Performance Analysis of Pulsed Chirp UWB Schemes used Hopping Sequence for Wearable Wireless Body Area Network

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Abstract

In this paper, we compare conventional coherent low data rate IR UWB (DS-UWB， Chirp on UWB) and our proposed system of pulsed chirp UWB with or without frequency hopping. IEEE 802.15.4a channel model has been utilized for BER evaluation under multi pico-net interference conditions. Our results show that proposed pulsed chirp UWB with frequency hopping has superior performance compared to conventional methods.

Keywords: Body Area Network, Ultra Wide Band, Frequency Hopping

1 Introduction

Recently, there has been considerable amount of research effort directed towards applied information and communications technology to medical services [1, 2]. As main concept, WBAN (Wireless Body Area Network) has been researched. WBAN are networks composed of wireless communication inside, outside or between inside and outside of the human body. Communication between devices located outside of a human body is called Wearable WBAN; similarly, wireless network composed of devices located inside of a human body is called Implanted BAN.

In this work, we will limit our discussion to Wearable WBAN. Wearable WBAN is expected to have numerous applications. For example, sensors can continuously measure and transmit vital parameters data via wearable WBAN.

Since Wearable WBAN is consistent of small, autonomous network nodes, the consequent low transmission power is required for their longer battery life. Vital signs are important information, so it is important to achieve privacy. Furthermore, medical information and communication technology has need for data rates of about 10 kbps. Considering practical purposes, however, it is necessary to achieve higher data rates.

On the other hand, a lot of attention has been paid to UWB (ultra wideband) wireless communications systems due to their great potential to reach high data rates in wireless communications. UWB signal is defined as one with relative bandwidth (bandwidth/center frequency) surpasses either 20% (for consumer use) or 25% (for military use). In addition to the possible implementation of high speed wireless access with over 1 Gbps data-rates, UWB systems also have the potential to simplify the RF circuitry of the transceivers and lower the transmit power. These features correspond with the demand for the wearable WBAN communications.

In this paper, we compare conventional low data rate IR UWB (DS-UWB， Chirp on UWB) and our proposed system of pulsed chirp UWB with or without frequency hopping. IEEE 802.15.4a channel model has been utilized for BER evaluation under multi pico-net interference conditions.

2 UWB communication technology

2.1 DS-UWB system

2.1.1 Transmitter's Description

The transmitted signal for DS-UWB using the spreading sequence of the sequence length N, denoted $f(t)$, is given by

$$f(t) = \sum_{j=0}^{N-1} m_j \delta(t - jT_c)\ . \qquad (1)$$

Here, $\delta(t)$ represents the transmitted monocycle waveform, m_j is the j-th component of the spreading sequence and T_c is the chip width. We assume that $f(t)$ consists of N pulses.

2.12 Receiver's Description

The received signal $f_{rec}(t)$ is represented by

$$f_{rec}(t) = \sum_{j=0}^{N-1} m_j \delta(t - jT_c\ ) + n(t)\ , \qquad (2)$$

Where $n(t)$ represents additive white Gaussian noise (AWGN) and multiuser interference (MUI). At the receiver, the spreading sequence is assumed to be known and the template function to be correlated with the received signal is assumed to be the same as the transmitted signal. Thus the signal generated at the receiver, $f_{rep}(t)$ is given by

$$f_{rep}(t)=\sum_{j=0}^{N-1} m_j \delta(t-jT_c)\ . \qquad (3)$$

The correlation function $R(\tau)$ between $f_{rec}(t)$ *and* $f_{rep}(t)$ is calculated as

$$R(\tau)=\int_{-\infty}^{+\infty} f_{rec}(t) f_{rep}(t-\tau)dt\ . \qquad (4)$$

Transmitted symbol is decided by calculating $R(\tau)$.

