

Double Binary Turbo Coded Data Transmission for STBC BPAM-DS UWB System

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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. The indoor wireless channel is modeled as a modified Saleh and Valenzuela (SV) channel, which is proposed as a UWB indoor channel model by IEEE 802.15.SG3a. From simulation results, it is shown that the STBC scheme does not have an influence on improving bit error probability performance of the PAM-DS UWB systems. It is also shown that the double binary turbo coding scheme offers considerable coding gain compared with an uncoded system according as the number of iterations increases.

Keywords— Binary pulse amplitude modulation-direct sequence (BPAM-DS), double binary turbo code, modified Saleh and Valenzuela (SV) channel, space time block coding (STBC), ultra-wideband (UWB).

I. INTRODUCTION

Ultra-wideband (UWB) systems utilize very short pulses, whose duration is below 1 pico-second, in transmission [1-4]. Therefore, UWB signal occupies ultra-wideband spectrum. In order not to make an effect to existing narrow-band radio systems, emission power of UWB systems is restricted to noise level. This makes interception and detection quite difficult.

UWB has a number of advantages [5], 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 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 [6] 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 [7].

In this paper, we simulate and analyze performance of space-time block coded (STBC) binary pulse amplitude modulation-direct sequence (BPAM-DS) ultra-wideband (UWB) systems with double binary turbo codes in indoor wireless channels.

This paper is organized as follows. In Section II, double binary turbo coded STBC BPAM-DS UWB system model including wireless channel is described. And double binary turbo coding and decoding algorithms are shown in Section III. For decoding process, the Max Log-MAP algorithm employed in this paper is introduced. Simulation results are presented in Section IV. Finally, concluding remarks are drawn in Section V.

II. SYSTEM MODEL

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

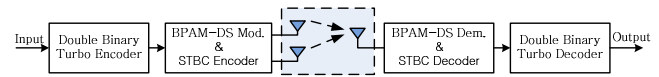


Figure 1. Double binary turbo coded STBC-UWB system.

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 $\mathbf{b} = (\dots, b_0, b_1, \dots, b_k, \dots)$, 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 $\mathbf{a}^* = (\dots, b_0, b_0, \dots, b_0, b_1, \dots, b_1, \dots, b_k, b_k, \dots, b_k, \dots)$. Then, the $\mathbf{a}^*$ sequence is transformed into a positive- and negative-valued sequence $\mathbf{a} = (\dots, a_0, a_1, \dots, a_j, \dots)$. And a direct sequence spread spectrum (DSSS) modulator applies a binary code $\mathbf{c} = (\dots, c_0, c_1, \dots, c_j, \dots)$ composed of ± 1 's to the sequence $\mathbf{a} = (\dots, a_0, a_1, \dots, a_j, \dots)$, 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

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

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.

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

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

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.

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. In order to employ STBC scheme, we define the channel impulse responses from antennas 0 and 1 by $h_0(t)$ and $h_1(t)$, respectively, at time t . Then, these can be represented as

$$h_0(t) = X_0 \sum_{u=0}^{U-1} \sum_{k=0}^{K(u)-1} \alpha_{0uk} \delta(t - T_{0u} - \tau_{0uk}), \quad (3)$$

$$h_1(t) = X_1 \sum_{u=0}^{U-1} \sum_{k=0}^{K(u)-1} \alpha_{1uk} \delta(t - T_{1u} - \tau_{1uk}), \quad (4)$$

where X_i , $i=0,1$, is a log-normal random variable representing the amplitude gain from the antenna i in the channel, U is the number of observed clusters, $K(u)$ is the number of multipath contributions received within the u^{th} cluster, α_{iuk} is the coefficient of the k^{th} multipath contribution of the u^{th} cluster, T_{iu} is the time of arrival of the u^{th} cluster, and τ_{iuk} is the delay of the k^{th} multipath contribution within the u^{th} cluster.

