a relative comparison of several wireless standards that may fit to be used for medical applications, the figure shows the data rate capability range of each standard versus the possible relative operation range. The operation range becomes an obstacle for medical device communication, since it can impair the mobility of the device and may result in a reduction in the possible data rate.

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There are several wireless technologies currently being used for wireless medical applications, those may include but not limited to, Bluetooth, Zigbee, and WiFi. Those technologies suffer from limited bandwidth, but can potentially provide various transmission ranges. UWB offers the luxury of high data rate transmission at the expense of a somewhat constrained range. A more detailed comparison between the various technologies can be found in [5]. Table I, shows a list of some common wireless technologies that can be used for wireless medical applications.

Table I: Potential Wireless Technologies for medical applications

Wireless Technology	Frequency Band	Data Rate	Transmitted Power
WLAN (802.11b/g)	2.4 GHz	> 11 Mbps	250 mW
IEEE 802.15.1 (Bluetooth)	2.4 GHz	1 Mbps	20 dBm
IEEE 802.15.4 (Zigbee)	2.4 GHz	250 kbps	0 dBm
UWB	3.1 – 10.6 GHz	27.24 Mbps	-41 dBm

Some of the medical applications that may benefit from wireless radio technologies include: wireless ECG/EKG and respiratory information Systems, for patients with heart stroke risks; Accelerometer, Gyroscope and Electromyogram (EMG) sensor systems for monitoring patients with strokes; wearable BAN systems that collect vital sign and bio signals and transmission over a high speed phone link such as 4G LTE; wireless physiological sensors for implantable applications, for monitoring heart and prosthetic limb functions over a long period of time; some other applications may include monitoring blood pressure and weight, automatic emergency communications, and monitoring locations of equipment, doctors and patient via wireless links.

UWB operates over a safe wireless band and it offers a number of major benefits that makes it most desirable over other technologies for the very low power consumption required for data transmission which helps in extending battery life of the transmitting device (wearable or implantable), also it has low interference effect on the other wireless systems in use in medical centers, and it offers high data rate to achieve the appropriate level of resolution required for physiological signals.

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UWB technology has several major advantages over competing wireless standards. First, since the transmitted signal power spectral density (PSD) is below the noise floor, transmissions can be unlicensed. Second, since the available bandwidth for UWB is the range 3.1 GHz – 10.6 GHz, very high data rates or very low error control code rates are achievable. This gives remarkable flexibility to trade-off data rate and data reliability. Spread spectrum technology can also be employed to combat multiuser and multipath interference. Lastly, since UWB is a carrier-less form of wireless transmission, the transceivers can be very compact. The need for bulky oscillators, mixers and filters can be eliminated. All of these factors make UWB a very attractive choice for medical applications. Our objective is to increase the relative operation range of UWB system, at a reasonable reduction in the possible data rate, by employing a channel coding method; for simplicity; we're going to use orthogonal channel coding.

The remainder of this paper is organized as follows: Section II shows the system diagram and explains how the UWB systems may function. Section III shows the simulation setup and the results obtained from simulating the system with the proposed coding technique. Sections IV and V conclude the paper with our comments, observations and potential extensions and applications.

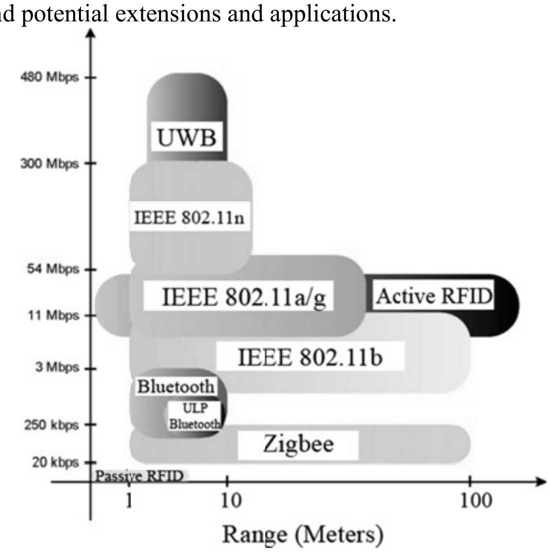

Fig 1: A Data rate vs. Range Comparison of Wireless Standards.

