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Double Binary Turbo Coded Data Transmission of STBC UWB Systems for U-Healthcare Applications

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Abstract

In this paper, we analyze and simulate performance of space time block coded (STBC) binary pulse amplitude modulation-direct sequence (BPAM-DS) ultra-wideband (UWB) systems with double binary turbo code in indoor environments for various ubiquitous healthcare (u-healthcare) applications. Indoor wireless channel is modeled as a modified Saleh and Valenzuela (SV) model proposed as a UWB indoor channel model by the IEEE 802.15.SG3a in July 2003. In the STBC encoding process, an Alamouti algorithm for real-valued signals is employed because UWB signals have the type of real signal constellation. It is assumed that the transmitter has knowledge about channel state information. From simulation results, it is shown that the STBC scheme does not have an influence on improving bit error probability performance of the BPAM-DS UWB systems. It is also confirmed that the results of this paper can be applicable for u-healthcare applications.

Key words : Binary turbo code, UWB, STBC, u-healthcare.

1. INTRODUCTION

UWB has a number of advantages [5-8], which are low complexity, low cost, noise-like signal, resistance to severe multipath and jamming, and good time domain resolution allowing for location and tracking applications. Then, it is a promising candidate for short-range and high throughput wireless communication.

In indoor wireless channels, transmitted signals are distorted by channel errors since Ultra-wideband (UWB) signals are highly time scattered with large number of multi-path and the transmitted power is limited to low level. In order to resolve this problem, channel coding schemes [9,10] are required. Also, the performance of UWB systems decreases due to multiple access interference (MAI). One efficient technique for overcoming this problem is utilizing space time block coding (STBC) schemes [11-13].

In this paper, we simulate and analyze performance of the STBC BPAM-DS UWB systems with double binary turbo code in indoor wireless channels for various ubiquitous healthcare (u-healthcare) applications. The indoor wireless channel is modeled as a modified Saleh and Valenzuela (SV) channel [14], which is proposed as the UWB indoor channel model by IEEE 802.15.SG3a. Also, simulation results are analyzed and simulated in term of bit error probabilities (BER) according to signal-to-noise (SNR) ratio.

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This paper is organized as followed. In Section 2, UWB system model considered in this paper is depicted. And double binary turbo encoding and decoding schemes are described in Section 3. In Section 4, simulation results are shown. Finally, target application fields of this paper and concluding remarks are presented in Section 5 and 6.

2. SYSTEM MODEL

A. Transmitter

We consider the double binary turbo coded STBC-UWB system with two transmit antennas and one receiver antenna as shown in Fig. 1.

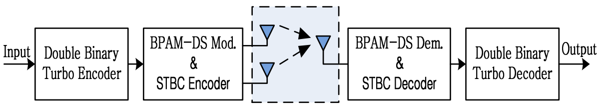

Fig. 1. Double binary turbo coded STBC-UWB system.

Digitalized Information bits are encoded by a double binary turbo code encoder. The results, which are information and parity bits, modulate a train of very short pulses and are spread by the DS code in the BPAM-DS UWB part. The modulated and spread waveforms are encoded by the STBC encoder. The STBC encoding scheme utilizes the Alamouti algorithm for real-valued signals. The received signals passing through the indoor wireless channel feed into the STBC decoder. And the STBC decoder outputs are demodulated by the BPAM-DS demodulator. Finally, the original information bits are estimated after the double binary turbo code decoding procedure.

