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A New Space-time Coded Transmission Scheme for Two-user MIMO-MAC ⋆

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Abstract

A new space-time coded transmission scheme with limited feedback is proposed in order to eliminate interference for two-user MIMO-MAC. Each user employs rate-2 space-time block code with phase rotation, which requires a phase feedback. The multiuser interference is eliminated through simple addition of the received signal, and full diversity is realized. the signal to noise ratio is increased in the proposed scheme and the system performance is improved compared with the existing space-time coded transmission scheme with limited feedback.

Keywords: Multi-input Multi-output; Multiple Access Channels; Space-time Code; Multi-user Interference; Signal to Noise Ratio

1 Introduction

Multiple-input multiple-output (MIMO, which is one of the mandatory techniques for the next generation wireless communication systems, has the features of spatial multiplexing and spatial diversity [1]. MIMO multiple access channels (MAC) offer substantial capacity improvements and have attracted considerable research attention [2]. For MIMO-MAC, the performance is deteriorated due to the multiuser interference since multiple users send signals simultaneously in the same frequency [3, 4, 5, 6, 7]. Thus, it is important to design a transmission technique to eliminate the interference over MIMO-MAC.

A number of space-time code designs with feedback information have been proposed to mitigation multiuser interference for two-user MIMO-MAC [8, 9]. In [8], multiuser interference is canceled by linear transformation to space-time codeword at the transmitters while keeping low complexity of decoding. However, it requires too much feedback information. In [9], an Alamouti code based transmit scheme with a phase feedback is presented for two-user MIMO-MAC. This scheme improves the performance the MIMO-MAC system, while preserving the lower decoding complexity. However, [9] only reduces partial multiuser interference and can't realize full diversity.

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In this paper, we propose a new space-time coded transmission scheme for two-user MIMO-MAC. Each user employs rate-2 space-time block code with phase rotation, which requires a phase feedback [10], and each codeword is transmitted twice. The multiuser interference is eliminated through addition and subtraction operation of the received signals, and full diversity is realized. In addition, the signal to noise ratio (SNR) at the receiver is also presented. Simulation results show that the SNR is increased and the gain is no less than 2.5dB at the BER of 10^{-5}.

This paper is organized as follows. In section 2, the system model is described. In section 3, we analyze the diversity gain and SNR of the proposed scheme. Simulation results are given in section 4, and Section 5 concludes the paper.

Notation: The operators $(\cdot)^*$, $(\cdot)^T$ and $(\cdot)^H$ stand for complex conjugation, transpose, and conjugation transpose, respectively. $\|\cdot\|^2$ denotes Frobenius norm of the enclosed term. $Re[\cdot]$ and $Im[\cdot]$ represents real parts and imaginary parts of the enclosed term, respectively. $E(\cdot)$ and $tr(\cdot)$ are the expectation and trace operations, respectively.

2 System Model

The system model is shown in Figure 1. There are two users and one receiver each with two antennas. Let $\mathbf{H}$ and $\mathbf{G}$ denote the channel matrix from user 1 and user 2 to the receiver, respectively. $\mathbf{H} = [\mathbf{h}_1, \mathbf{h}_2]$, $\mathbf{h}_i = [h_{1i}, h_{2i}]^{\mathrm{T}}$, $i = 1, 2$, $\mathbf{G} = [\mathbf{g}_1, \mathbf{g}_2]$, $\mathbf{g}_i = [g_{1i}, g_{2i}]^{\mathrm{T}}$. Assume that the real parts and imaginary parts of the elements of channel and noise are obtained from an independent and normal distribution, with mean 0 and variance 0.5.

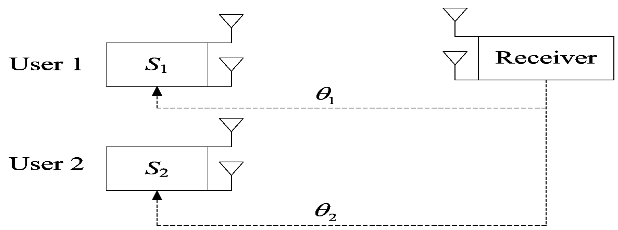

Fig. 1: System model of the proposed scheme

s_i and s_k are the modulated signals for user 1 and user 2, respectively, $i = 1, 2, 3, 4$, $k = 5, 6, 7, 8$. Each user empolys rate-2 space time block code with phase rotation. The codeword of each user is denoted by $\mathbf{S}_i\,(i = 1, 2)$ as

