Enhancing Performance of Four Transmit Antennas and One Receive Antenna System with Partial Feedback

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***Abstract*— Extended orthogonal space time block code (EO-STBC) schemes were demonstrated that they can achieve a significant improvement in performance for closed-loop multiple antenna systems with limited feedback channel. This paper investigates a new closed-loop multiple antenna scheme for four transmit antennas and single receive antenna under quasi-static flat Rayleigh fading. In comparison to conventional EO-STBC schemes, the proposed new scheme not only has simpler structure due to not using STBC encoder and decoder, but also has better BER performance without additional feedback bits.**

I. INTRODUCTION

In open-loop MIMO systems where channel state information (CSI) is available only at the receiver but not available at transmitter, orthogonal space-time block codes (OSTBC) are efficient methods to achieve maximum transmit diversity gain and single-symbol maximum likelihood decoding [1], [2]. In contrast, closed-loop MIMO systems can utilize knowledge of the channel at the transmitter to further improve the system performance. While a fully known CSI in the transmitter side is a great benefit in system in various ways (antenna selection [3] and beamforming [4]), it is not realizable due to the infinite resolutions. Partial feedback information to save bandwidth and reduce complexity in the feedback channel is commonly implemented.

A class of partial feedback system, extended orthogonal space-time coding (EO-STBC) was suggested by Akhtar in [5] with just one bit feedback information. This scheme offers full rate and full diversity, with more, simple decoding. And also, Yu in [6] proposed another scheme with two bits feedback information to increase the BER performance by improving average receive SNR and showed that it can be applied to odd number of antennas. Further, Eltayeb in [7] proposed another modified EO-STBC with optimal phase rotation which can be quantized properly according to BER performance demands of systems. The latest, Lee in [8] proposed EO-STBC with combination between optimal phase rotation and code selection which also can quantized properly according to BER performance demands of systems.

In this paper, we propose a new closed-loop scheme without space-time block coding in four transmit antennas and single receive antenna case in particular. Since do not use STBC encoder and decoder, so the proposed scheme has simpler structure than the conventional EO-STBC schemes [5-8]. In addition, the new scheme only require a limited feedback channel with 3 bits per coherent time of channel, so it satisfies requirements for saving bandwidth and reducing complexity in the practical feedback channel. Moreover, the proposed new scheme achieves a significant enhancement of the BER performance in comparison to conventional EO-STBC schemes.

The remainder of this paper is organized as follows. In Section II, we describe the channel model and a brief review of the conventional EO-STBC schemes. Section III presents the proposed new scheme. Simulation results and performance comparison are presented in Section IV. Finally, we conclude in Section V.

II. CHANNEL MODEL AND CONVENTIONAL EO-STBC SCHEMES

A. Chanel Model

Let us consider four transmit antennas and one receive antenna. In this case, channel matrix $\boldsymbol{H} = [\, h_1\ h_2\ h_3\ h_4\,]^T$ be the 4×1. The channel is assumed to be quasi-static flat Rayleigh fading which maintains constant over a frame and it changes independently every frame. Each element h_i, i = 1, 2, 3, 4, of matrix $\boldsymbol{H}$ represents path gain from i-th transmit antenna to receive antenna and is independent identically distributed (*i.i.d*) complex circular symmetric Gaussian random variables with zero mean and variance one. We also assume that the channel model is uncorrelated. Lastly, we assume perfect channel estimation and no feedback error. This channel model is applied to both conventional EO-STBC schemes and the proposed scheme in all sections of this paper.

B. Conventional EO-STBC schemes

In Figure 1, we present conventional EO-STBC schemes in transmitter side. Firstly, we define column vectors, $\boldsymbol{S_1}$ and $\boldsymbol{S_2}$ in order to build EO-STBC.

$$\boldsymbol{S_1} = \begin{bmatrix} x_1 \\ -x_2^* \end{bmatrix}, \quad \boldsymbol{S_2} = \begin{bmatrix} x_2 \\ x_1^* \end{bmatrix} \tag{1}$$

where, x_1 and x_2 are modulated symbols which taken value from a constellation $\mathcal{A}$, and $*$ denotes complex conjugation.

