Adaptive Space Time Spreading-UWB for WBAN Medical and Non-Medical Uses

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***Abstract*— Wireless Body Area Network (WBAN) expected to be widely and deeply involved in our daily life enabling various types of wireless applications (e.g. medical, sportive, or even entertainment). Sharing the same frequency band, an expected frequent situation will occurred where coexistence between a considerable numbers of WBAN causing significant performance degradation to the system. Direct Sequence Ultra WideBand (DS-UWB) mechanism is a considerable solution to that problem, but the variety of required Quality of Services (QoS) and demands for these services' customers introduce a bigger challenge. In this paper, we propose a multiple transmit and single receiving antenna (MISO) system where a special coding applied to the transmitted data which known as Space Time Spreading (STS) to mitigate the WBAN channel fading effects. To accommodation higher number of sensors in the same frequency band and grantee a reasonable performance, we combine STS with DS-UWB spreading scheme. Moreover, varying the spreading sequence length depending on the number of active sensors would provide an improvement to the proposed scheme.**

***Index Terms*— Body Area Network, UWB, STS, STBC, Medical Applications, Entertainment Applications**

I. INTRODUCTION

ULTRA WIDEBAND (UWB) technology is a useful and safe new technology in the area of wireless body area network (WBAN). There are many advantages of using UWB as a communication standard for biomedical applications. Its interesting features can be summarized in its very low radiated power (−41.3 dBm/MHz), low power consumption, good coexistence with the other existing instruments, robustness to interference and multipath [1].

With its 7.5 GHz of spectrum allocated to the UWB devices by Federal communications Commission (FCC), entertainment applications can be more enjoyable with the wide frequency range which allows the communications to achieve high data rate transmission [2].

These enormous advantages for UWB offer a promising future for this technology for short-range communications. For low power peer-to-peer and multiple access communications, IR-UWB is preferred because of its nanosecond (or less) width pulses which usually combined with some spreading technique to offer low power spectral density across the bandwidth.

Recently, there has been a high demand for the body area networks (BANs) devices that supports both medical and entertainment purposes. The coexistence of these applications is a challenging task because of the gap in the required Quality of Service (QoS) for these applications which can be seen as a diversity-multiplexing tradeoff.

Medical applications are related to the human health and require high reliability transmission with small power consumption and limited effect on human body, which can be achieved by increasing the diversity order of the transmission system. The high data rate is the main factor for the entertainment devices sacrificing a comparatively low error probability, where we should improve the multiplexing order.

Moreover, wearable WBAN communication devices have another challenge imposed by the adverse nature of the channel affecting communication between on-body to on-body sensors. The channel is susceptible to frequency selectivity (arises from multipath propagation) and time delay due to cyclostationary nature of the sensors [3].

To mitigate these effects, we can think in a different way. Instead of coping with only one channel trying to improve the extracted information, we can utilize multiple channels combined together with a proper coding of transmitted data to improve retrieved information. We assume a scenario where coordinator (or hub) has two antennas and the different sensors employing one receiving antenna only. The transmitted data passes through two different channels and with a proper decoding at the sensor nodes, the probability to loss the data becomes much smaller even with a single receiving antenna.

An elegant technique which employs Coding Theory, Matrix Algebra, and Signal Processing has been proposed to yield diversity gains with minimum computational complexity. Space-Time Block Codes (STBC) represents a recent, exciting development in the field of physical layer (PHY) data transmission. By employing more than one antenna at the transmitter, and by properly coding data across the transmit antennas, STBC-equipped PHYs promise increased data rates with minimal decoding complexity at the receiver.

For the previous reasons, Space Time Spreading (STS) with a two transmit antenna and single receiving antenna (MISO) system combined with DS-UWB technology would be a unique proposal to achieve our target performance and to allow accommodation of a larger number of sensors sharing the same frequency band. Moreover, varying the spreading code length can grantee various QoS and achieve required demands.

STS provide an interesting feature for WBAN system where it maintains the same total transmit power from the

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two antennas is the same as the transmit power from a single transmit antenna. So the transmission power doesn't change from the normal cases with one transmit antenna.