The channel coefficient α_{iuk} can be defined as follows.

$$\alpha_{iuk} = p_{iuk} \beta_{iuk}, \quad (5)$$

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

$$\beta_{iuk} = 10^{\frac{x_{iuk}}{20}}, \quad (6)$$

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

$$x_{iuk} = \mu_{iuk} + \xi_{iu} + \zeta_{iuk}, \quad (7)$$

where ξ_{iu} and ζ_{iuk} are two Gaussian random variables that represent the fluctuations of the channel coefficient on each cluster and on each contribution, respectively. The total energy contained in the β_{iuk} terms needs to be normalized to unity as shown below.

$$\sum_{u=0}^{U-1} \sum_{k=0}^{K(u)-1} |\beta_{iuk}|^2 = 1. \quad (8)$$

In this paper, it is assumed that impulse responses in (9) and (10) are constant across two consecutive symbol transmission periods. Then, these can be rewritten as

$$h_0^n(t) = h_0^n(t+T) = h_0^n, \quad (9)$$

$$h_1^n(t) = h_1^n(t+T) = h_1^n, \quad (10)$$

where h_i^n ($i=0,1$) is the overall channel gain for the path from transmit antenna i to the receive antenna, and T is the symbol duration.

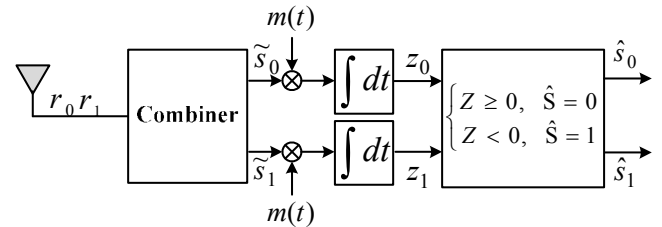


Figure 2. Block diagram of UWB receiver.

The receiver model is presented in Figure 2. 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.

The received signals r_0 and r_1 for the first and second symbol durations, respectively, can be expressed as

$$\begin{aligned} r_0 = r(t) &= -\alpha_0 s_1(t) + \alpha_1 s_0(t) + n_1(t) \\ &= -X \sqrt{\frac{E_{TX}}{2}} \sum_{j=-\infty}^{\infty} \sum_{n=0}^{N-1} \alpha_{n0} a_j p(t - jT_s - \varphi_j - \tau_{n1}) \\ &\quad + X \sqrt{\frac{E_{TX}}{2}} \sum_{j=-\infty}^{\infty} \sum_{n=0}^{N-1} \alpha_{n1} a_j p(t - jT_s - \varphi_j - \tau_{n0}) + n_1(t) \end{aligned} \quad , \quad (11)$$

$$\begin{aligned} r_1 &= r(t+T) = \alpha_0 s_0(t+T) + \alpha_1 s_1(t+T) + n_0(t) \\ &= X \sqrt{\frac{E_{TX}}{2}} \sum_{j=-\infty}^{\infty} \sum_{n=0}^{N-1} \alpha_{n0} a_j p(t+T-jT_s - \varphi_j - \tau_{n0}) \\ &\quad + X \sqrt{\frac{E_{TX}}{2}} \sum_{j=-\infty}^{\infty} \sum_{n=0}^{N-1} \alpha_{n1} a_j p(t+T-jT_s - \varphi_j - \tau_{n1}) + n_0(t) \end{aligned} \quad , \quad (12)$$

where both α_i and α_{ni} ($i=0, 1$) are the channel gain of the i^{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. E_{TX} is the transmitted energy per one pulse, and φ_i is a random TH dither.

If we assume that the channel coefficients are constant across two consecutive symbol transmission periods, the combiner outputs can be expressed as

$$\begin{aligned}\tilde{s}_0 &= r_0 + r_1 \\ &= (\alpha_0 + \alpha_1)s_0 + n_0 + n_1,\end{aligned}\quad (13)$$

$$\begin{aligned}\tilde{s}_1 &= -r_0 + r_1 \\ &= (\alpha_0 + \alpha_1)s_1 - n_0 + n_1.\end{aligned}\quad (14)$$

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 mask can be expressed as

$$\begin{aligned} m_i(t) &= m(t - \tau) \\ &= c p_0(t - T_c), \end{aligned} \quad (15)$$

where $p_0(t)$ is an basic pulse signal before the PAM modulation.