$$\mathbf{S}_i = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\theta_i} \end{bmatrix} \begin{bmatrix} \alpha_1 s'_{4i-3} - \beta_1 s'^*_{4i-2} & \beta_1 s'^*_{4i-1} + \alpha_1 s'_{4i} \\ \alpha_2 s'_{4i-1} - \beta_2 s'^*_{4i} & \beta_2 s'^*_{4i-3} + \alpha_2 s'_{4i-2} \end{bmatrix}$$

where $\mathrm{j} = \sqrt{-1}$; θ_1 and θ_2, explained in detail in [10], are feedback information; α_1,α_2,β_1, and β_2 are real number with $\alpha_1^2 + \beta_1^2 = 1$ and $\alpha_2^2 + \beta_2^2 = 1$ [11]; $s'_i\,(i = 1, 2, \cdots, 8)$ is defined as

$$\begin{bmatrix} s'_{4i-3} \\ s'_{4i-2} \\ s'_{4i-1} \\ s'_{4i} \end{bmatrix} = \begin{bmatrix} Re[s_{4i-3}] + \mathrm{j}Re[s_{4i-1}] \\ Im[s_{4i-3}] + \mathrm{j}Im[s_{4i-1}] \\ Re[s_{4i-2}] + \mathrm{j}Re[s_{4i}] \\ Im[s_{4i-2}] + \mathrm{j}Im[s_{4i}] \end{bmatrix}$$

The transmission is divided into two steps. Step 1, user 1 and user 2 transmit $\mathbf{S}_1$ and $\mathbf{S}_2$ respectively. The received signals of size 2 is denoted by $\mathbf{Z}_1$ as

$$\mathbf{Z}_1 = P\left(\mathbf{HS}_1 + \mathbf{GS}_2\right)\Big/\sqrt{2} + \mathbf{N}_1 \tag{1}$$

where P is the transmit power, $\mathbf{N}_1$ is the noise of size 2×2 at the receiver.

Step 2, user 1 and user 2 transmit $\mathbf{S}_1$ and $-\mathbf{S}_2$ respectively. The received signals of size 2×2 is denoted by $\mathbf{Z}_2$ as

$$\mathbf{Z}_2 = P\left(\mathbf{HS}_1 - \mathbf{GS}_2\right)\Big/\sqrt{2} + \mathbf{N}_2 \tag{2}$$

where $\mathbf{N}_2$ is the noise of size 2×2 at the receiver.

Two users sends 8 modulated signals during four time slot in the proposed scheme while 4 modulated signals in [10]. So, the transmission efficiency of the proposed scheme is the same as that of [9].

Combining (1) and (2), we have

$$\mathbf{Y}_1 = \left(\mathbf{Z}_1 + \mathbf{Z}_2\right)/2 = P\mathbf{HS}_1\Big/\sqrt{2} + \mathbf{W}_1 \tag{3}$$

$$\mathbf{Y}_2 = \left(\mathbf{Z}_1 - \mathbf{Z}_2\right)/2 = P\mathbf{GS}_2\Big/\sqrt{2} + \mathbf{W}_2 \tag{4}$$

where $\mathbf{W}_1 = \left(\mathbf{N}_1 + \mathbf{N}_2\right)/2$, $\mathbf{W}_2 = \left(\mathbf{N}_1 - \mathbf{N}_2\right)/2$. It is obvious that we separate the signals of user 1 from user 2 by simple addition of the received signals. In other words, the multiuser interference is eliminated.

3 Analysis of Diversity Gain and SNR

By (3) and (4), we know that the elements of channel and noise, corresponding to $\mathbf{S}_i\,(i = 1, 2)$, follow independent normal distribution. Therefore, the diversity is full for each codeword sent by each user [11].