The remainder of this paper is organized as follows: In section II we give a brief discussion for some related literatures that inspired us with the proposed scheme. In Section III we introduce STS signaling model. Computer simulation scenario setup and parameters used in those simulations are presented in Section IV. Conclusion is drawn in Section V.

II. Related Research

Space Time Coding (STC) techniques capture a lot of interest because it introduces a spatial and temporal correlation in signals transmitted from multiple antennas to provide diversity and coding gain at the receiver [4].

Alamouti in [5] present his remarkable system of the first space time code depending on two transmitting antennas and one or more receiving antennas. This work has been generalized for arbitrary number of transmitting antennas in [6] and notated as STBC.

Coupling UWB and STC has been proposed in some literatures, for example, as [7] where the Space Time (ST) coding has been coupled with Ultra Wide Band Impulse Radio (UWB-IR) based on Time Hopping (TH) scheme to utilize the advantage of both techniques to gain better bit error rate performance and increase the number of users that can be accommodated. The proposal in [8] is another technique for UWB-IR which depends on space hopping SH-UWB-IR to allow each user to transmit different symbols from different antennas using a unique time hopping sequence assigned to each antenna which is well known to the receiver.

A novel practical approach in [9] which increases the bit rate and/or improve the quality and range in the downlink of either mobile or fixed CDMA systems. The authors called it Space Time Spreading (STS) and based it on two transmitter and single-receiver antennas where it was accepted and included as an optional diversity mode in release A of the IS-2000 wideband CDMA standard.

While STS can exploit channel diversity and mitigate the interference effectively, it does not exploit the available spectrum efficiently. To improve spectral efficiency, a combination between orthogonal STBC and STS in [10] has been placed to increase transmission rates.

In [11], the author try to fulfill the requirements for consumer electronics and PC industries where low cost, low power, flexible and reliable wireless home entertainment networks are needed. To do this, they propose the use of DS-UWB scheme employing STS technique combined with adaptive detection with some extra hardware complexity is needed.

In the meantime, an adaptive transmission scheme presented in [12] using variable-length spreading sequence (VLSS) based on IR-UWB for wireless communication. According to the system load, the length of the spreading sequence changes adaptively which proven to be able to reduce the inter-chip interference, inter-symbol interference and multiple-access interference and thus improve the system performance. Also, they show that using RAKE receivers allow the proposed scheme to achieve a better performance than the conventional system.

In this paper, we introduce an adaptive transmission scheme for a combination of STS scheme with UWB technology in order to mitigate the WBAN channel effects and grantee a reasonable QoS performance for medical and non-medical applications.

III. Signaling Model

In our scenario, we assume a typical BAN consists of a hub and some sensor nodes organized in a star topology. The hub coordinates the transmission within the BAN. There are two groups of sensors and they are employed for different applications (medical and entertainment) and hence assigned spreading code length accordingly. We assume that the interference occurs between two sensors nodes belong to different piconets. Also we assume a perfect synchronization between the different nodes in the DS-UWB system.

In this scenario, the transmitted data from a node with DS-UWB transmission technique can be represented as:

$$x_k(t) = \sum_{i=-\infty}^{\infty} d_k(i) s_k(t - iT_b)$$

Where d_k is the k^{th} transmitter equiprobable binary bit stream modulated as BPSK and s_k is the normalized spreading spectrum waveform given by

$$s_k(t) = \sqrt{E_b/N} \sum_{j=0}^{N-1} c_k(j) w_{tr}(t - iT_p)$$

Where $c_k(j)$ is a pseudorandom spreading code that takes values {-1,1} and has a period $N = N_m$ in case of medical nodes and $N = N_e$ for entertainment nodes. $w_{tr}(t)$ denotes the UWB pulse, which is normalized to $\int_{-\infty}^{\infty} w_{tr}^2(t) = 1$

T_b denotes the duration of one data bit.

E_b is the energy of one bit.

T_p is the pulse duration of $w_{tr}(t)$ and N_m/N_e copies of T_p gives one medical/entertainment bit duration.