II. System Model

A. Block Diagram

The block diagrams representing the UWB transmitter and receiver are shown in Fig. 2 and Fig. 3, respectively.

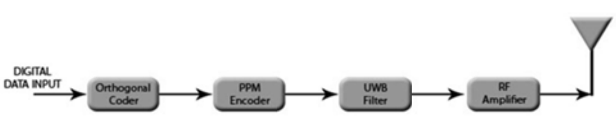

Fig 2: UWB Transmitter Block Diagram

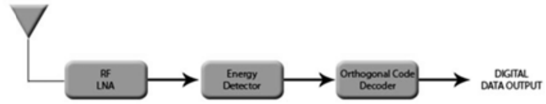

Fig 3: UWB Receiver Block Diagram

UWB transmission is done by generating narrow rectangular pulse trains that is filtered to meet the spectrum mask requirements of the FCC. In general, ultra wideband communication can broadly be classified into impulse UWB (I-UWB) and multiband orthogonal frequency division multiplexing (MB-OFDM). I-UWB signals require less power consumption at the transmitter for them to be generated, and they are easier to be generated.

I-UWB uses extremely short pulses with duration on the order of nanoseconds to transmit information, having low duty cycle pulses which cause the required transmitter power to be small and it doesn't require carrier modulation and no RF power amplifiers, also it is robust to multipath fading. On the other hand MB-OFDM is based on OFDM and it divides the available bandwidth of UWB into smaller non-overlapping sub-bands each has more than 500MHz of bandwidth (per FCC requirements for UWB systems) as OFDM symbols are transmitted one of the small sub-bands during a certain time slot. The time slots are determined by a Time-Frequency-Code (TFC) which acts like a distinguishing factor between multiple users and is required for frequency diversity.

I-UWB is going to be used in this paper, and the required pulse shape is achieved through pulse shaping, such that no carrier will be required, which result in Gaussian pulse shapes. A UWB binary PPM encoder encodes each message bit by transmitting a single pulse in one of two possible time shifts, for N times per bit, this method allows more energy to be assigned per bit to accommodate various transmission rates and ranges for the same system. At the transmitter, data is encoded by an orthogonal coder and is then passed thru the system for UWB waveform generation. At the receiver, the operation is reversed and data is decoded by the orthogonal code decoder where data is reconstructed.

A non-coherent receiver based on energy collection achieves low complexity, low cost and low power consumption device that is suitable for the medical applications. The receiver is assumed to have acquired timing with the transmitted signal [3]. Energy detection for UWB systems could suffer from multipath problems due to dispersive channels, such problems can be mitigated by the solution suggested in [12].

The radio interface is a major challenge, since its power consumption must be reduced below 100μW (energy scavenging limit) [8]. After the signal is received at the antenna and passed thru a band-pass filter, the receiver squares the received binary PPM signal for at both time slots at the pulse locations in order to measure the energy content is each time slot, and based on the energy content at the

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pulse location for a number of pulses representing the binary content, the receiver declares receiving a binary 0 or a binary 1.

B. Orthogonal Coding

A data set can be transformed, using orthogonal codewords, described by the rows of a matrix as per the simple example shown, in Table II, below:

Table II: Example of Orthogonal Coding

Data Set	Orthogonal Codeword Set
0 0 1 1 1 0 1 1	$H = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$

Orthogonality of codewords is determined by the following simple equation:

$$z_{i,j} = \frac{x - y}{x + y}$$

where:
x = number of digit agreements
y = number of digit disagreement
i,j are the two codewords being checked for orthogonality.

Thus

$$z_{i,j} = \begin{cases} 1 & for\ i = j \\ 0 & otherwise \end{cases}$$

Like M-ary signaling with orthogonal modulation formats such as frequency shift keying (FSK), the error probability can be improved by using codes with lower code rates.

The codeword error probability has an upper bound by the following formula

$$P_E = (M-1)Q\left(\sqrt{\frac{Es}{No}}\right)$$

where m equal to 2^k, where k is the number of data bits per codeword.