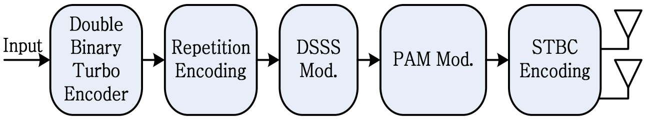

Fig. 2. Double binary turbo coded STBC-UWB transmitter

The structure of double binary turbo coded STBC-UWB transmitter considered in this paper is shown in Fig. 2. Given the binary sequence to be transmitted $\mathbf{b} = (\ldots,\ b_0,\ b_1,\ldots,\ b_k,\ldots)$, each sequence is encoded by the double binary turbo encoder. And a repetition encoder repeats each output bit of the turbo encoder N_s times and generates a binary sequence $\mathbf{a}^* = (\ldots,\ b_0,\ b_0,\ldots,\ b_0,\ b_1,\ b_1,\ldots,\ b_1,\ldots,\ b_k,\ b_k,\ldots,\ b_k,\ldots)$. Then, the $\mathbf{a}^*$ sequence is transformed into a positive- and negative-valued sequence $\mathbf{a} = (\ldots,\ a_0,\ a_1,\ldots,\ a_j\ ,\ldots)$. And a direct sequence spread spectrum (DSSS) modulator applies a binary code $\mathbf{c} = (\ldots,\ c_0,\ c_1,\ldots,\ c_j,\ldots)$ composed of ±1's to the sequence $\mathbf{a} = (\ldots,\ a_0,\ a_1,\ldots,\ a_j\ ,\ldots)$, and generates a new sequence $\mathbf{d} = \mathbf{a}\cdot\mathbf{c}$ composed of elements $d_j = a_j c_j$. The output sequence $\mathbf{d}$ enters a PAM modulator, which generates a sequence of unit pulses. The modulator outputs are encoded by a STBC encoder. When there are two transmit antennas shown in Fig. 2, the transmission matrix for real-valued signal is shown as

$$\mathbf{S} = \begin{bmatrix} -s_0 & s_1 \\ s_1 & s_0 \end{bmatrix}, \tag{1}$$

where both s_0 and s_1 are the elements of sequence $\mathbf{d}$. s_0 is the sequence transmitted from the first antenna and s_1 is the sequence transmitted from the second antenna.

The BPAM-DS UWB signal $s_i(t)$ with STBC at the output of the transmitter can be expressed as

$$s_i(t) = \sqrt{\frac{E_{TX}}{2}} \sum_{j=-\infty}^{\infty} \mu_{i,j} d_j p(t - jT_s), \tag{2}$$

where d_j is the DS encoder output sequence and can be expressed as

$$d_j = a_j k_j, \tag{3}$$

where k_j is a direct sequence.

Then the resulting signals are transmitted through a pulse shaper filter with impulse response $p(t)$. The outputs of the transmit antennas can be expressed as

$$s_i(t) = \sqrt{\frac{E_{TX}}{2}} \sum_{j=-\infty}^{\infty} \mu_{i,j} d_j p(t - jT_s), \tag{4}$$

where i $(i = 0,\ 1)$ is the number of transmit antennas, E_{TX} is the transmitted energy per pulse, $\mu_{i,j} \in \{\pm 1\}$ is the STBC encoding factor of the j^{th} pulse at the number of antenna i, and t is the clock time.

B. Channel

In this paper, the modified SV model, which is selected as the UWB indoor multipath channel model by IEEE 802.15.SG3a, is adopted as an indoor wireless channel model. The channel impulse response of the IEEE model can be expressed as

$$h(t) = X\sum_{l=0}^{N-1}\sum_{k=0}^{K(n)}\alpha_{nk}\delta\left(t - T_n - \tau_{nk}\right), \tag{5}$$

where X is a log-normal random variable representing the amplitude gain of the channel, N is the number of observed clusters, $K(n)$ is the number of multipath contributions received within the n^{th} cluster, α_{nk} is the coefficient of the k^{th} multipath contribution of the n^{th} cluster, T_n is the time of arrival of the n^{th} cluster, and τ_{nk} is the delay of the k^{th} multipath contribution within the n^{th} cluster. In order to employ STBC scheme, $K(n)$ is set to be 2.