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According to Akhtar in [5], Yu in [6], Eltayeb in [7], and Lee in [8], 2×4 EO-STBC is represented by as follows.

$$\boldsymbol{E_A} = \begin{bmatrix} \boldsymbol{S_1} & \boldsymbol{S_2} & \boldsymbol{S_1} & \boldsymbol{S_2} \end{bmatrix} \tag{2}$$

$$\boldsymbol{E_Y} = \boldsymbol{E_E} = \begin{bmatrix} \boldsymbol{S_1} & \boldsymbol{S_1} & \boldsymbol{S_2} & \boldsymbol{S_2} \end{bmatrix} \tag{3}$$

$$\boldsymbol{E_L} = \begin{cases} \begin{bmatrix} \boldsymbol{S_1} & \sqrt{2}\boldsymbol{S_1} & \boldsymbol{0} & \boldsymbol{S_2} \end{bmatrix}; & \text{if } |h_2|^2 \geq |h_3|^2 \\ \begin{bmatrix} \boldsymbol{S_1} & \boldsymbol{0} & \sqrt{2}\boldsymbol{S_2} & \boldsymbol{S_2} \end{bmatrix}; & \text{if } |h_2|^2 < |h_3|^2 \end{cases} \tag{4}$$

$\boldsymbol{E}_{\mathrm{A}}$, $\boldsymbol{E}_{\mathrm{Y}}$, $\boldsymbol{E}_{\mathrm{E}}$, $\boldsymbol{E}_{\mathrm{L}}$ indicates encoder matrix of EO-STBC by Akhtar, Yu, Eltayeb, and Lee respectively. Each column corresponds to the symbols transmitted from the each antenna and each row represents each transmission period. This notation of code matrix is commonly used in this paper.

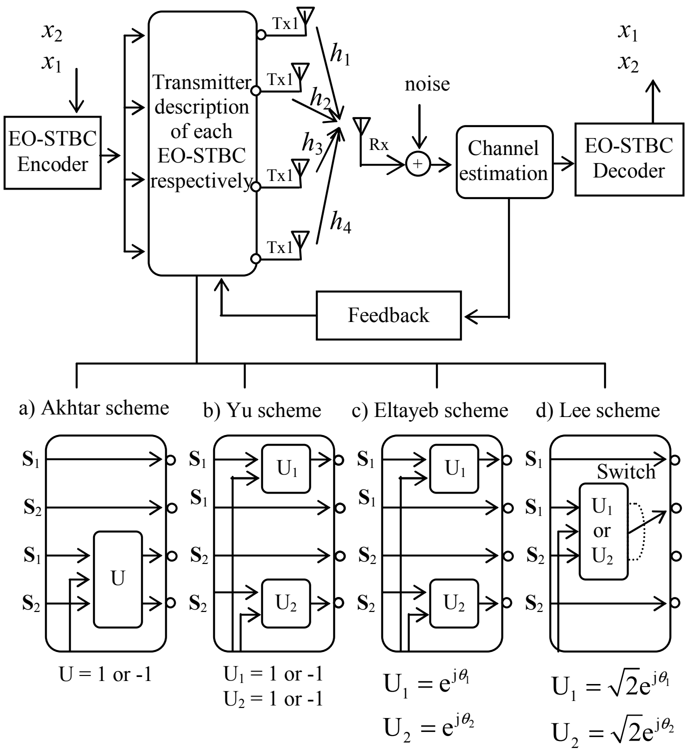

Figure 1: Conventional EO-STBC schemes with four transmit antennas and single receive antenna.

For open loop EO-STBC system, we can obtain received signal, $\boldsymbol{Y} = \frac{1}{2}\boldsymbol{EH} + \boldsymbol{N}$, where $\boldsymbol{E}$ is 2×4 general EO-STBC encoder matrix, $\boldsymbol{H}$ is 4×1 channel matrix, $\boldsymbol{N}$ is 2×1 complex additive white Gaussian noise (AWGN) vector and 1/2 that is determined by $1/N_{\mathrm{T}}$, N_{T} is the number of transmit antennas, maintain constant transmit power even if the number of antennas is changed. It is also denoted by $\bar{\boldsymbol{Y}} = \frac{1}{2}\bar{\boldsymbol{H}}\boldsymbol{X} + \bar{\boldsymbol{N}}$, where $\bar{\boldsymbol{H}}$ is equivalent channel matrix including the orthogonal nature of code matrix and $\mathbf{X} = [x_1\ x_2]^{\mathrm{T}}$ is uncoded transmit signal. After obtaining $\bar{\boldsymbol{H}}$ and multiplying it by its Hermitian that means decoding matrix, we can obtain the matrix that is called Grammian.

$$\boldsymbol{G} = \bar{\boldsymbol{H}}^{\mathrm{H}}\bar{\boldsymbol{H}} = \begin{bmatrix} \alpha+\beta & 0 \\ 0 & \alpha+\beta \end{bmatrix} \tag{5}$$

Grammian matrix with only diagonal elements indicates that EO-STBC schemes have simple decoder. The elements of G can also be utilized to represent the receive SNR as follows.

$$\gamma = \gamma_0(\alpha+\beta)/4 \tag{6}$$

where $\gamma_0 = E_s / N_0$ is the receive SNR without diversity gain, α is conventional channel gain in all STBC scheme and β is additional receive SNR gain only in EO-STBC schemes.