Bit error probability is linked to the codeword error probability by the following formula.

$$\frac{P_B(M)}{P_E(M)} = \frac{M/2}{(M-1)}$$

Thus,

$$P_B(M) \le \frac{M}{2} Q\left(\sqrt{\frac{Eb}{No}}\right)$$

C. Expected Results

The bit error rate graph, shown in Fig. 4, compares error rate for an un-coded UWB signal and a 3/8 coded UWB signal.

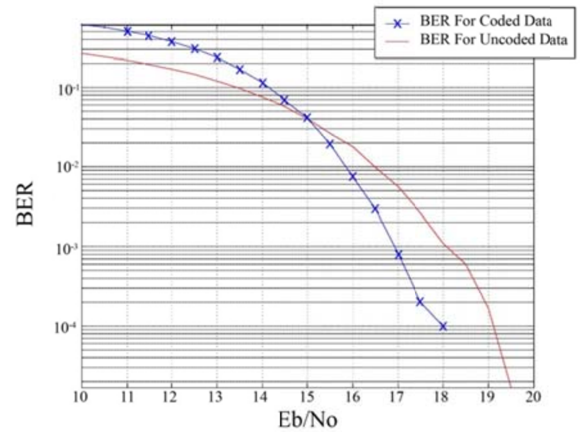

Fig 4: UWB Bit Error Rate Graph for coded and un-coded data

This graph shows that the un-coded UWB signals tend to have lower bit error rate for Eb/No < 15 dB, however, for Eb/No > 15 dB, the bit error rate of the coded data is lower than that of the un-coded data.

Fig. 5 shows the time domain and frequency domain representation for the UWB signals used in simulation.

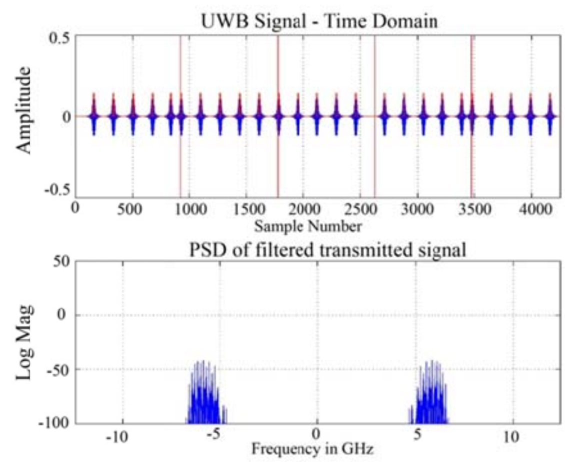

Fig 5: UWB Time Domain Waveform and PSD

Fig. 6 shows the time domain and frequency domain representation for the UWB signals when Eb/No = 20dB.

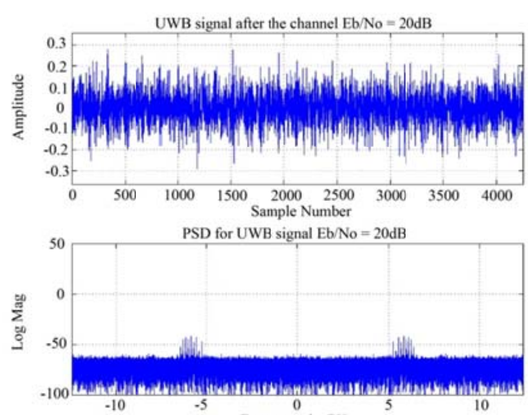

Fig 6: UWB Time Domain Waveform and PSD at Eb/No = 20dB

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Figures above should give the reader a good idea about how UWB signals are affected by noise, and how the effect of noise can be mitigated by using orthogonal codes.

III. Matlab Simulation Results

Based on the results obtained above, another simulation was done. This time the UWB system is used to transmit an x-ray image using coded and un-coded data, with Eb/No = 18dB. The results of the simulation are shown below.

Fig. 7 shows the original X-ray image at the transmitter. Fig. 8 shows the received X-ray image when transmitted without coding; while Fig. 9 shows the received X-ray image when orthogonal coding is used. As can be seen the image sent without coding suffers some imperfections (lost pixels) that can rapidly increase as SNR decreases, while the one where coding was used shows no imperfections.