In [9], the Space Time Spreading (STS) technique has been proposed for the downlink CDMA systems to increase the bit rate and/or improve the quality of the link, with the condition that there is no extra spreading codes, transmit power, or channel information are required.

During this paper, we will assume that the amplitudes of fading from each transmit antenna to each receive antenna are mutually uncorrelated and also we assume that the receiver has perfect knowledge of the channel.

We consider a wireless communication system with two transmitter antennas and one single receiver signaling over frequency flat fading channels.

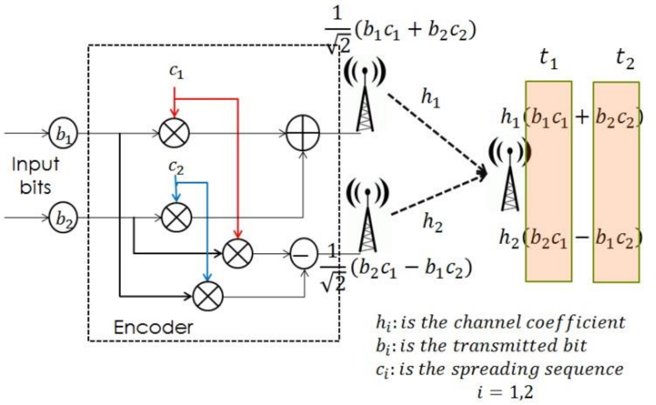

Fig.1 STS system design

Using the space time spreading scheme proposed in [9] where it is assumed that the system transmitting two data symbols $\{b_1,b_2\}$ using the transmitting antennas and two spreading codes $\{c_1,c_2\}$ as shown in Fig. 1, the signal transmitted on the first antenna would be

$$x_1 = \frac{1}{\sqrt{2}}(b_1c_1 + b_2c_2)$$

and the signal transmitted on the other antenna would be

$$x_2 = \frac{1}{\sqrt{2}}(b_2c_1 - b_1c_2)$$

where now, c_1,c_2 are any set of orthogonal 2Px1 unit-norm spreading sequences. The factor $\frac{1}{\sqrt{2}}$ normalizes the total transmitted power to be the same as for one transmit antenna.

There are some proposals to generate c1 and c2 and grantee to be orthogonal and generated from one sequence only. In this paper, we choose to generate c1 as the orthogonal spreading sequence annexed with the same length of zeros and c2 generated as zeros first and annexed with the orthogonal spreading sequence. So c1 and c2 could be represented as

$$c_1 = \begin{bmatrix} SP_{P\times1} \\ 0_{P\times1} \end{bmatrix}$$

$$c_2 = \begin{bmatrix} 0_{P\times1} \\ SP_{P\times1} \end{bmatrix}$$

Since, we transmitting two symbols and employing two codes, we satisfy STS conditions.

The received signal in the receiver antenna would be

$$r_1 = h_1x_1 + h_2x_2 + n$$

where n is a Px1 vector of additive Gaussian noise with zero mean and variance $N_0/2$

After despreading with c_1 and c_2 respectively, we get

$$d_1 = \frac{1}{\sqrt{2}}(h_1b_1 + h_2b_2) + \tilde{c_1}n$$

$$d_2 = \frac{1}{\sqrt{2}}(-h_2b_1 + h_1b_2) + \tilde{c_1}n$$

where $\sim$ represent the vector conjugate transpose

Previous results can be represented in a matrix form as

$$D = \frac{1}{\sqrt{2}}XH + N$$

where $D = [b_1 \quad b_2]^T$, and N is the AWGN noise added by every channel between a transmitter and receiver.

In contrast to normal Space Time Spreading (STS) system which employs a fixed length spreading sequence, the proposed scheme adaptively changes the length of the spreading sequence according to the number of active sensors in the system.

IV. Numerical Analysis and discussion

In this section, we present the simulation analysis results of the proposed scheme adaptive STS-UWB using orthogonal spreading code. The scenario assumed here is a downlink scenario between wearable devices where a coordinator (or hub) is using a two transmit antennas and medical/non-medical sensor uses a signal receiving antenna (MISO scheme). We assume that transmitted data is modulated by binary-phase shift-keying (BPSK) scheme.