From (3) and (4), we can obtain that the SNR of user 1 and use 2 are $E\left[P\left\|\mathbf{HS}_1\right\|^2 \Big/ \left(2\left\|\mathbf{W}_1\right\|^2\right)\right]$ and $E\left(P\left\|\mathbf{GS}_2\right\|^2 \Big/ \left(2\left\|\mathbf{W}_2\right\|^2\right)\right)$, respectively. The calculation of $\left\|\mathbf{HS}_1\right\|^2$ and $\left\|\mathbf{GS}_2\right\|^2$ are complexity. In what follows, we present a simple method of calculating the SNR. For simplicity of computation, we assume $\alpha_1 = \beta_2$ and $\alpha_2 = \beta_1$.

From [10], (3) can be effectively written as following

$$\begin{bmatrix} Re\left[\mathbf{Y}_1'\right] \\ Im\left[\mathbf{Y}_1'\right] \end{bmatrix} = \frac{P}{\sqrt{2}}\mathbf{H}_{\theta_1}'' \begin{bmatrix} Re\left[\mathbf{s}_1'\right] \\ Im\left[\mathbf{s}_1'\right] \end{bmatrix} + \begin{bmatrix} Re\left[\mathbf{W}_1'\right] \\ Im\left[\mathbf{W}_1'\right] \end{bmatrix} \tag{5}$$

where $\mathbf{Y}_1' = \left[y_{11}, y_{12}^*, y_{21}, y_{22}^*\right]^{\mathrm{T}}$, $\mathbf{W}_1' = \left[w_{11}, w_{12}^*, w_{21}, w_{22}^*\right]^{\mathrm{T}}$, y_{ik} and w_{ik} denote the entry of $\mathbf{Y}_1$ and $\mathbf{W}_1$ at i-th row and k-th column respectively, $\mathbf{s}_1' = \left[s_1', \left(s_2'\right)^*, s_3', \left(s_4'\right)^*\right]^{\mathbf{T}}$, and $\mathbf{H}_{\theta_1}''$ is given by

$$H_{\theta_1}'' = \begin{bmatrix} Re\left[\mathbf{H}_{\theta_1}'\right] & -Im\left[\mathbf{H}_{\theta_1}'\right] \\ Im\left[\mathbf{H}_{\theta_1}'\right] & Re\left[\mathbf{H}_{\theta_1}'\right] \end{bmatrix} \tag{6}$$

$$\mathbf{H}_{\theta_1}^{'} = \begin{bmatrix} \alpha_1 h^{\theta_1}{}_{11} & -\beta_1 h^{\theta_1}{}_{11} & \alpha_2 h^{\theta_1}{}_{12} & -\beta_2 h^{\theta_1}{}_{12} \\ \beta_2 h^{\theta_1}{}_{12}{}^{*} & \alpha_2 h^{\theta_1}{}_{12}{}^{*} & \beta_1 h^{\theta_1 *}_{11} & \alpha_1 h^{\theta_1}{}_{11}{}^{*} \\ \alpha_1 h^{\theta_1}{}_{21} & -\beta_1 h^{\theta_1}{}_{21} & \alpha_2 h^{\theta_1}{}_{22} & -\beta_2 h^{\theta_1}{}_{22} \\ \beta_2 h^{\theta_1}{}_{22}{}^{*} & \alpha_2 h^{\theta_1}{}_{22}{}^{*} & \beta_1 h^{\theta_1}{}_{21}{}^{*} & \alpha_1 h^{\theta_1}{}_{21}{}^{*} \end{bmatrix} \tag{7}$$

in which $h_{ik}^{\theta_1}$ represents the entry of $\mathbf{H}_{\theta_1}$ at i-th row and k-th column, $\mathbf{H}_{\theta_1} = \mathbf{H} \begin{bmatrix} 1 & 0 \\ 0 & e^{\mathrm{j}\theta_1} \end{bmatrix}$.

