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A NOVEL METHOD FOR ENHANCED QUASI-ORTHOGONAL SPACE TIME BLOCK CODES IN WIRELESS COMMUNICATION

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A complex orthogonal design that provides full diversity and full transmission rate for a space–time block code is not possible for more than two antennas. We design rate one codes which are quasi-orthogonal and provide partial diversity. The decoder of the proposed codes works with pairs of transmitted symbols instead of single symbols. A number of Quasi-Orthogonal Space-Time Block Codes (QOSTBC) have been proposed for using in multiple transmit antennas systems. In this paper, based on circulant matrix, we propose a novel method of extending any QOSTBC constructed for 4 transmit antennas to a closed-loop scheme. We show that with the aid of multiplying the entries of QOSTBC code words by the appropriate phase factors which depend on the channel information, the proposed scheme can improve its transmit diversity with one bit feedback. The performances of the proposed scenario extended from Jafarkhani's QOSTBC as well as its optimal constellation rotated scheme are analyzed. The simulation results suggest that there is a significant Eb/No advantage in the proposed scheme which is able to be designed easily.
Keywords: QOSTBC, Feedback, Closed-loop, Rotation, Circulant

1. Introduction

Jafarkhani designed Full Rate Quasi-Orthogonal Space Time Block Code (QOSTBC) that provides half of the maximum possible diversity for four transmit antennas. Recently, a lot of researches have been put into designing the STBC with full rate and full diversity for four transmit antennas. For open-loop communication systems, the optimum constellation rotation proposed for QOSTBC with different modulation schemes is the one of good diversity improvement approaches. Although a lot of partial feedback methods can be adopted to improve the closed-loop system performance, the major problems of such systems are high cost and high complexity due to the more feedback information. For practical interests of the design of the closed-loop transmission schemes, it is desirable to have features such as a limited amount of feedback information, low decoding delay, low cost and simple decoding processing

In this paper, we present a novel closed-loop scenario extended from Jafarkhani's QOSTBC as well as its optimal rotated scheme for the quasi-static flat fading channels with four transmit antennas. We show that, by feeding back one bit channel information, our proposed scheme can increase the transmit diversity and reduce the self interference from adjacent symbols in QOSTBC scheme. The proposed approach, unlike which need to sacrifice the optimal rotated phase in open-loop system for the feedback variable in closed-loop system, can avoid the damage on optimal rotated phase by employing circulant matrix. It, therefore, is able to offer not only more flexibility but also a performance advantage over exiting methods.

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2. Quasi-Orthogonal Space–Time Block Code

a. Encoding of QOSTBC

The encoding using N transmits antennas and a space–time block code is described t. Let denote a signal constellation of size 2^b. At time one; Kb bits arrive at the encoder, where K is the number of the variables in the transmission matrix. These Kb bits choose K constellation symbols $s_1, s_2, \ldots s_k$. The encoder replaces s_k everywhere for x_k in the transmission matrix for all $1 \le k \le K$. Let us denote the resulting matrix C. Then at time t, t = 1,2,...N the n^{th} element of the t^{th} row C of C_{tn}, is transmitted using antennas n = 1, 2, ...N. We emphasize that all these transmissions are simultaneous and that all the transmitted signals have the same time duration. Since elements of are linear combinations of $x_1, x_2, \ldots x_k$ and their conjugates, the encoding only requires linear processing.

b. Transmission Model

We consider a wireless communication system with N antennas at the base station and M antennas at the remote. The channel is assumed to be a flat fading channel The path gains are modeled as samples of independent complex Gaussian random variables. The real part and imaginary part of path gain have equal variance 0.5. This assumption can be relaxed without any change to the method of encoding and decoding. The wireless channel is assumed to be quasi-static so that the path gains are constant over a frame of length T and vary from one frame to another. and the path gain from transmit antenna n to receive antenna m is defined to be $\alpha_{n,m}$.

At time t, the received signal $r_{t,m}$ at antenna m is given by

$$r_{t,m} = \sum_{n=1}^{N} \alpha_{n,m} C_{tn} + \eta_{t,m} \quad (1)$$

where the noise samples $\eta_{t,m}$ are independent samples of a zero-mean complex Gaussian random variable. The real part and imaginary part of noise have equal variance N/ (2 SNR). The average energy of the symbols transmitted from each antenna is normalized to be 1, so that the average power of the received signal at each receive antenna N is and the signal-to-noise ratio is SNR.