As a general case, we assume that the medical sensors' spreading code length is longer than its counter partner in entertainment sensors.

For the channel model, first we assume that the transmitted data is passing through a Rayleigh fading channel and suffer from white Gaussian noise at the receiver. Secondly, we introduce Rician channel model because the nature of the channel between WBAN wearable sensors is close to Rician channel model.

The medical sensors investigated in this paper are assumed to be employed for Electroencephalography (EEG) monitoring and the entertainment sensors are accelerometer sensors.

The medical/entertainment sensor’s information rate is assumed to be 4200/7000 bps respectively.

As a general case, the paper follows closely the specifications and parameters of IEEE 802.15.6 protocol physical (PHY) layer proposed for UWB.

A. Evaluation by BER

We evaluate the system performance in terms of Bit Error Rate (BER) in average for each application separately. We examine the system performance by running it under various simulations. The parameters for the two different scenarios are shown in Table I. The first scenario assumes a fixed medical spreading code length while the entertainment spreading code length is changing. On the other scenario, assumption of fixed entertainment spreading code length is used, while medical sensors spreading code length is changing.

TABLE I
TWO SIMULATION SCENARIOS PROPOSED FOR PERFORMANCE ANALYSIS OF VARIABLE PROCESSING GAIN COMBINED WITH STS

Criteria	Medical	Entertainment
Number of Sensors	5	4
Spreading sequence length (scenario 1)	64	8,16,32
Spreading sequence length (scenario 2)	16,32,64	8

The general simulation parameters are summarized up in Table II.

TABLE II
SIMULATION PARAMETERS FOR THE PROPOSED SCENARIO MODEL

Criteria	Value
Channel	Rayleigh-Rician
WB Pulse Width	0.5 nSec
UWB Pulse	Gaussian 5th order
Modulation	BPSK
Receiver	Matched Filter
Spreading Code	Walsh

The results shows that, in the first scenario, incrementing the entertainment spreading sequence length in Fig. 3 improves the BER for entertainment and worsen its counter partner with a considerable value. Even though the medical sensors' code length is fixed, the performance of the Matched Filter receiver used here degraded due to increase in entertainment sensors' code length and their partial cross correlation. Partial cross correlation causes a shift in the tag corresponds to the correlation peak as in shown in Fig. 2.

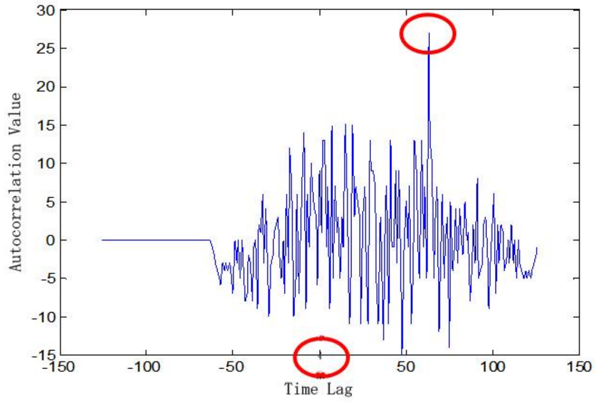

Fig. 2 An example of partial cross correlation between two Gold code sequences of length 127, 63

On the other side in the second scenario shown in Fig. 4, the medical sensors' sequence length increasing which achieves a better performance for these sensors without showing noticeable degradation in entertainment performance which approximately constant for the different variations.

B. Evaluation with different number of sensors

In a different point of view, we fix the used signal to noise ratio (SNR) and vary the total number of active sensors in the system to examine the proposed scheme attitude. Increasing the number of active sensors is highly related to the ability to provide a unique spreading code to each sensor in the different applications. Moreover, the Matched Filter receiver's ability to differentiate a higher number of sensors decreases with the increase in number of allowed to access sensors.