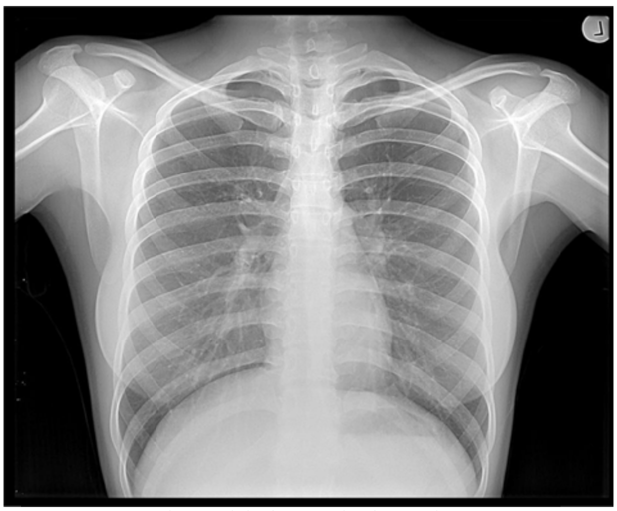

Fig 7: Original Transmitted X-ray image.

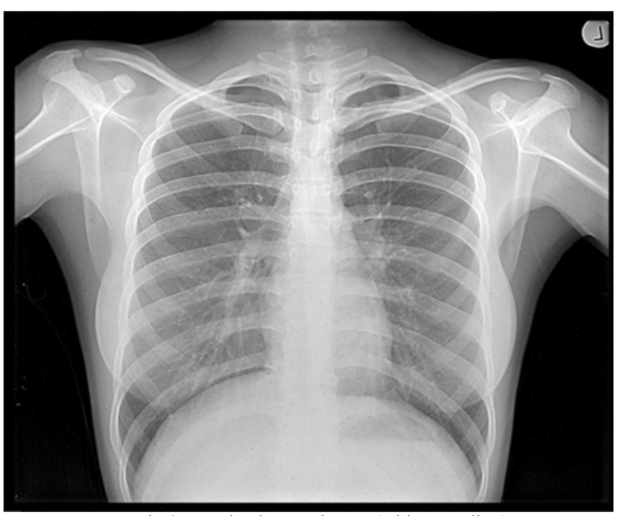

Fig 8: Received X-ray image (with no coding)

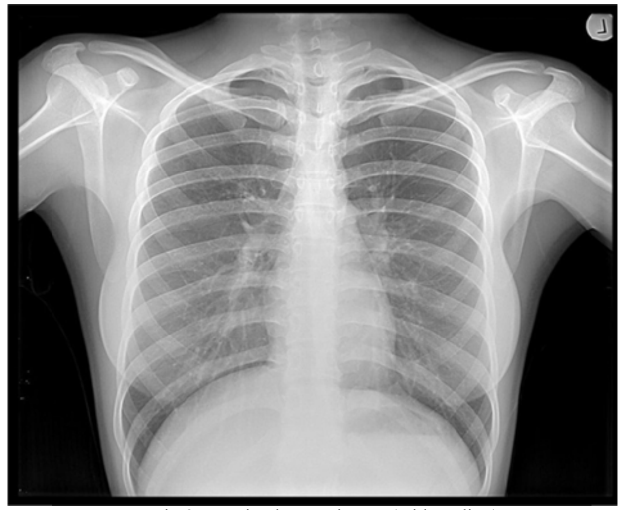

Fig 9: Received X-ray image (with coding)

IV. Conclusions

In this paper, we proposed a novel UWB communication system that is well suited for medical applications. The transmitter is made extremely simple and power efficient by the use of Hadamard codes. The receiver is made simple by employing energy detection. The system can easily be adapted to different data rates and reliabilities. The resulting design can be very compact and power-efficient. It can be used in several applications that require small implantable wireless devices. We showed simulation results with this system in this paper.

V. Possible Applications And Future Work

There are many applications that can make use of this simple type of coding that can enhance UWB usage in the medical field and yield higher data rate capabilities with better mobility, provided that this type of coding is easy to implement any does not required a big deal of processing when implemented at the transmitting device.

More work is required in order imperially validate the simulated results in this paper, and for evaluating the possible signal to noise ratio for UWB signals for the environments where UWB systems can be used.

Another possible enhancement that can be done is by SNR estimation that can have the system run without coding when SNR drops below a certain threshold or even change the coding method to a different one to yield better Bit Error Rate at low SNR.

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