An example of a full-rate full-diversity complex space–time block code is Alamouti scheme, which is defined by the following transmission matrix A_{12}:

$$A_{12} = \begin{pmatrix} A_1 & A_2 \\ -A^*_2 & A^*_1 \end{pmatrix} \quad (2)$$

Here we use the subscript 12 to represent the indeterminate x_1 and x_2 and in the transmission matrix. Now, let us consider the following space–time block code for

$$A = \begin{pmatrix} A_{12} & A_{34} \\ -A^*_{34} & A^*_{12} \end{pmatrix} \quad (3)$$

$$A = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & -x_3 & -x_2 & x_1 \end{pmatrix} \quad (4)$$

The received signals during four time slots can be expressed as

$$\begin{pmatrix} r_1 \\ r_2^* \\ r_3^* \\ r_4 \end{pmatrix} = \begin{pmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3^* & h_4^* & -h_1^* & -h_2^* \\ h_4 & -h_3 & -h_2 & h_1 \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2^* \\ n_3^* \\ n_4 \end{pmatrix} \quad (5)$$

$$= H_J S + N \quad (6)$$

where the noise samples and the entries of HJ are independent samples of a zero-mean complex Gaussian random variable with variance 1.

A. Proposed Scheme for QOSTBC with One Bit Feedback

After multiplying the entries of SJ by four phase factors, we present our proposed scheme as below:

$$S_P = \begin{pmatrix} s_1 e^{j\alpha} & s_2 e^{j\beta} & s_3 e^{j\gamma} & s_4 e^{j\theta} \\ -s_2^* e^{-j\alpha} & s_1^* e^{-j\theta} & -s_4^* e^{-j\gamma} & s_3^* e^{-j\beta} \\ -s_3^* e^{-j\alpha} & -s_4^* e^{-j\beta} & s_1^* e^{-j\gamma} & s_2^* e^{-j\theta} \\ s_4 e^{j\alpha} & -s_3 e^{j\theta} & -s_2 e^{j\gamma} & s_1 e^{j\beta} \end{pmatrix} \quad (7)$$

The received signals are given as:

$$\begin{pmatrix} r_1 \\ r_2^* \\ r_3^* \\ r_4 \end{pmatrix} = \begin{pmatrix} h_1 e^{j\alpha} & h_2 e^{j\beta} & h_3 e^{j\gamma} & h_4 e^{j\theta} \\ h_2^* e^{j\theta} & -h_1^* e^{j\alpha} & h_4^* e^{j\beta} & -h_3^* e^{j\gamma} \\ h_3^* e^{j\gamma} & h_4^* e^{j\theta} & -h_1^* e^{j\alpha} & -h_2^* e^{j\beta} \\ h_4 e^{j\beta} & h_3 e^{j\gamma} & h_2 e^{j\theta} & h_1 e^{j\alpha} \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2^* \\ n_3^* \\ n_4 \end{pmatrix} \quad (8)$$

$$= H_P S + N \quad (9)$$

where the relevant channel matrix

$H_P = H_J \,.^*\, C_4$, and C_4 is circulant matrix which can be expressed as:

$$C_4 = \begin{pmatrix} e^{j\alpha} & e^{j\beta} & e^{j\gamma} & e^{j\theta} \\ e^{j\theta} & e^{j\alpha} & e^{j\beta} & e^{j\gamma} \\ e^{j\gamma} & e^{j\theta} & e^{j\alpha} & e^{j\beta} \\ e^{j\beta} & e^{j\gamma} & e^{j\theta} & e^{j\alpha} \end{pmatrix} \quad (10)$$

where $e^{j\alpha}$, $e^{j\beta}$, $e^{j\gamma}$ and $e^{j\theta}$ are introduced phase factors.