2.2 Chirp on UWB system

2.2.1 Characteristics of chirp on UWB

The chirp waveform is represented by

$$s(t)=\begin{cases}\cos(\theta(t))(0\le t\le T)\\ 0(otherwise)\end{cases}\ . \qquad (5)$$

$\theta(t)$ is the change of phase depending on time. In the case of liner chirp, chirping rate $\mu(t)$ is constant so that frequency $f_M(t)$ is liner function with the respect to t and $\theta(t)$ is a quadratic function.

$$f_M(t)=f_0+\mu(t), \qquad (6)$$

$$s(t)=\cos(2\pi f_0 t+\pi\mu t^2)\ . \qquad (7)$$

Band width B is a function of time duration T and chirping rate μ.

$$B=|\mu|T\ . \qquad (8)$$

Chirp on UWB waveform is made by multiplying root raised cosine pulse and linear chirp. Root raised cosine pulse $r(t)$ is represented by

$$r(t)=\frac{4\beta}{\pi\sqrt{T_p}}\frac{\cos\left[\frac{(1+\beta)\pi t}{T_p}\right]+\frac{\sin\left[\frac{(1-\beta)\pi t}{T_p}\right]}{\frac{4\beta t}{T_p}}}{(\frac{4\beta t}{T_p})^2-1}\ . \qquad (9)$$

$\beta=0.6$ is roll-off factor. Using this pulse, Chirp on UWB waveform is represented by

$$P_{cou}(t)=\begin{cases}r(t)\exp(-j\frac{\pi\alpha t^2}{2})(-\frac{T}{2}\le t\le\frac{T}{2})\\ 0(otherwise)\end{cases}\ . \qquad (10)$$

2.2.2 Chirp on UWB system model

In this section, we describe Chirp on UWB system. Data $b(t)$ was modulated by chirp waveform $P_{cou}(t)$. Transmitted waveform $s(t)$ is represented by

$$s\ (t)=b\ (t)P_{cou}(t)\ . \qquad (11)$$

Each user is assigned a frequency band of *500 MHz* and positive or negative chirp slope, as defined in table. 1. Description of the Chirp on UWB receiver is the same as DS-UWB one.

3 Pulsed Chirp UWB method

In this section, we describe two proposed Pulsed Chirp UWB methods. Proposed method 1 does not use frequency hopping. Proposed method 2 uses frequency hopping between used bands.

In this paper, we used Reed-Solomon (RS) sequence and One Coincidence Code (OCC) sequence as a frequency hopping sequences. Thereinafter we will show details of proposed methods.

Table 1: User assigned bands and chirping slopes.

user	Chirping rate	Center frequency f_c[GHz]
1	*μ□0*	*3.25*
2	*μ□0*	*3.25*
3	*μ□0*	*3.75*
4	*μ□0*	*3.75*
5	*μ□0*	*4.25*
6	*μ□0*	*4.25*
7	*μ□0*	*4.75*
8	*μ□0*	*4.75*

3.1 Proposed method 1

Transmitted waveform $f(t)$ is

$$f(t)=\sum_{j=0}^{N_s-1} m_{i,j}(s_{i,j}(t-jT_f)) \qquad (12)$$
$$(c_{i,j}=1\rightarrow m_{i,j}=1, c_{i,j}=0\rightarrow m_{i,j}=-1)$$

T_f is time frame, $c_{i,j}$ is j-th element of PN sequence assigned to the i-th user; N_s is the length of the PN sequence. Similarly, $s_{i,j}$ is a waveform of the j-th corresponding pulse for the i-th user. Chirp pulse waveforms $s_{i,j}$ are described in detail below.

First, maximum and minimum value of used frequency is defined - f_{max} and f_{min} respectively. Second, we divide the bandwidth by applied length of sequence. Bandwidth B and chirped bandwidth Δf are

$$B=f_{\max}-f_{\min}\ , \qquad (13)$$

$$\Delta f=\frac{B}{N}\ . \qquad (14)$$

All central frequencies of used frequency bands are defined as $f_{c1}, f_{c2}, \ldots f_{cNs}$. Frequency hopping sequence of the i-th user is defined as

$$f_i=(f_{ci}, f_{c(i+1)}\cdots f_{c(i+N_s-1)}) \qquad (15)$$
$$(f_{ci}=f_{c(i+N_s)}=\ldots=f_{c(i+nN_s)}=\ldots)$$

Chirping rate of j-th chip of i-th user is calculated as

$$\mu_{i,j}=\frac{\Delta f}{T}m_{i,j}\ , \qquad (16)$$

$$T = 2\tau \,. \qquad (17)$$

Here, τ denotes pulse width. Fig. 1 illustrates described principle.