From (5), the SNR of user 1 at the receiver is

$$r_1 = \frac{P^2 E\left[\left\|\mathbf{H}_{\theta_1}^{''} \left[Re\left[\mathbf{s}_1'\right], Im\left[\mathbf{s}_1'\right]\right]^{\mathbf{T}}\right\|^2\right]}{2E\left[\left\|\left[Re\left[\mathbf{W}'\right], Im\left[\mathbf{W}'\right]\right]^{\mathbf{T}}\right\|^2\right]} \tag{8}$$

Let $\Delta 1 = E\left[\left\|\mathbf{H}_{\theta_1}^{''} \left[Re\left[\mathbf{s}_1'\right], Im\left[\mathbf{s}_1'\right]\right]^{\mathbf{T}}\right\|^2\right]$. From (3,4) in [12], we have

$$\Delta 1 = E\left[tr\left(\left[Re\left[\mathbf{s}_1'\right], Im\left[\mathbf{s}_1'\right]\right] \mathbf{H}_{\theta_1}{}^{''\mathbf{H}} \mathbf{H}_{\theta_1}{}^{''} \left[Re\left[\mathbf{s}_1'\right], Im\left[\mathbf{s}_1'\right]\right]^{\mathbf{T}}\right)\right] \tag{9}$$

By [7], we have

$$\mathbf{H}_{\theta_1}{}^{''\mathbf{H}} \mathbf{H}_{\theta_1}{}^{''} = \begin{bmatrix} \mathbf{F} & 0 \\ 0 & \mathbf{F} \end{bmatrix} \tag{10}$$

$F = Re\left[\mathbf{H}_{\theta_1}^{'}\right]^{H} Re\left[\mathbf{H}_{\theta_1}^{'}\right] + Im\left[\mathbf{H}_{\theta_1}^{'}\right]^{H} Im\left[\mathbf{H}_{\theta_1}^{'}\right]$. Substituting (7) into $\mathbf{F}$, and then substituting $\mathbf{F}$ into (10), we get

$$\mathbf{H}_{\theta_1}{}^{''H} \mathbf{H}_{\theta_1}{}^{''} = \begin{bmatrix} \mathbf{A} & \mathbf{C} & 0 & 0 \\ \mathbf{C} & \mathbf{B} & 0 & 0 \\ 0 & 0 & \mathbf{A} & \mathbf{C} \\ 0 & 0 & \mathbf{C} & \mathbf{B} \end{bmatrix} \tag{11}$$

where, $\mathbf{A} = \begin{bmatrix} a & b \\ b & d \end{bmatrix}$, $\mathbf{B} = \begin{bmatrix} d & -b \\ -b & a \end{bmatrix}$, $\mathbf{C} = \begin{bmatrix} c & 0 \\ 0 & c \end{bmatrix}$, $a = \alpha_1^2 \sum_{i=1}^{2} \left(h^{\theta_1}{}_{i1}\right)^2 + \beta_2^2 \sum_{i=1}^{2} \left(h^{\theta_1}{}_{12}{}^{*}\right)^2$, $b = \sum_{i=1}^{2} \left(-\alpha_1\beta_1 \left(h^{\theta_1}{}_{11}\right)^2 + \alpha_2\beta_2 \left(h_{i2}^{\theta_1 *}\right)^2\right)$, $d = \sum_{i=1}^{2} \left(\beta_1^2 \left(h^{\theta_1}{}_{i1}\right)^2 + \alpha_2^2 \left(h_{12}^{\theta_1 *}\right)^2\right)$,
$c = \sum_{i=1}^{2} \begin{bmatrix} \alpha_1\alpha_2 \left(Re\left[h^{\theta_1}{}_{i1}\right] Re\left[h^{\theta_1}{}_{i2}\right] + Im\left[h^{\theta_1}{}_{i1}\right] Im\left[h_{i2}^{\theta_1}\right]\right) \\ +\beta_1\beta_2 \left(Re\left[h^{\theta_1 *}_{i1}\right] Re\left[h^{\theta_1 *}_{i2}\right] + Im\left[h^{\theta_1 *}_{i1}\right] Im\left[h^{\theta_1 *}_{i2}\right]\right) \end{bmatrix}$.

