An Improved Quasi- Orthogonal Space-Time Block Codes for Diversity Reception in Wireless Communication

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ABSTRACT

Quasi orthogonal space time block codes have been proposed to achieve higher symbol transmission rates for more than 2 transmit antennas at the expense of losing the diversity gain. In this paper we propose a method to improve its transmit diversity with one bit feedback. This method useful for extend any space-time code constructed for 4 transmit antennas to M receive antennas. An improvement in transmit diversity is achieved by multiplying each QOSTBC code word with appropriate phase factor which depend on the channel information. Jafarkhani's Quasi Orthogonal Space Time Block Codes as well as its optimal constellation rotated scheme are extended and analyzed.

Keywords- closed-loop, diversity, feedback, Quasi-Orthogonal STBC

1. INTRODUCTION

Spatial diversity transmission and/or reception is a spectrally efficient method to combat multipath fading. Orthogonal space-time block coding [1] in which full diversity is achieved while a very simple maximum-likelihood decoding algorithm is used at the decoder. It is proved in [2] that a complex orthogonal design and the corresponding space-time block code which provides full diversity and full transmission rate is not possible for more than 2 antennas.

Various QOSTBCs have been proposed [3],[4] for 4 transmit antennas with more decoding complexity than OSTBCs. These codes are full rate and provide partial diversity. Recently, many researches designed the STBC with full rate and full diversity for four transmit antennas [5]-[10]. For open-loop communication systems, the optimum constellation rotation proposed for QOSTBC with different modulation schemes is the one of good diversity improvement approaches [5]. Although a lot of partial feedback methods can be adopted to improve the closed-loop system performance [6],[7],[10], the major problems of such systems are high cost and high complexity due to the more feedback information. For practical 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 process.

It is needed to sacrifice the optimal rotated phase in open-loop system for the feedback variable in closed-loop system [11].

A novel closed loop technique is presented by extending the Jafarkhani's QOSTBC and its optimal rotated scheme for the quasi-static flat fading channels with four transmitting antennas. Here one bit feedback of channel information increases the transmit diversity and reduces self interference from adjacent symbols in QOSTBC scheme without sacrificing the optimal rotating phase. The proposed method is more flexible and simple than other methods.

2.THE PROPOSED CLOSED LOOP SCENARIO FOR JAFARKHANI'S QOSTBC

The (4x4) QOSTBC by Jafarkhani is described by the square matrix as

$$S_{JF} = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ -s_3^* & -s_4^* & s_1^* & s_2^* \\ s_4 & -s_3 & -s_2 & s_1 \end{bmatrix} \quad (1)$$

A quasi-static flat fading channel with four transmit antennas and one receive antenna is considered. The received signals during four successive time slots can be expressed

$$\begin{bmatrix} r_1 \\ r_2^* \\ r_3^* \\ r_4 \end{bmatrix} = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3^* & h_4^* & -h_1^* & -h_2^* \\ h_4 & -h_3 & -h_2 & h_1 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \\ n_3^* \\ n_4 \end{bmatrix} \quad (2)$$

$$= H_{JF} S + N$$

Where, the noise samples and the channel entries are independent samples of a zero-mean complex Gaussian random variable with variance one.

Multiplying each element of S_{Jf} by four phase factors, the resultant is:

$$S_P = \begin{bmatrix} s_1 e^{j\alpha} & s_2 e^{j\beta} & s_3 e^{j\gamma} & s_4 e^{j\theta} \\ -s_2^* e^{-j\alpha} & s_1^* e^{-j\theta} & -s_4^* e^{-j\gamma} & s_3^* e^{-j\beta} \\ -s_3^* e^{-j\alpha} & -s_4^* e^{-j\beta} & s_1^* e^{-j\gamma} & s_2^* e^{-j\theta} \\ s_4 e^{j\alpha} & -s_3 e^{j\theta} & -s_2 e^{j\gamma} & s_1 e^{j\beta} \end{bmatrix} \quad (3)$$