With the conditions

$$e^{j(\beta-\alpha)} = e^{j(\alpha-\theta)},$$
$$e^{j(\theta-\gamma)} = e^{j(\gamma-\beta)},\ e^{j(\alpha-\gamma)} = e^{j(\gamma-\alpha)} \text{ and}$$
$$e^{j(\beta-\theta)} = e^{j(\theta-\beta)}.$$

The Grammian matrix which can be calculated by left-multiplying the matched filtering $H^H{}_P$ with H_P is given as:

$$G_P = H_P^H H_P = h^2 \begin{bmatrix} I_2 & 0 \\ 0 & I_2 \end{bmatrix} + \omega \begin{bmatrix} 0 & J_2 \\ -J_2 & 0 \end{bmatrix} \quad (11)$$

$$\text{Where } U_P = h^2 \begin{bmatrix} I_2 & 0 \\ 0 & I_2 \end{bmatrix} \quad V_P = \omega \begin{bmatrix} 0 & J_2 \\ -J_2 & 0 \end{bmatrix} \quad (12)$$

$$h_2 = \sum_{i=1}^{4} |h_i|^2$$

It indicates the total channel gain for the four transmit antennas. ω can be interpreted as the channel dependent interference parameter, and given by

$$\omega = e^{j(\alpha-\beta)}.2\,\mathrm{Re}(h_1^* h_4) - e^{j(\gamma-\theta)}.2\,\mathrm{Re}(h_2 h_3^*) \quad (13)$$

I_2 is identity matrix and

$$J_2 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

As presented in G_P, the Grammian matrix G_P, can be divided into two components, which are the channel gain matrix U_P and the interference matrix VP . i.e., $G_P = U_P + V_P$. It is well known that the presence of the channel dependent interference ω in VP can cause the performance degradation in contrast with the optimal orthogonal design. Hence, in order to achieve the ideal 4-path diversity, GP should approach UP as close as possible, in other words, the absolute value of ω in VP should be minimized. The effect of ω in VP is explained in . From (7), on the premise of knowing the partial channel information, we can achieve the minimal absolute value of ω by adjusting the value of the two factors $e^{j(\alpha-\beta)}$ and $e^{j(\gamma-\theta)}$, namely:

when $Re(h^*_1 h_4) \cdot Re(h_2 h^*_3) \geq 0$, we set $e^{j(\alpha-\beta)} \cdot e^{j(\gamma-\theta)} = 1$;

when $Re(h^*_1 h_4) \cdot Re(h_2 h^*_3) < 0$, we set $e^{j(\alpha-\beta)} \cdot e^{j(\gamma-\theta)} = -1$.

This issue can be interpreted as follows:

Assuming we know the channel information at the receiver, and adopt one bit k = 0 or 1 to indicate

$Re(h^*_1 h_4) \cdot Re(h_2 h^*_3) \geq 0$ or $Re(h^*_1 h_4) \cdot Re(h_2 h^*_3) < 0$ respectively.

Then this one bit information will be fed back to the transmitter. Supposing the system channel is quasi-static flat fading channel, at the transmitter we first judge the value of k,

If k = 0, we set $\alpha = \gamma = \pi$ and $\beta = \theta = 0$, which ensure $e^{j(\alpha-\beta)} \cdot e^{j(\gamma-\theta)} = 1$,

If k = 1, we set $\alpha = \beta = \theta = 0$ and $\gamma = \pi$ which ensure $e^{j(\alpha-\beta)} \cdot e^{j(\gamma-\theta)} = -1$.

Hence, we give the solution for this closed-loop scheme as follows:

If $Re(h^*_1 h_4) \cdot Re(h_2 h^*_3) \geq 0$ feedback k = 0 setting $\alpha = \gamma = \pi$, $\beta = \theta = 0$

If $Re(h^*_1 h_4) \cdot Re(h_2 h^*_3) < 0$ feedback k = 1 setting $\alpha = \beta = \theta = 0$, $\gamma = \pi$.

The block diagram of the proposed closed-loop QOSTBC scheme extended from S_J with four transmit antennas and one receive antenna is depicted below:

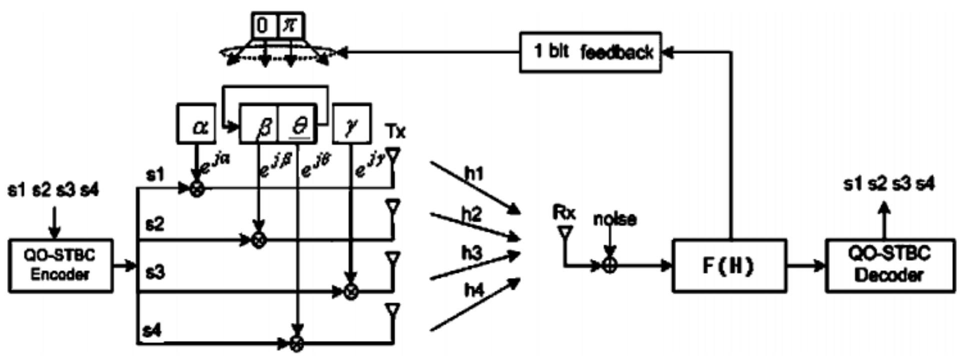

Fig.1: The Proposed Closed-loop Scheme for S_J.

where $F(H) = Re(h^*_1 h_4) \cdot Re(h_2 h^*_3)$.