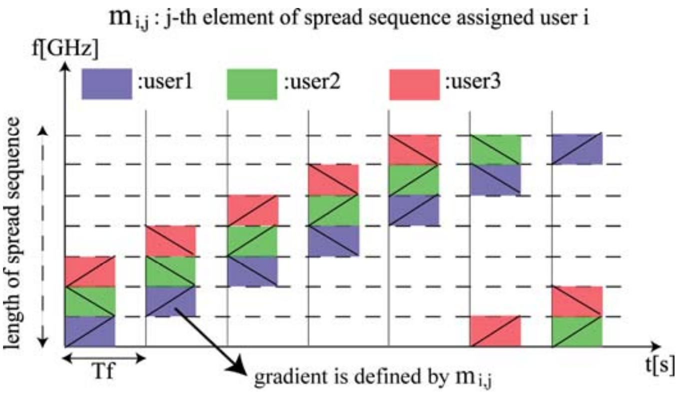

Figure 1: Frequency hopping of proposed method 1.

Finally, chirp pulse waveform of the *j*-th chip for the i-th user, $s_{i,j}(t)$, is represented as

$$s_{i,j}(t) = \begin{cases} r(t-\frac{T}{2})\exp(-j\omega_{i,j}(t))(0 \le t \le T) \\ 0(otherwise) \end{cases}, \qquad (18)$$

$$\omega_{i,j}(t) = 2\pi f_{i,j}(t-\frac{T}{2}) + (\frac{\pi\mu_{i,j}}{2})(t-\frac{T}{2})^2 \,. \qquad (19)$$

For this method, f_{c1}~f_{cNs} are defined in table. 2.

Table 2:Frequency divided each center frequency (length of sequence 7)

	Center frequency f_c[GHz]		Center frequency f_c[GHz]
1	*3.228*	5	*4.257*
2	*3.485*	6	*4.514*
3	*3.742*	7	*4.771*
4	*3.999*		

3.2 Proposed method 2

In this section, we will describe proposed method 2 which uses RS sequence or OCC sequence to determine occupied frequency band. Transmitted waveform *f(t)* remains the same as in the method 1 (12). Maximum value of applied frequency is defined f_{max}, and minimum is defined f_{min}, so bandwidth *B* and chirped band width Δf are also as before (13),(14). In this paper, length of RS sequence is 8, and length of OCC sequence is 10. In contrast with method 1, here, bandwidth *B* is divided in somewhat smaller frequency bands, denoted as $f_1, f_2 \ldots$. Center frequency of each frequency band is denoted as $f_{c1}, f_{c2}, \ldots$. Defining n_i as hopping sequence of user i, f_{useri} which is applied frequency of user *i* is represented by

$$f_{useri} = (f_{n_i(1)}, f_{n_i(2)}, \ldots, f_{n_i(j),\ldots}) \,. \qquad (20)$$

Chirping rate is represented by

$$\mu = \frac{\Delta f}{T} \qquad (21)$$

$$T = 2\tau \qquad (22)$$

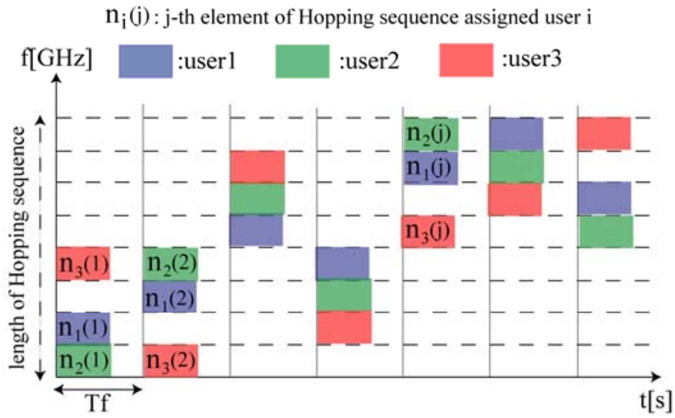

Figure 2: Frequency hopping of proposed method 2.

Fig. 2 illustrates described principle.