The channel coefficient α_{nk} can be defined as follows

$$\alpha_{nk} = p_{nk}\beta_{nk}, \tag{6}$$

where p_{nk} is a discrete random variable assuming values of ± 1 with equal probability and β_{nk} is the log-normal distributed channel coefficient of multi-path contribution k belonging to cluster n. The β_{nk} term can be expressed as

$$\beta_{nk} = 10^{\frac{x_{nk}}{20}}, \tag{7}$$

where x_{nk} is assumed to be a Gaussian random variablewith mean μ_{nk} and variance σ_{nk}^2. Variable x_{nk} can be further decomposed as

$$x_{nk} = \mu_{nk} + \xi_n + \zeta_{nk}, \tag{8}$$

where ξ_n and ζ_{nk} are two Gaussian random variables that represent the fluctuations of the channel coefficient on each cluster and on each contribution, respectively.

C. Receiver

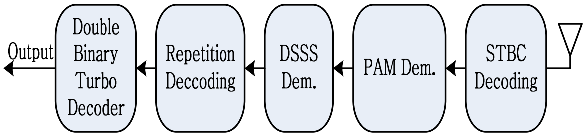

Fig 3. Double binary turbo coded STBC-UWB receiver

The double binary turbo coded STBC-UWB receiver is presented in Fig. 3. The received signal passing through the indoor wireless channel is decoded at the STBC decoder and demodulated by the BPAM demodulator. Then, after despreading with DS code identical to that at the transmitter and repetition decoding processes, the output sequence enters the double binary turbo code decoder. Finally, the original transmitted bits are estimated.

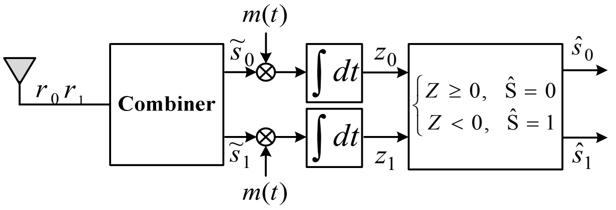

Fig. 3. STBC decoder and UWB demodulator structures.

Fig. 4 shows the detail STBC decoder and UWB demodulator structures. The received signal r_0 and r_1 for the first and second symbol durations, respectively, can be expressed as

$$\begin{aligned} r_0 = r(t) &= -\alpha_0 s_1(t) + \alpha_1 s_0(t) + n_1(t) \\ &= -X\sqrt{\frac{E_{TX}}{2}}\sum_{j=-\infty}^{\infty}\sum_{n=0}^{N-1}\alpha_{n0}a_j p\left(t - jT_s - \tau_{n1}\right) \\ &\quad + X\sqrt{\frac{E_{TX}}{2}}\sum_{j=-\infty}^{\infty}\sum_{n=0}^{N-1}\alpha_{n1}a_j p\left(t - jT_s - \tau_{n0}\right) + n_1(t) \end{aligned}, \tag{9}$$

$$\begin{aligned} r_1 = r(t+T) &= \alpha_0 s_0(t+T) + \alpha_1 s_1(t+T) + n_0(t) \\ &= X\sqrt{\frac{E_{TX}}{2}}\sum_{j=-\infty}^{\infty}\sum_{n=0}^{N-1}\alpha_{n0}a_j p\left(t + T - jT_s - \tau_{n0}\right) \\ &\quad + X\sqrt{\frac{E_{TX}}{2}}\sum_{j=-\infty}^{\infty}\sum_{n=0}^{N-1}\alpha_{n1}a_j p\left(t + T - jT_s - \tau_{n1}\right) + n_0(t) \end{aligned}, \tag{10}$$

(4)

where α_i and α_{ni} $(i = 0, 1)$ is the channel gain of the n^{th} path contribution of the n^{th} cluster. And $n_i(t)$ $(i = 0, 1)$ is additive white Gaussian noise (AWGN) with zero mean and variance σ_i^2. a_j represents the magnitude of the j transmitted pulse. If we assume that the channel coefficients are constant across two consecutive symbol transmission periods, the combiner outputs can be expressed as

$$\begin{aligned} \tilde{s}_0 &= r_0 + r_1 \\ &= (\alpha_0 + \alpha_1)s_0 + n_0 + n_1 \end{aligned}, \tag{11}$$

$$\begin{aligned} \tilde{s}_1 &= -r_0 + r_1 \\ &= (\alpha_0 + \alpha_1)s_1 - n_0 + n_1 \end{aligned}, \tag{12}$$