Substituting (11) into (9) yields

$$\Delta 1 = E\left[Tr\left(\begin{array}{l} Re\left[s_1\right]\left(aRe\left[s_1\right]+bIm\left[s_1\right]+cRe\left[s_2\right]\right) \\ +Im\left[s_1\right]\left(bRe\left[s_1\right]+dIm\left[s_1\right]+cIm\left[s_2\right]\right) \\ +Re\left[s_2\right]\left(cRe\left[s_1\right]+dRe\left[s_2\right]-bIm\left[s_2\right]\right) \\ +Im\left[s_2\right]\left(cIm\left[s_1\right]-bRe\left[s_2\right]+aIm\left[s_2\right]\right) \\ +Re\left[s_3\right]\left(aRe\left[s_3\right]-bIm\left[s_3\right]+cRe\left[s_4\right]\right) \\ -Im\left[s_3\right]\left(bRe\left[s_3\right]-dIm\left[s_3\right]-cIm\left[s_4\right]\right) \\ +Re\left[s_4\right]\left(cRe\left[s_3\right]+dRe\left[s_4\right]+bIm\left[s_4\right]\right) \\ -Im\left[s_4\right]\left(-cIm\left[s_3\right]-bRe\left[s_4\right]-aIm\left[s_4\right]\right) \end{array}\right)\right] \tag{12}$$

Since all the real parts and imaginary parts of the elements of channel matrix have distribution $CN(0,\,0.5)$, $E\left[b\right]=E\left[c\right]=0$. Thus, (12) can be written as

$$\Delta 1 = E\left[Tr\left(a\left(Re\left[s_1\right]^2+Im\left[s_2\right]^2+Re\left[s_3\right]^2+Im\left[s_4\right]^2\right)+d\left(Im\left[s_1\right]^2+Re\left[s_2\right]^2+Im\left[s_3\right]^2+Re\left[s_4\right]^2\right)\right)\right] \tag{13}$$

Since 4QAM is adopted, $Re\left[s_1\right]^2=Im\left[s_1\right]^2=0.5$. Thus, $\Delta 1$ reduces to

$$\Delta 1 = 2E\left[\sum_{i=1}^{2}\left(h^{\theta_1}{}_{i1}\right)^2+\sum_{i=1}^{2}\left(h^{\theta_1}{}_{12}{}^{*}\right)^2\right]=8$$

Similarly, we get $E\left[\left[Re\left[\mathbf{W}'\right], Im\left[\mathbf{W}'\right]\right]^T\right]=2$.

From the above analysis, we get $r_1 = 2P^2$. Similarly, the SNR of user 2 at the receiver is also $2P^2$.

4 Simulation Results

In this section, the performance of the proposed scheme and the Alamouti coded transmission scheme in [9] are compared through simulation. We consider uncoded systems with $4QAM$ and $16QAM$ constellations.

Table 1 shows the SNR of the two schemes with $P = 1$. The SNR of the proposed scheme is close to 2 for $4QAM$, demonstrating the validity of theoretical analysis. The SNR of the proposed scheme is also close to 2 for $16QAM$. We know from this Table that the channel gain of the proposed scheme is magnified by 43% effectively. Two reasons can explain this improvement. Firstly, all the multiuser interference is canceled by the proposed scheme while partial multiuser interference in [9]. Secondly, each codeword is transmitted twice in the proposed scheme while once in [10].

Figure 2 compares the BER of the two schemes. It can be seen that the performance of the proposed scheme shows better than the scheme in [9] significantly. The gain is no less than 3.5dB and 2.5dB at the BER of 10^{-5} for *4QAM* and $16QAM$, respectively. That is because the SNR of the proposed scheme is higher than that of [9] with the same modulation and channel condition.

Table 1: The SNR of the two schemes

Modulation	4QAM	16QAM
Proposed	1.9995	2.0053
Alamouti coded transmission scheme	1.4011	1.4050

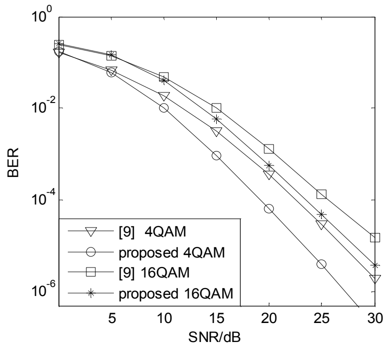

Fig. 2: The BER of the two schemes

5 Conclusions

A new space-time coded transmission scheme for two-user MIMO-MAC is proposed in this paper. Our main idea is to cancel multiuser interference through addition and subtraction operation of the received signals. Furthermore, each codeword is transmitted twice. The drawback of the proposed scheme is one phase feedback overhead compared with [9]. However, full diversity is realized and the system performance is improved significantly. Moreover, the proposed scheme is not restricted to system with rate-2 space-time block code. It can be extended to other type of perfect space-time block code.

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