III. DOUBLE BINARY TURBO CODE

The double binary turbo encoder [9, 10] is shown in Figure 3, 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, convolutional turbo code (CTC) interleaver, where a switch is in position 2. The encoder is fed by blocks of W bits or F couples, $W = 2 \times F$ bits. F 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. In order to perform a complete encoding operation of the data sequence, two circulation states have to be determined, one for each component encoder,

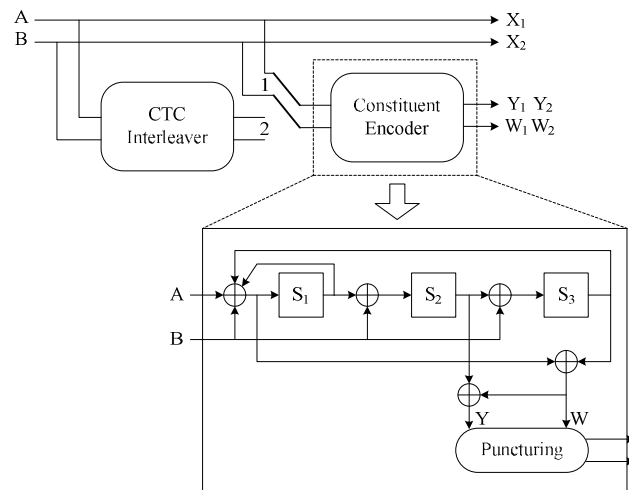


Figure 3. Double binary turbo encoder structure.

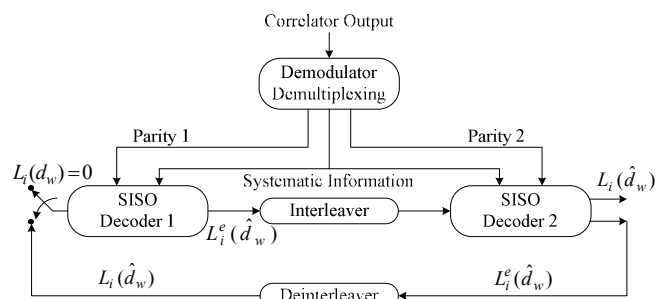


Figure 4. Double binary turbo decoder structure.

And the sequence has to be encoded four times instead of twice. For each data couple, the encoded code word involves two systematic bits that are the copy of input pair (X_1 and X_2) and 4 parity bits (Y_1 , W_1 , Y_2 , and W_2) for the normal and the interleaved order, respectively.

Figure 4 shows the structure of the double binary turbo decoder [11]. 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

a log-likelihood ratio (LLR) of a posteriori probability (APP) for $i = 1, 2, 3$. And $L_i^e(\hat{d}_w)$ is an extrinsic information.

In this paper, the sub-optimal Max-Log-MAP algorithm is considered for the double binary turbo decoding because of its characteristics, that is, low computational complexity, high throughput, and low power consumption [12]. Extrinsic information coupling for the feedback is performed in accordance with [13].

First, according to the decoding rule, find logarithm of the branch transition probability as

$$\bar{\gamma}_w^i(S_{w-1}, S_w) = \ln \gamma_w^i(S_{w-1}, S_w) = \ln p(y_w | d_w) P(d_w), \quad (16)$$

where S_w is the encoder state at time w . y_w is the received symbol and d_w is the information symbol. As shown in [11], the result of (18) is as follows.