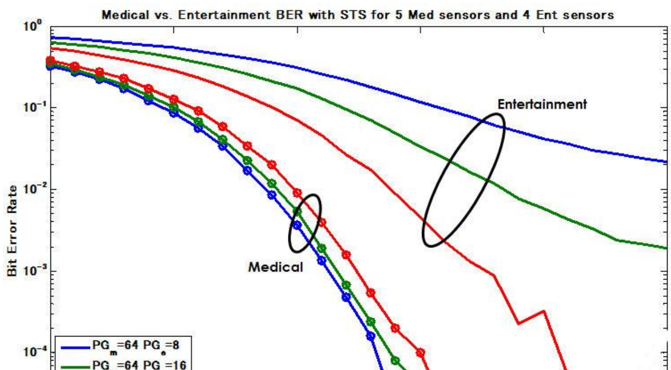

Fig. 3 BER for increasing processing gain of Entertainment sensors against fixed processing gain of Medical sensors using STS

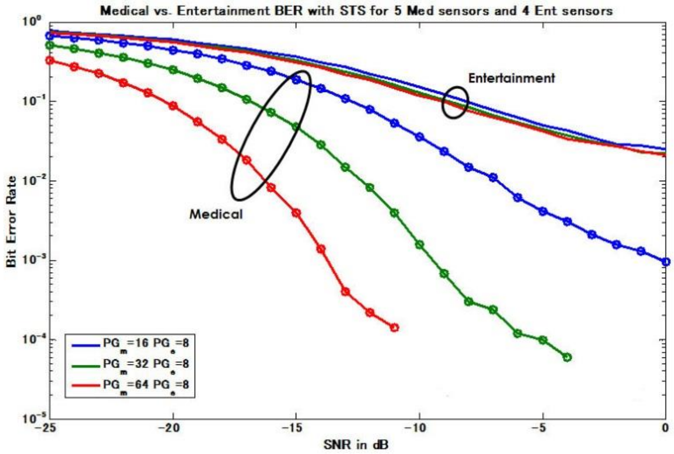

Fig. 4 BER for increasing processing gain of Medical sensors against fixed processing gain of Entertainment sensors using STS

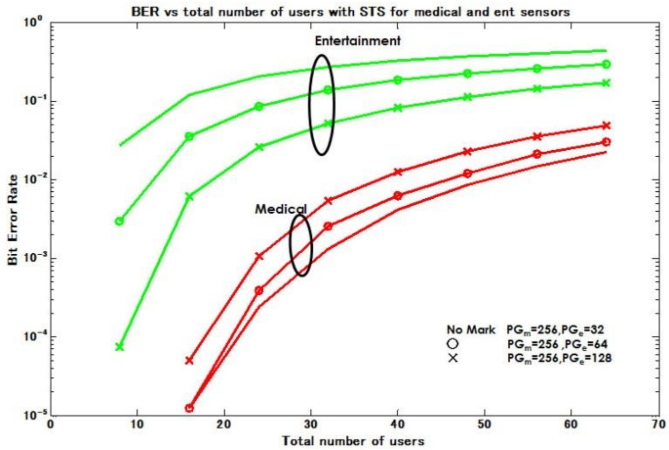

Fig. 5 BER vs. total number of users for various Entertainment sensors' processing gain using STS

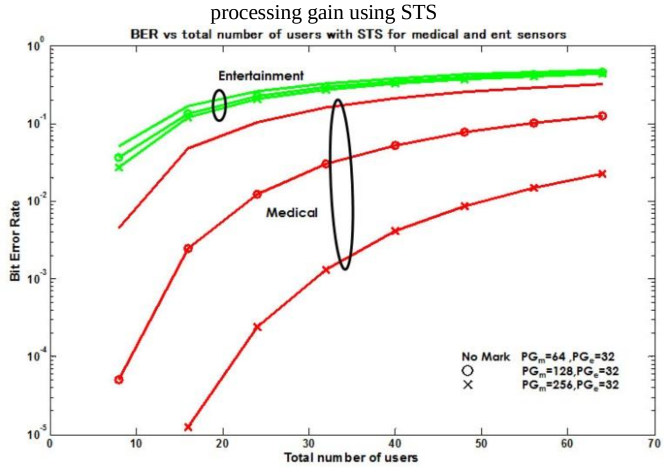

Fig. 6 BER vs. total number of users for various Medical sensors' processing gain using STS