Accordingly, chirp pulse waveform for *j*-th chip of *i*-th user $s_{i,j}(t)$ is represented by

$$s_{i,j}(t) = \begin{cases} r(t-\frac{T}{2})\exp(-j\omega_{i,j}(t))(0 \le t \le T) \\ 0(otherwise) \end{cases}, \qquad (23)$$

$$\omega_{i,j}(t) = 2\pi f_{cn_i(j)}(t-\frac{T}{2}) + (\frac{\pi\mu}{2})(t-\frac{T}{2})^2 \,. \qquad (24)$$

This time, f_{c1}~f_{cNs} are defined in table.3, for both RS and OCC frequency hopping sequences.

4 Wearable WBAN

Wearable WBAN is different from usual indoor and outdoor UWB propagation models. Propagation through the body is negligible in the gigahertz frequency range and can be ignored. In the Wearable WBAN, path loss is defined for the distance traveled by the wave around the perimeter of the body, not a shortest path distance between transmitter and receiver.

Table 3: Frequency divided each center frequency (length of RS sequence 8 and OCC sequence 10).

	Center frequency f_c[GHz]			Center frequency f_c[GHz]	
	RS	OCC		RS	OCC
1	*3.2125*	*3.19*	6	*4.3375*	*4.09*
2	*3.4375*	*3.37*	7	*4.5625*	*4.27*
3	*3.6625*	*3.55*	8	*4.7875*	*4.45*
4	*3.8875*	*3.73*	9		4.63
5	*4.1125*	*3.91*	10		4.79

Furthermore, in the IEEE 802.15.4a Wearable WBAN channel model there are two clear clusters of multi-path components. The first cluster is due to diffraction of the wave around the torso. The second cluster is due to a reflection from the ground; hence, it strength depends on the electrical properties of the floor material.

We assume that multi-nodes which are taken on body are synchronized. In this paper, we consider that effect of interference wave which is asynchronous transmitted (multi pico-net interference). We assume IEEE 802.15.4a BAN channel model with AWGN. Two scenarios of multi pico-net interference are considered.

Scenario 1 is assumes equal power of all interferers.

Scenario 2 assumes that SIR is defined as average power of all interference signals. For example, if declared SIR is –5dB, number of interference user is 3 and distribution range of SIR is ±5dB, interference wave 1 can be –7dB, interference wave 2 –3dB and interference wave 3 –5dB. Therefore, average interference power is –5dB.

In this paper, we assume that distribution range of SIR is –5dB. Fig.3 illustrates example of interference scenario 2.

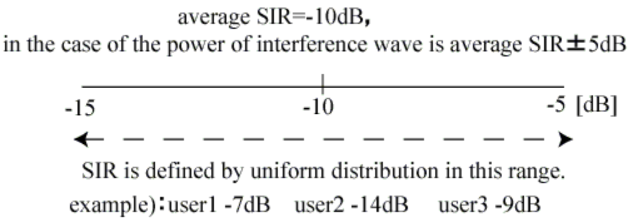

Figure 3: example of interference scenario 2 .

5 Simulation

5.1 Simulation setup

Simulation setup is shown in table 4 and table 5. Transmitted pulse waveform is root raised cosine pulse with roll-off factor equal to 0.6. In this simulation, we consider multi pico-net interference. At the receiver, the spreading sequence is assumed to be known and it is perfectly synchronized.

Table 4: Simulation setup of conventional method.

Transmit signal	DS-UWB Chirp on UWB (CoU)
Spread Sequence	DS-UWB: Gold sequence (length:7)
Frequency band	3-5GHz (τ=0.75ns)(DS-UWB) (τ=3ns)(CoU)
Sampling Time	0.3125[ns]
Bit rate	10Mbps
Transmitter position	Front body
Receiver position	Arm
Number of interference pico-net	8
Ground	Concrete

5.2 Simulation results

The BER (Bit Error Rate) characteristics under multi pico-net interference are shown in Fig. 4 and Fig. 5. Fig. 4 shows BER characteristics in the case of 8 pico-net and interference scenario 1. Fig 5 shows BER characteristics in the case of 8 pico-net and interference scenario 2. When SIR is low, Chirp on UWB is superior to others. This is because Chirp on UWB is resistant to near-far problem.

When SIR is high, proposed method is superior to conventional methods. This is because proposed method is combined characteristic of Chirp on UWB and DS-UWB. Furthermore, proposed method 2 which uses hopping sequence is superior to proposed method 1.