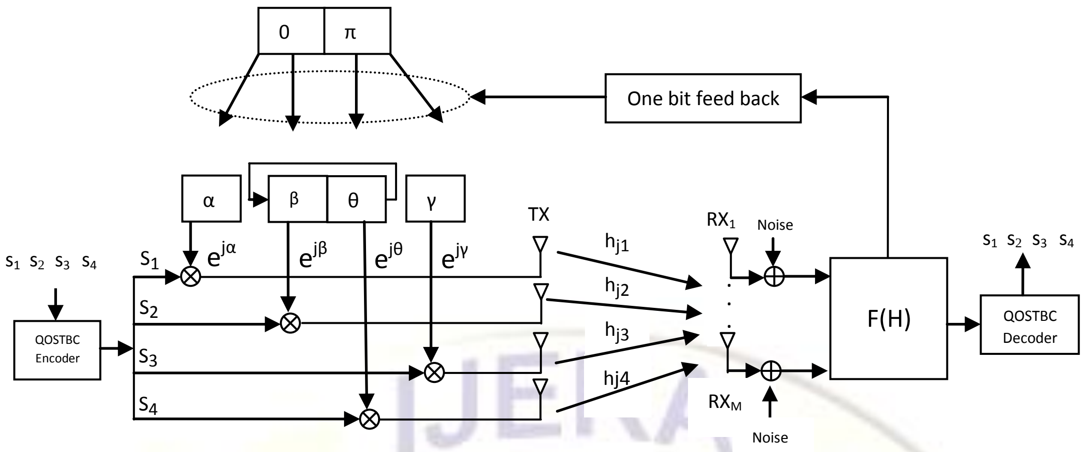

Fig 1: Proposed closed-loop scheme for QOSTBC

The received signals are

$$\begin{bmatrix} r_1 \\ r_2^* \\ r_3^* \\ r_4 \end{bmatrix} = \begin{bmatrix} h_1 e^{j\alpha} & h_2 e^{j\beta} & h_3 e^{j\gamma} & h_4 e^{j\theta} \\ h_2^* e^{j\theta} & -h_1^* e^{j\alpha} & h_4^* e^{j\beta} & -h_3^* e^{j\gamma} \\ h_3^* e^{j\gamma} & h_4^* e^{j\theta} & -h_1^* e^{j\alpha} & -h_2^* e^{j\beta} \\ h_4 e^{j\beta} & -h_3 e^{j\gamma} & -h_2 e^{j\theta} & h_1 e^{j\alpha} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \\ n_3^* \\ n_4 \end{bmatrix} \quad (4)$$

$$= H_P S + N$$

Where he relevant channel matrix H_p is the element-by-element product of matrix H_{JF} and ciculant matrix C_4, where

$$C_4 = \begin{bmatrix} e^{j\alpha} & e^{j\beta} & e^{j\gamma} & e^{j\theta} \\ e^{j\theta} & e^{j\alpha} & e^{j\beta} & e^{j\gamma} \\ e^{j\gamma} & e^{j\theta} & e^{j\alpha} & e^{j\beta} \\ e^{j\beta} & e^{j\gamma} & e^{j\theta} & e^{j\alpha} \end{bmatrix} \quad (5)$$

$e^{j\alpha}, e^{j\beta}, e^{j\gamma}$ and $e^{j\theta}$ are the phase factors. With satisfying the following conditions

$$e^{j(\beta-\alpha)} = e^{j(\alpha-\theta)}, e^{j(\theta-\gamma)} = e^{j(\gamma-\beta)}$$
$$e^{j(\alpha-\gamma)} = e^{j(\gamma-\alpha)}, e^{j(\beta-\theta)} = e^{j(\theta-\beta)} \quad (6)$$

The grammian matrix which can be calculated by left-multiplying the H_P^H with H_p is

$$G_P = H_P^H H_P = h^2 \underbrace{\begin{bmatrix} I_2 & 0 \\ 0 & I_2 \end{bmatrix}}_{U_P} + w \underbrace{\begin{bmatrix} 0 & J_2 \\ -J_2 & 0 \end{bmatrix}}_{V_P} \quad (7)$$