And the combiner outputs $\tilde{s}_0$ and $\tilde{s}_1$ are correlated with correlation masks $m_i(t)$ $(i = 0, 1)$. The outputs of the correlators become decision variables z_i $(i = 0, 1)$. The original message is estimated by comparing z_i with a threshold, which is zero. If the delay of each path is assumed to be identical to τ, the correlation masks can be expressed as

$$m_i(t) = m(t-\tau) = k_j p_0(t-\tau), \qquad (13)$$

where $p_0(t)$ is an basic pulse signal before the modulation process. The binary sequences $\hat{s}_0$ and $\hat{s}_1$ are fed into the double binary turbo decoder.

3. DOUBLE BINARY TURBO ENCODING AND DECODING SCHEMES

Double binary turbo encoder is shown in Fig. 5, where S_1, S_2, and S_3 indicate the shift registers. The data sequence to be encoded, made up of W information bits, feeds the circular recursive systematic convolutional (CRSC) encoder twice. The first is in the natural order of the data, where a switch is in position 1. And the next is in an interleaved order, given by time permutation block, CTC interleaver, where a switch is in position 2. The encoder is fed by blocks of W bits or M couples, $W = 2 \times M$ bits. M is a multiple of 4. So W is a multiple of 8. The most significant bit (MSB) of the first byte after the burst preamble is assigned to A, the next bit to B, and so on for the remainder of the burst content. For each data couple, the encoded code word involves two systematic bits that are the copy of input pair (X1 and X2) and 4 parity bits (Y1, W1, Y2, and W2) for the normal and the interleaved order, respectively.

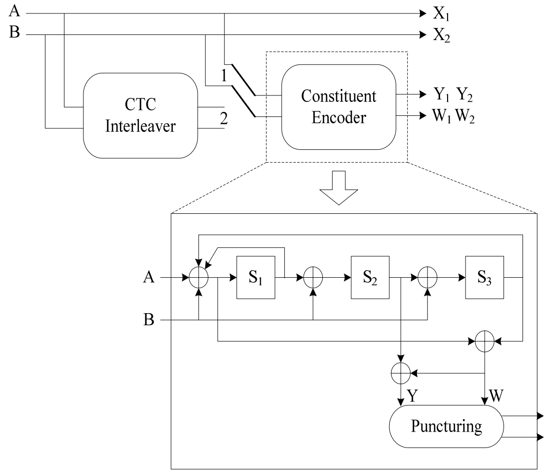

Fig. 4. Encoder structure of double binary turbo code.

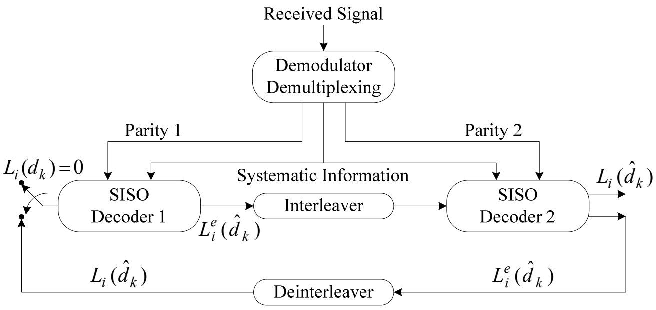

Fig. 5. Decoder structure of double binary turbo code.

Fig. 6 shows the structure of double binary turbo decoder. The systematic information is the channel value of information symbols $d_w = \{00, 01, 10, 11\}$. Parity 1 and parity 2 are the channel value of the outputs of encoder parity bits. $L_i(\hat{d}_w)$ is the log-likelihood ratio (LLR) of a posteriori probability (APP) for $i = 1, 2, 3$. And $L_i^e(\hat{d}_w)$ is the extrinsic information.