This is because, in the case of proposed method 2, probability of collision on the same frequency band is lower than in the case of proposed method 1.

Comparing method 2 with RS and OCC sequence; length of the OCC sequence is adjusted to length of gold sequence. In this case, the proposed method 2 with OCC sequence is similar to the proposed method 2 with RS sequence. If length of sequence is long, however, the difference of lengths will affect BER characteristics.

From the Fig. 5, we can see that proposed method is superior to conventional methods in the case of interference scenario 2, with interference waves come with various power.

Table 5: Simulation setup of proposed method.

Transmit signal	Pulsed chirp UWB
Spread Sequence	Gold sequence (length:7)
Hopping sequence	RS sequence (length:8) OCC sequence (length:10)
Pulse width	Propose method 1: 2.5[ns] Propose method 2 with RS: 2.5[ns] Propose method 2 with OCC: 3[ns]
Frequency band	3-5GHz
Sampling Time	0.3125[ns]
Bit rate	10Mbps

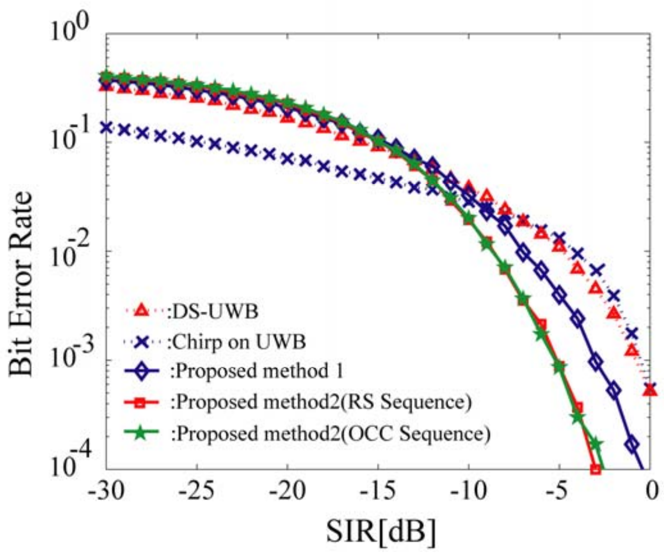

Figure 4: BER characteristics of 8 pico-net.

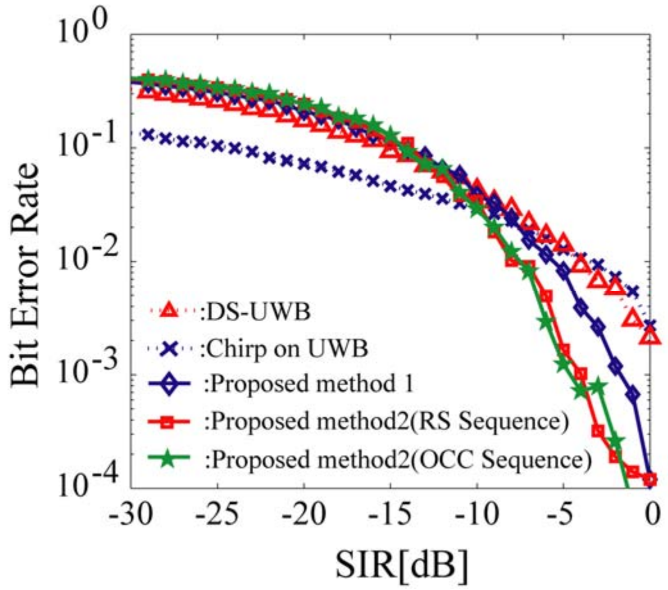

Figure 5: BER characteristics of 8 pico-net, distribution range of SIR is ±5dB.

6 Conclusions

In this paper, we compared conventional methods of UWB IR with proposed method of pulsed chirp with and without frequency hopping. Proposed method with hopping sequence and proposed method without hopping sequence were tested on the scenario of multi pico-net interference.

Both proposed methods with and without hopping sequence are superior to conventional methods. Especially in the case of scenario 2, which assumes interference received with various powers, proposed method is superior to conventional methods.

For a future research, we will consider interference to and from narrowband system. Also, we will propose a system model suitable for Implant WBAN.

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