$$\begin{aligned} \bar{\gamma}_w(S_{w-1}, S_w) &= \frac{1}{2} L_C \left[\gamma_w^{s,I} x_w^{s,I}(i) + \gamma_w^{s,Q} x_w^{s,Q}(i) \right] + \ln P(d_w) + W \\ &= \frac{1}{2} L_C \left[\gamma_w^{p,I} x_w^{p,I}(i, S_{w-1}, S_w) + \gamma_w^{p,Q} x_w^{p,Q}(i, S_{w-1}, S_w) \right] \end{aligned} \quad (17)$$

where $\gamma_w^{s,I}$, $\gamma_w^{s,Q}$, $\gamma_w^{p,I}$, and $\gamma_w^{p,Q}$ represent the received systematic and parity values transmitted through the I and Q channels, respectively. And $x_w^{s,I}(i)$, $x_w^{s,Q}(i)$, $x_w^{p,I}(i, S_{w-1}, S_w)$, and $x_w^{p,Q}(i, S_{w-1}, S_w)$ represent the bits of codeword mapped to quadrature phase shift keying (QPSK) constellation, respectively. And W is a constant. In this paper, for modulation scheme BPPM or BPAM is used instead of QPSK. Therefore, there is no data transmitted through the I and Q channels. Then, double binary turbo coding can not be applied to UWB systems. In order to employ double binary turbo code, it is assumed that the coded sequence of the odd position is transmitted through the I channel and that of the even position is transmitted through the Q channel.

Next, compute the values of $\alpha_w(S_w)$ and $\beta_w(S_w)$, which are yielded by the forward and backward recursion, respectively, and then take max-function,

$$\bar{\alpha}_w(S_w) \approx \max_{S_{w-1}} [\bar{\gamma}_w(S_{w-1}, S_w) + \bar{\alpha}_{w-1}(S_{w-1})], \quad (18)$$

$$\bar{\beta}_{w-1}(S_{w-1}) \approx \max_{S_w} [\bar{\gamma}_w(S_{w-1}, S_w) + \bar{\beta}_w(S_w)]. \quad (19)$$

The LLR value is given by

$$L_i(d_w) = \ln \frac{\sum_{d_w=i}^{(S_{w-1}, S_w)} \gamma_w^i(S_{w-1}, S_w) \alpha_{w-1}(S_{w-1}) \beta_w(S_w)}{\sum_{d_w=0}^{(S_{w-1}, S_w)} \gamma_w^0(S_{w-1}, S_w) \alpha_{w-1}(S_{w-1}) \beta_w(S_w)}, \quad (20)$$

where $i = 1, 2, 3$. And, the extrinsic information can be calculated as

$$L_i^e(\hat{d}_w) = \ln \frac{\sum_{d_w=i}^{(S_{w-1}, S_w)} \gamma_w^{(e)}(S_{w-1}, S_w) \alpha_{w-1}(S_{w-1}) \beta_w(S_w)}{\sum_{d_w=0}^{(S_{w-1}, S_w)} \gamma_w^{(e)}(S_{w-1}, S_w) \alpha_{w-1}(S_{w-1}) \beta_w(S_w)}. \quad (21)$$

$L_i^e(\hat{d}_w)$ of the SISO decoder 1 is a priori information of the SISO decoder 2. Also, the decoding processing in the SISO decoder 2 is performed the same method in the SISO decoder 1. $L_i^e(\hat{d}_w)$ of the SISO decoder 2 is a priori information of the SISO decoder 1. After several decoding iterations, the soft decisions are made according to

$$\hat{d}_w = \begin{cases} 01 & \text{if } L(\hat{d}_w) = L_1(\hat{d}_w) \text{ and } L_1(\hat{d}_w) > 0 \\ 10 & \text{if } L(\hat{d}_w) = L_2(\hat{d}_w) \text{ and } L_2(\hat{d}_w) > 0 \\ 11 & \text{if } L(\hat{d}_w) = L_3(\hat{d}_w) \text{ and } L_3(\hat{d}_w) > 0 \\ 00 & \text{else} \end{cases} \quad (22)$$

IV. SIMULATION RESULTS

In a simulation, an indoor wireless channel is modeled as the modified Saleh and Valenzuela (SV) channel. This model was proposed as a UWB indoor channel model by IEEE 802.15.SG3a. The performance is evaluated in terms of bit error probability (BEP).