For closed-loop system, the employment of appropriate feedback information for obtaining positive β at all times can be good strategy to elevate BER performance in EO-STBC systems. In Table 1, we summarize receive SNR representations of each EO-STBC scheme with closed-loop. EO-STBC in [5] utilize proper one bit feedback information using U and the idea in [9] is the modification of [6] for increasing receive SNR using U1 and U2 with 2-bits feedback. Eltayeb [7] and Lee [8] propose generalization of feedback information, which is denoted as phase θ.

III. THE PROPOSED SCHEME

A. Construction of the proposed scheme

The block diagram of the proposed scheme is depicted in Figure 2.

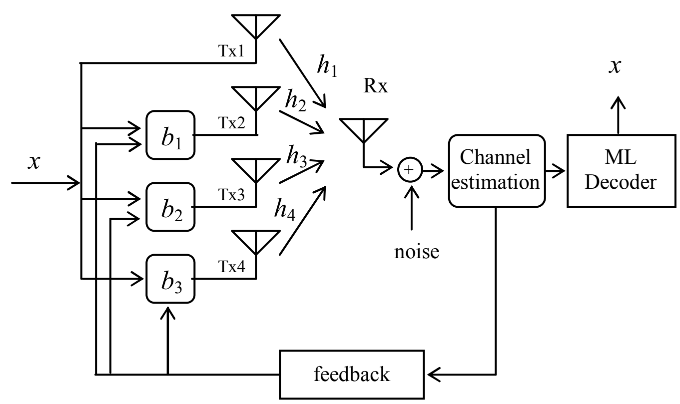

Figure 2: The proposed scheme with four transmit antennas and single receive antenna.

Assuming we have a modulated signal x, a transmitted signal vector for four transmit antennas is constructed as

$$\boldsymbol{E_P} = \begin{bmatrix} x & b_1x & b_2x & b_3x \end{bmatrix} \tag{7}$$

where b_i, i = 1, 2, 3, gets value 1 or -1 depend on feedback information from receiver. Equivalent channel matrix of the proposed scheme is $\bar{\boldsymbol{H}} = h_1 + b_1 h_2 + b_2 h_3 + b_3 h_4$, and the received signal can represented as

$$r = \bar{\boldsymbol{H}} x + n \tag{8}$$

where n is independent identically distributed (*i.i.d*) complex circular symmetric Gaussian random variables with zero mean and variance N_0.

Equation (8) indicates that the proposed new scheme has simple maximum likelihood decoder

$$\hat{x} = \arg\min_{x \in \mathcal{A}} \left| r - \bar{\boldsymbol{H}} x \right|^2 \tag{9}$$

and its the receive SNR is

$$\gamma = \left(\alpha_P + \beta_P \right) \gamma_0 \tag{10}$$

where

$$\alpha_P = \left| h_1 \right|^2 + \left| h_2 \right|^2 + \left| h_3 \right|^2 + \left| h_4 \right|^2 \tag{11}$$

$$\beta_P = 2\,\mathrm{Re}\left\{ \begin{array}{l} b_1 h_1 h_2^* + b_2 h_1 h_3^* + b_3 h_1 h_4^* \\ + b_1 b_2 h_2 h_3^* + b_1 b_3 h_2 h_4^* + b_2 b_3 h_3 h_4^* \end{array} \right\} \tag{12}$$

B. Feedback Bit Selection

Proposition 1: Three bits of feedback are sufficient to ensure a positive β_P value.

Proof: From (12) we have

$$\begin{aligned} \beta_P = 2 b_1 \,\mathrm{Re}\left\{ h_1 h_2^* \right\} + 2 b_2 \,\mathrm{Re}\left\{ \left(h_1 + b_1 h_2 \right) h_3^* \right\} \\ + 2 b_3 \,\mathrm{Re}\left\{ \left(h_1 + b_1 h_2 + b_2 h_3 \right) h_4^* \right\} \end{aligned} \tag{13}$$

It is clear that, the inductive algorithm follows with ensure a positive β_P value.

Initial: $b_0 = 1$;

Inductive: *for* $i = 1$ *to* 3

$$b_i = \begin{cases} 1 & \text{if } \mathrm{Re}\left\{ \left(\sum_{k=1}^{i} b_{k-1} h_i \right) h_{i+1}^* \right\} \geq 0 \\ -1 & \text{if } \mathrm{Re}\left\{ \left(\sum_{k=1}^{i} b_{k-1} h_i \right) h_{i+1}^* \right\} < 0 \end{cases} \tag{14}$$

end.