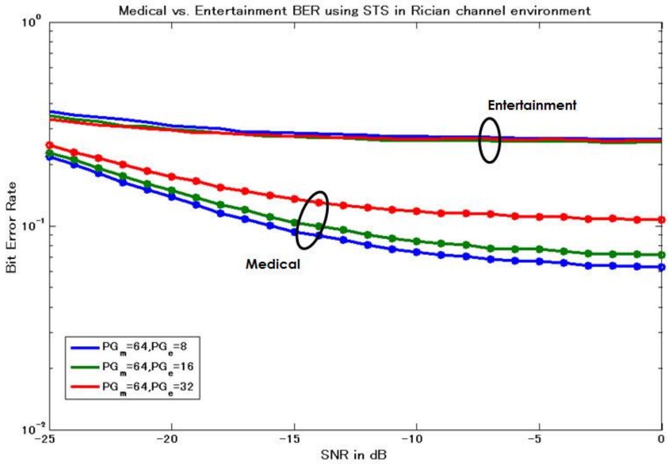

Fig. 7 BER for increasing processing gain of Entertainment sensors against fixed processing gain of Medical sensors using STS in Rician environment

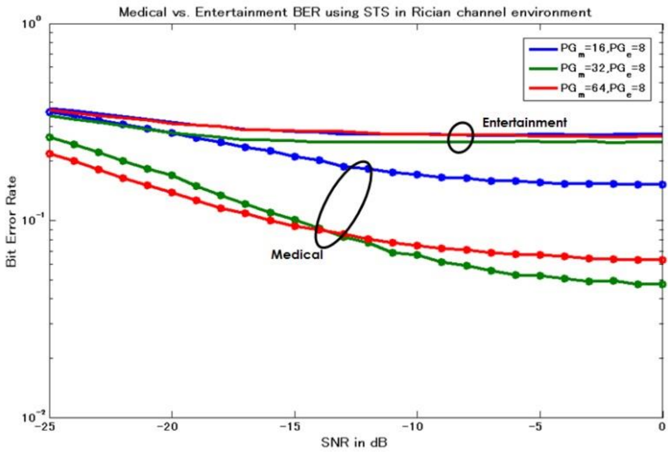

Fig. 8 BER for increasing processing gain of Medical sensors against fixed processing gain of Entertainment sensors using STS in Rician environment

The results in Fig. 5, shows a considerable degradation in performance with the increase of the total number of active users in the system in both medical and non-medical applications. More specifically, the effect of changing the entertainment sensors' spreading code length on medical sensors performance is considerable. Even though the medical sensors doesn't change its code length, but the partial cross correlation due to the variation of code lengths shows a considerable performance degradation and this degradation increases with the increase in entertainment sensors' code length.

While in Fig. 6, entertainment sensors maintain the same performance with a change in medical sensors' spreading code length. We think that the partial cross correlation has a little effect in that case because the medical sensors' code length is always longer than its counter partner code length. So the change in performance almost the same and tends toward being constant with the increase in number of sensors in the system.

Rician channel effect using Rician factor k=2 has been shown in Fig. 7, where in general a noticeable degradation in performance follows and the change of the entertainment spreading code length give a near constant effect of these sensors. Fig. 8, also discussing the second scenario where medical spreading code length changing and gave an improvement in the performance.

V. Conclusion

In this paper, we proposed Space Time Spreading (STS) scheme combined with DS-UWB spreading scheme in order to add more diversity to our system which would lead to an improvement in mitigating the effect of channel fading and allow accommodation of more number of sensors. In addition, with multiuser environment, using two antennas for transmission and single antenna for receiver with applying special coding scheme can offer a reasonable improvement in the performance. The advantages also appear when no need for any extra transmission power by using the same spreading sequence for the two transmitting antennas and gaining two folding of diversity of SNR at receiver antenna.

Adaptively choosing the length of spreading code which fit with the existing number of active users shown to be successful for STS scheme with UWB transmission technology.

The effect of changing the medical sensors' spreading code length on the entertainment sensors' performance is not so strong comparing to the effect of changing the entertainment sensors' spreading code length on medical sensors' performance.

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