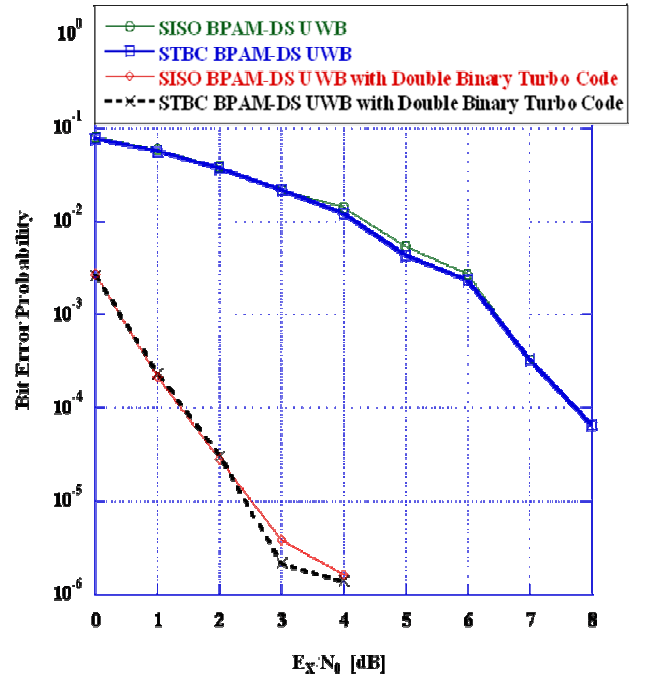


Figure 5. Bit error probability versus E_X/N_0 performance for STBC BPMA-DS UWB Systems with double binary turbo code.

V. CONCLUSIONS

In this paper, the performance of STBC BPAM-DS UWB systems is analyzed and simulated in the indoor wireless channel. From the simulation results, it is confirmed that the double binary turbo coding scheme has the effect of enhancing the bit error probability performance for the BPAM-DS UWB systems. Also, it is shown that the bit error probability performance is significantly improved by increasing the number of iterations in the decoding process. The results of this paper can be applied for implementing the UWB system.

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Figure 2 shows bit error probability versus E_x/N_0 performance of the STBC BPAM-DS UWB systems applying the double binary turbo code in the indoor wireless channels, where E_x 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 E_x/N_0 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.

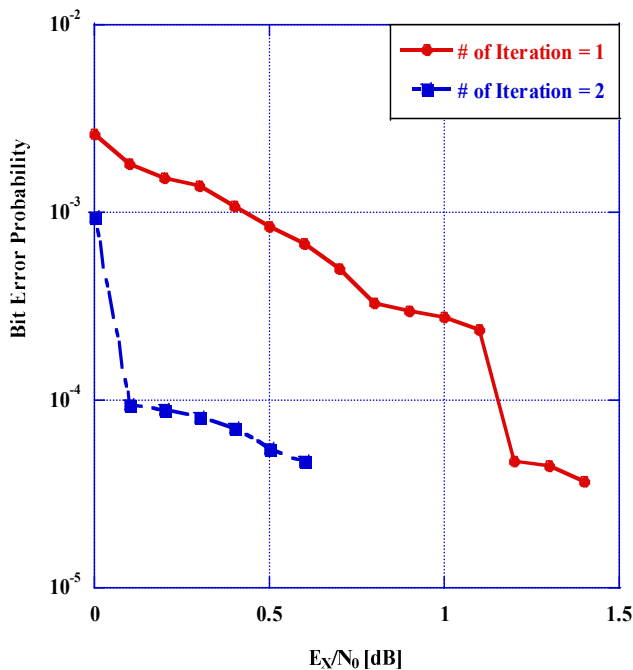


Figure 6. Bit error probability versus E_x/N_0 performance for STBC BPMA-DS UWB Systems with double binary turbo code for different number of iterations.

Figure 3 shows bit error probability versus E_x/N_0 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.