In turbo decoder, the sequential input bits are divided into the information and the parity bits through the trellis MUX. And the information and the parity bits and a priori information produced by the soft input soft output (SISO) decoder are used in the decoding procedure. The results of decoding process are compared with the previously decoded results. Then, this decoding procedure is repeated for increasing the reliability of the decoding outputs. After some iteration, the final values are determined by the soft decision. In this paper, the sub-optimal Max Log-MAP algorithm is considered for double binary turbo decoding because of its characteristics, that is, low computational complexity, high throughput, and low power consumption. Extrinsic information coupling for the feedback is performed according. $L_i(\hat{d}_w)$ is the LLR of a posteriori probability (APP) for $i = 1, 2, 3$ and $L_i^e(\hat{d}_w)$ is the extrinsic information.

4. SIMULATION RESULTS

In this Section, we present simulation results in order to illustrate the performance of double binary turbo coded BPAM-DS UWB systems with STBC in indoor wireless channels. For verifying the system performance, its bit error probability is tested. In BPAM modulation, the number of pulses per one bit is set to be one. And the average transmission power is set to be -30 dBm. We consider the

Table 1. Parameter settings for the modified SV channel model

Scenarios	Λ $(1/ns)$	λ $(1/ns)$	Γ	γ	σ_ξ (dB)	σ_ζ (dB)	σ_g (dB)
Case A LOS (0-4m)	0.0233	2.5	7.1	4.3	3.3941	3.3941	3

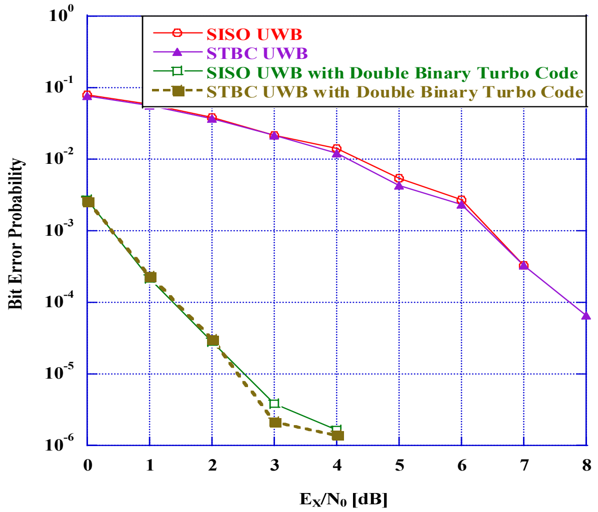

Fig. 6. Bit error probability versus EX/N0 performance for various systems.

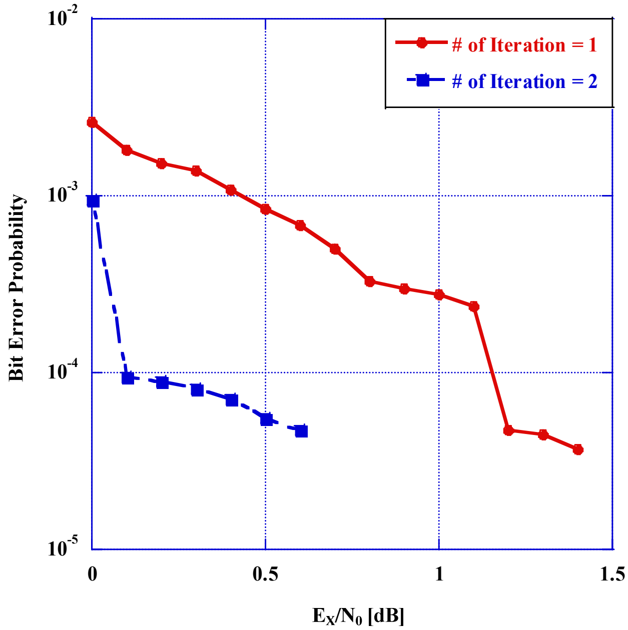

Fig. 7. Bit error probability versus EX/N0 performance for different number of iterations.

system with two transmit antennas and one receive antenna.