Since α, β, θ and γ only equal to 0 or π, we have $e^{-j\alpha} = e^{j\beta}$, $e^{-j\beta} = e^{j\beta}$, $e^{-j\theta} = e^{j\theta}$, and

$e^{-j\gamma} = e^{j\gamma}$. Moreover, β and θ will take a right circulation during every time slot.

It is worth pointing out that this proposed scheme in Fig.1, for S_J is also fit for all of the existing QOSTBC. However, in terms of various code words, the introduced angles at the transmitter and the function F(H) at the receiver will be a little different.

4. SIMULATION RESULTS

In this section, we evaluate the error performance of the proposed scheme. In all simulations, we consider only one receiving antenna for simplicity. It is assumed that the channel is quasi-static flat fading channel, and the fading is constant within a frame and changes independently from frame to frame. Besides, the receiver has perfect channel state information.

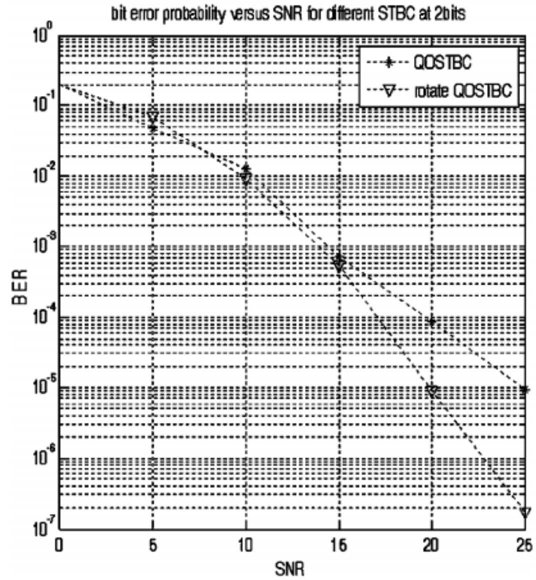

Fig. 2: Bit Error Probability Versus Eb/No for different STBC at 2 bits/(sHz)

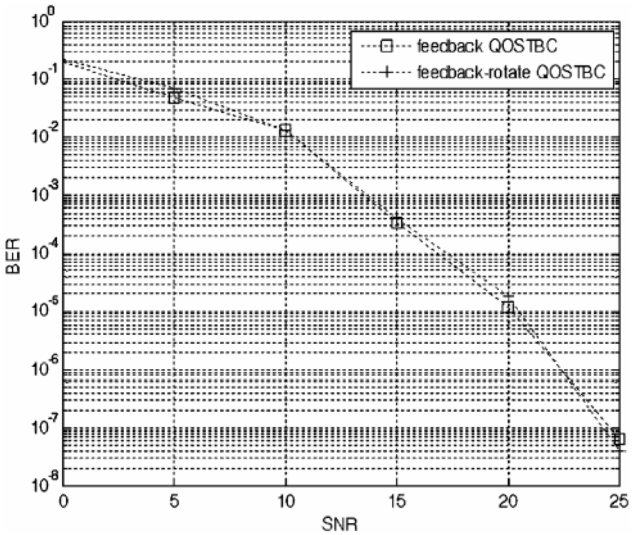

Fig.3: Performances of Rotated QOSTBC and Feedback-Rotated QOSTBC

5. CONCLUSION

A simple closed-loop QOSTBC based on circulant matrix is proposed in this letter. For systems with four transmit antennas and multiple receive antennas, it can enhance the performance with the feedback information as few as 1 bit. In particular, the presented closed-loop scheme can be applied in any existing QOSTBC without increasing the design complexity. Moreover, one important advantage of the proposed scheme is that it needn't to sacrifice the optimal rotated phase for the feedback variable. Simulation results show that the optimal rotated phase in our proposed closed-loop scheme also makes a great contribution to the system performance

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