Where I_2 is identity matrix where J_2 and h^2 are

$$J_2 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \qquad h^2 = \sum_{i=1}^{4} |h_i|^2$$

h^2 indicates the total channel gain. w is the channel dependent interference parameter, and given by

$$w = e^{j(\alpha-\beta)}\, 2\mathrm{Re}(h_1^* h_4) - e^{j(\gamma-\theta)}\, 2\mathrm{Re}(h_2 h_3^*) \quad (8)$$

Grammian matrix G_P consists of two components. They are channel gain matrix U_P and the interference matrix V_P. In order to achieve the ideal 4-path diversity, G_P should approach U_P very closely. In other words, the absolute value of w in V_P is to be minimized. The effect of w in V_P is explained in [4]. From Equation (8) on the premise of knowing the partial channel information, we can achieve the minimal absolute value of w by adjusting the value of the two factors $e^{j(\alpha-\beta)}$ and $e^{j(\gamma-\theta)}$.

$$\text{when } \mathrm{Re}(h_1^* h_4)\,\mathrm{Re}(h_2 h_3^*) \ge 0, \text{ set } e^{j(\alpha-\beta)} e^{j(\gamma-\theta)} = 1$$
$$\text{when } \mathrm{Re}(h_1^* h_4)\,\mathrm{Re}(h_2 h_3^*) < 0, \text{ set } e^{j(\alpha-\beta)} e^{j(\gamma-\theta)} = -1 \quad (9)$$

This can be interpreted as follows:
Assuming we know the channel information at the receiver and adopt one bit k = 0 or 1 to indicate

$$\mathrm{Re}(h_1^* h_4)\,\mathrm{Re}(h_2 h_3^*) \ge 0 \quad \text{or} \quad \mathrm{Re}(h_1^* h_4)\,\mathrm{Re}(h_2 h_3^*) < 0$$

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

if $k = 0$ set $\alpha = \gamma = \pi$ and $\beta = \theta = 0$ which gives, $e^{j(\alpha-\beta)} e^{j(\gamma-\theta)} = 1$
if $k = 1$ set $\gamma = \pi$ and $\alpha = \beta = \theta = 0$ which gives, $e^{j(\alpha-\beta)} e^{j(\gamma-\theta)} = -1$

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

$$\text{if } \mathrm{Re}(h_1^* h_4)\,\mathrm{Re}(h_2 h_3^*) \ge 0 \Rightarrow k = 0 \text{ setting } \alpha = \gamma = \pi, \beta = \theta = 0$$
$$\text{if } \mathrm{Re}(h_1^* h_4)\,\mathrm{Re}(h_2 h_3^*) < 0 \Rightarrow k = 1 \text{ setting } \gamma = \pi, \alpha = \beta = \theta = 0$$

The block diagram of proposed scheme is depicted in Fig.1.

$$\text{where } F(H) = \mathrm{Re}(h_1^* h_4)\,\mathrm{Re}(h_2 h_3^*)$$

α, β, θ, γ only equal to 0 or π. Moreover, β and θ will take right circulation during every timeslot.

It is worth pointing out that this proposed scheme in Fig.1 for S_{JF} 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.

3. PROPOSED CLOSED LOOP SCENARIO FOR OPTIMAL ROTATED QOSTBC

In order to provide a full-diversity, a rotated QOSTBC [5] based on S_{JF} is introduced as below:

$$S_{RJF} = \begin{bmatrix} s_1 & s_2 & \mu s_3 & \mu s_4 \\ -s_2^* & s_1^* & -(\mu s_4)^* & (\mu s_4)^* \\ -(\mu s_3)^* & -(\mu s_4)^* & s_1^* & s_2^* \\ \mu s_4 & -\mu s_3 & -s_2 & s_1 \end{bmatrix} \quad (10)$$