We assume the position of the receiver to be two meters away from the transmitter. And it is assumed that the receiver and the transmitter are in line of sight (LOS). Also, it is assumed that there is no inter-symbol interference (ISI). Table 1 shows the parameters of the modified SV channel model for case A.

Fig. 7 shows bit error probability versus EX/N0 performance of the STBC BPAM-DS UWB systems applying the double binary turbo code in the indoor wireless channels, where EX is the energy received within a single pulse. The single-input single-output (SISO) channel is shown for comparison. It is demonstrated that the STBC scheme seldom affects the performance improvement of the BPAM-DS UWB systems. Also, it is confirmed that according as EX/N0 increases double binary turbo coding offers considerable coding gain compared with an uncoded system. Consequently, it is evident from these results that the double binary turbo coding scheme has the effect of enhancing the bit error probability performance for the BPAM-DS UWB systems. However, the STBC scheme only increases the implementation complexity and is of no use for improving the bit error probability performance of the BPAM-DS UWB systems.

Fig. 8 shows bit error probability versus EX/N0 performance of the STBC BPAM-DS UWB systems with the double binary turbo code for different number of iterations. It is shown that the bit error probability performance is significantly improved by increasing the number of iterations in the decoding process. After a sufficient number of iterations, it turns out again that further iterations provide only modest performance improvement.

5. APPLICATION FIELDS OF U-HEALTHCARE

Moreover, the proposed algorithm can be applicable to the medical ICT (Information and communication technology) using proposed UWB data transmission scheme, as shown in Fig. 9. Main application examples are ECG, pacemaker and wireless capsule endoscope. The ECG is a device which records contraction of heart according to stream of times while the pacemaker is a device which makes patient's heart working normally, and it is inserted inside human muscle. The wireless capsule endoscope is usually a tablet-sized capsule, and if a man swallows the capsule, it sends the moving capture data of internal organ to the external sensor. In the aspect of medical applications above mentioned, a

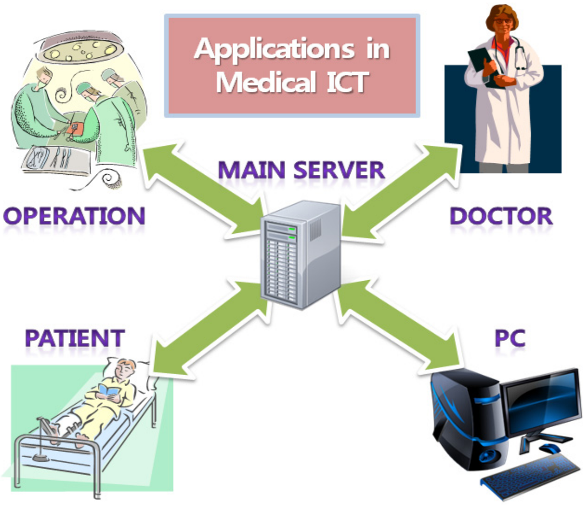

Fig. 9. Application fields of proposed algorithm based on UWB data transmission.

main issue is whether the medical system can coexist with other RF systems. This issue can be solved by the proposed algorithm where the WBAN based on UWB can effectively operate with the very low power spectral density. Therefore, algorithm and results of this paper are appropriate for medical ICT.

5. CONCLUSION

In this paper, we presented the double binary turbo coded transmission of the STBC BPAM-DS UWB systems for various u-healthcare applications. It was demonstrated that the double binary turbo coding offered considerable coding gain. And it was also confirmed that the system performance was significantly improved by increasing the number of iterations in the decoding process. The results of this paper can be applied for implementing the UWB systems.

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