As an alternative approach, the 3 bits for feedback may be selected according to:

$$b_1, b_2, b_3 = \arg \max_{b_1, b_2, b_3 \in \{1; -1\}} \beta_P \tag{15}$$

i.e., an exhaustive search can be used. The exhaustive search would provide the larger array gain but at additional computational complexity than the inductive search.

IV. COMPARISON RESULTS

This section shows simulation results on BER performance with the proposed scheme and conventional EO-STBC scheme [5]-[8] for channel model described in Section II.A. 4QAM modulation is used for all simulations. In the receiver, the received symbols are decoded by the linear maximum likelihood detector.

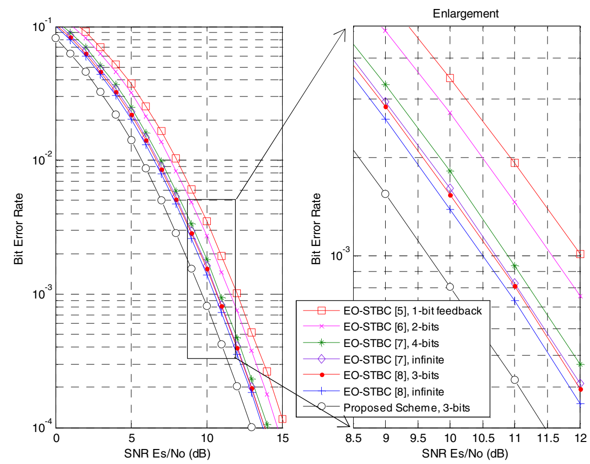

Figure 3: The BER performance comparison among the proposed scheme, conventional EO-STBC schemes proposed by Akhtar [5], Yu [6], Eltayeb [7] and Lee [8].

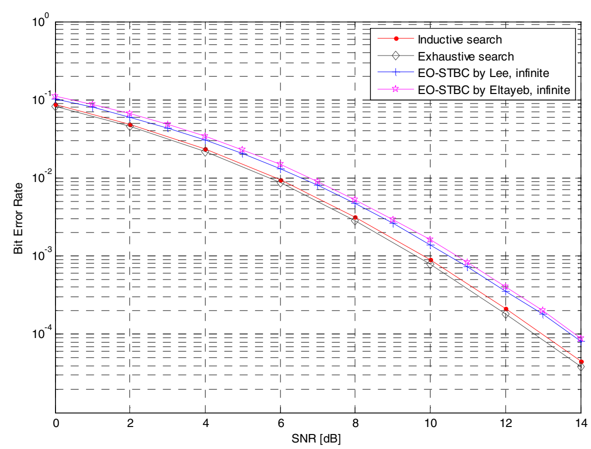

Figure 4: The BER performance of the proposed scheme with the exhaustive search and the inductive search.

Figure 3 shows comparisons of BER performance with the proposed scheme with exhaustive search and conventional EO-STBC scheme [5]-[8]. We can confirm that the proposed scheme is better than with other EO-STBC schemes. By using one or two additional bits compared to the existing EO-STBC schemes [6] and [5], the proposed scheme obtains about 1.8dB and 2.3dB gain at BER of 10^{-3}, respectively. Under the same feedback bits (3 bits), the proposed scheme has the improvement of about 1dB at the BER of 10^{-3} in contrast with quantized feedback EO-STBC scheme in [8] without additional feedback bits. In addition, the proposed scheme which utilizes only 3-bits feedback has respectively about 1dB and 0.8dB gain as compared to the existing EO-STBC schemes [7] and [8] which utilizes the ideal feedback information.

In Figure 4, we compare the BER performance of the proposed scheme with the exhaustive search (15) and the inductive search (14). From the figure we observe that the performance of the inductive search algorithm is worse than that of the exhaustive search algorithm. However, the proposed scheme with inductive search algorithm still outperforms the EO-STBC schemes [7] and [8] which utilizes the ideal feedback information.

V. Conclusions

In this paper, we proposed a simple new closed-loop scheme for four transmitting antennas and one receiving antenna in quasi-static flat fading. Different from the conventional EO-STBC schemes, our proposed scheme does not use STBC encoder and decoder, so our proposed is simpler than the EO-STBC schemes in practical implementation. Moreover, our scheme obtains more additional receive SNR gain than conventional EO-STBC schemes without the increase of complexity in the feedback channel. In particular, the proposed scheme which utilizes only 3-bits feedback has about 1dB gain compared to the existing EO-STBC schemes which utilizes the ideal feedback information. The proposed scheme with desirable capability will be expected to be utilized in advanced wireless communication systems.