Where $\mu = e^{j\o}$ is the rotated factor, it has been proved that when $\o=\pi/4$, it is optimal for QPSK constellation. Based on this optimal rotated QOSTBC, we present our scheme as:

$$S_{PR} = \begin{bmatrix} s_1 e^{j\alpha} & s_2 e^{j\beta} & \mu s_3 e^{j\gamma} & \mu s_4 e^{j\theta} \\ -s_2^* e^{-j\alpha} & s_1^* e^{-j\theta} & -(\mu s_4)^* e^{-j\gamma} & (\mu s_4)^* e^{-j\beta} \\ -(\mu s_3)^* e^{-j\alpha} & -(\mu s_4)^* e^{-j\beta} & s_1^* e^{-j\gamma} & s_2^* e^{-j\theta} \\ \mu s_4 e^{j\alpha} & -\mu s_3 e^{j\theta} & -s_2 e^{j\gamma} & s_1 e^{j\beta} \end{bmatrix} \quad (11)$$

and the expression of the Grammian matrix is

$$G_{PR} = H_{PR}^H H_{PR} = h^2 \underbrace{\begin{bmatrix} I_2 & 0 \\ 0 & I_2 \end{bmatrix}}_{U_{PR}} + [w_1 \quad w_2] \underbrace{\begin{bmatrix} 0 & J_2 \\ -J_2 & 0 \end{bmatrix}}_{V_{PR}} \quad (12)$$

where $w_1 = w e^{\frac{j\pi}{4}}$ and $w_2 = w e^{\frac{-j\pi}{4}}$.

Distinctly, both of w_1 and w_2 depended on w. Hence the solution derived for closed loop scenario of jafarkhani's QOSTBC is also fit for the optimal rotated QOSTBC

4. CLOSED-LOOP SCHEME FOR OPTIMAL ROTATED QOSTBC WITH MULTIPLE RECEIVE ANTENNAS

Proposed scheme can also be applied for a system with M receiver antennas. Assuming a quasi-static flat fading channel with four transmit and M receiver antennas, using the proposed feedback scheme for QOSTBC with optimal rotation, the received signals during four successive time slots can be expressed as:

$$\begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_M \end{bmatrix} = \begin{bmatrix} H_1 \\ H_2 \\ \vdots \\ H_M \end{bmatrix} S + \begin{bmatrix} N_1 \\ N_2 \\ \vdots \\ N_M \end{bmatrix} = HS + N, \quad (13)$$

Where the channel matrix H_j for the $j^{th} (1 \le j \le M)$ receive antenna is

$$H_j = \begin{bmatrix} h_{j1} e^{j\alpha} & h_{j2} e^{j\beta} & \mu h_{j3} e^{j\gamma} & \mu h_{j4} e^{j\theta} \\ h_{j2}^* e^{j\theta} & -h_{j1}^* e^{j\alpha} & \mu h_{j4}^* e^{j\beta} & -\mu h_{j3}^* e^{j\gamma} \\ h j_3^* e^{j\gamma} & h_{j4}^* e^{j\theta} & -\mu h_{j1}^* e^{j\alpha} & -\mu h_{j2}^* e^{j\beta} \\ h_{j4} e^{j\beta} & -h_{j3} e^{j\gamma} & -\mu h_{j2} e^{j\theta} & \mu h_{j1} e^{j\alpha} \end{bmatrix} \quad (14)$$

The received signal vector R_j and noise vector N_j on the j^{th} receive antenna are

$$R_j = [r_{j1} \quad r_{j2}^* \quad r_{j3}^* \quad r_{j4}]^T$$

$$N_j = [n_{j1} \quad n_{j2}^* \quad n_{j3}^* \quad n_{j4}]^T$$

and the transmitted symbol vector:

$$S = [s_1 \quad s_2 \quad s_3 \quad s_4]^T$$

Since the new channel matrix H is a (4M x 4) matrix, the expression of the (4x4) Grammian matrix takes the same form of Equation (12) but with h and w replaced by:

$$h^2 = \sum_{j=1}^{M} \sum_{i=1}^{4} |h_{ji}|^2, \quad (15)$$

$$w = e^{j(\alpha-\beta)} 2 \sum_{j=1}^{M} \mathrm{Re}(h_{j1}^* h_{j4}) - e^{j(\gamma-\theta)} 2 \sum_{j=1}^{M} \mathrm{Re}(h_{j2} h_{j3}^*) \quad (16)$$