Finally, although our scheme is introduced for four transmit antenna system. However, it is easy to extend for number of transmit antenna above four. In this case, inductive search algorithm can be applied to reduce computational complexity for feedback bit selection.

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Table 1: The comparison of receive SNR gain representation and feedback control factor each EO-STBC scheme

Scheme	Receive SNR gain representation	Feedback control factor
Akhtar [5]	$\alpha_A = \lvert h_1\rvert^2 + \lvert h_2\rvert^2 + \lvert h_3\rvert^2 + \lvert h_4\rvert^2$, $\beta_A = 2U\,\mathrm{Re}\{h_1h_3^* + h_2h_4^*\}$	$U = \{1,-1\}$; 1 bit feedback
Yu [6]	$\alpha_Y = \lvert h_1\rvert^2 + \lvert h_2\rvert^2 + \lvert h_3\rvert^2 + \lvert h_4\rvert^2$, $\beta_Y = 2U_1\,\mathrm{Re}\{h_1h_2^*\} + 2U_2\,\mathrm{Re}\{h_3h_4^*\}$	$U_1 = \{1,-1\}$; $U_2 = \{1,-1\}$, 2 bits feedback
Eltayeb [7]	$\alpha_E = \lvert h_1\rvert^2 + \lvert h_2\rvert^2 + \lvert h_3\rvert^2 + \lvert h_4\rvert^2$, $\beta_E = 2\,\mathrm{Re}\{U_1h_1h_2^*\} + 2\,\mathrm{Re}\{U_2h_3h_4^*\}$	$U_1 = \mathrm{e}^{\mathrm{j}\theta_1}$, $\theta_1 = \begin{cases} -angle(h_1h_2^*), & \text{for ideal feedback with infinite bits} \\ \{0, \pi/2, 3\pi/2, \pi\}, & \text{for quantized feedback with 4-bits} \end{cases}$ $U_2 = \mathrm{e}^{\mathrm{j}\theta_2}$, $\theta_2 = \begin{cases} -angle(h_3h_4^*), & \text{for ideal feedback with infinite bits} \\ \{0, \pi/2, 3\pi/2, \pi\}, & \text{for quantized feedback with 4-bits} \end{cases}$
Lee [8]	$\begin{pmatrix} \alpha_L \\ \beta_L \end{pmatrix} = \begin{pmatrix} \lvert h_1\rvert^2 + 2\lvert h_2\rvert^2 + \lvert h_4\rvert^2 \\ 2\,\mathrm{Re}\{U_1h_2h_1^*\} \end{pmatrix}$, if $\lvert h_2\rvert^2 \ge \lvert h_3\rvert^2$ $\begin{pmatrix} \alpha_L \\ \beta_L \end{pmatrix} = \begin{pmatrix} \lvert h_1\rvert^2 + 2\lvert h_3\rvert^2 + \lvert h_4\rvert^2 \\ 2\,\mathrm{Re}\{U_2h_3h_4^*\} \end{pmatrix}$, if $\lvert h_2\rvert^2 < \lvert h_3\rvert^2$	$U_1 = \sqrt{2}\mathrm{e}^{\mathrm{j}\theta_1}$, $\theta_1 = \begin{cases} -angle(h_2h_1^*), & \text{for ideal feedback with infinite bits} \\ \{0, \pi/2, 3\pi/2, \pi\}, & \text{for quantized feedback with 3-bits} \end{cases}$ $U_2 = \sqrt{2}\mathrm{e}^{\mathrm{j}\theta_2}$, $\theta_2 = \begin{cases} -angle(h_3h_4^*), & \text{for ideal feedback with infinite bits} \\ \{0, \pi/2, 3\pi/2, \pi\}, & \text{for quantized feedback with 3-bits} \end{cases}$
Proposed scheme	$\alpha_P = \lvert h_1\rvert^2 + \lvert h_2\rvert^2 + \lvert h_3\rvert^2 + \lvert h_4\rvert^2$, $\beta_P = 2\,\mathrm{Re}\{b_1h_1h_2^* + b_2h_1h_3^* + b_3h_1h_4^* + b_1b_2h_2h_3^* + b_1b_3h_2h_4^* + b_2b_3h_3h_4^*\}$	$b_1 = \{1,-1\}$; $b_2 = \{1,-1\}$; $b_3 = \{1,-1\}$, 3 bits feedback