The channel dependent interference parameter can be minimized with the aid of one bit feedback information which is determined by the value of the new F(H)

$$F(H) = \sum_{j=1}^{M} \mathrm{Re}(h_{j1}^* h_{j4}) \sum_{j=1}^{M} \mathrm{Re}(h_{j2} h_{j3}^*). \quad (17)$$

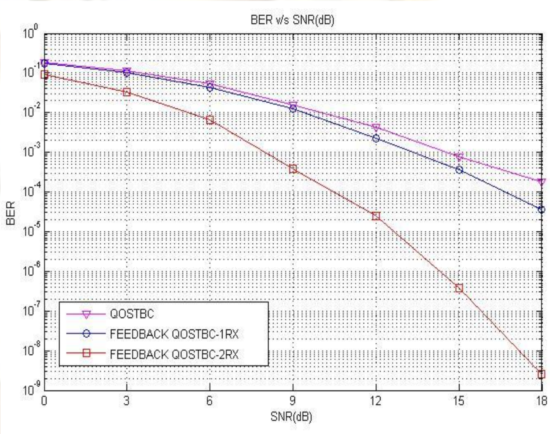

Fig 2: Bit Error Probability versus SNR(dB) for QOSTBC and proposed scheme at 2 bits/(sHz)

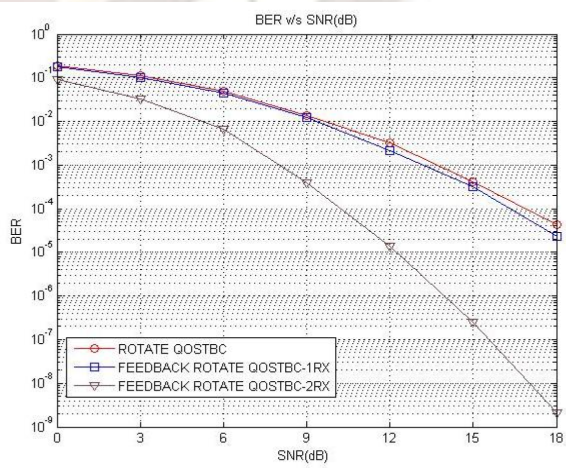

Fig 3: Bit Error Probability versus SNR(dB) for Rotated QOSTBC and proposed scheme at 2 bits/(sHz)

5. RESULTS

The performance of the QOSTBC and its optimal rotated scheme are compared with proposed scheme. 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 and Fig.3, shows the performances of the proposed closed-loop QOSTBC scheme with Maximum Likelihood receiver with one and two receiving antennas. The Jafarkhani's QOSTBC shown in Fig.2 and its optimal rotated scheme are also shown in Fig.3 for comparison. QPSK is adopted for QOSTBC schemes. Simulation results are presented for BER of QOSTBC & proposed closed loop, Simulation results also shown that the performance of feedback QOSTBC is similar with the performance of optimal rotated QOSTBC, nevertheless, the combination of one bit feedback and the optimal constellation rotation can achieve the best performance. For example, when the BER is 10^{-4}, the proposed feedback-rotated QOSTBC gets about 3dB gain over QOSTBC. Proposed scheme gets 0.5dB gain at BER is 10^{-4} over optimal rotated QOSTBC.

6. CONCLUSION

Proposed system with four transmit antennas and multiple receive antennas enhance the SNR performance with the feedback information of one bit only. 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 significant contribution to the system performance by reducing Bit Error Rate.

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