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Improved Interference Cancellation Scheme for *X* Channels with Four Antennas

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Abstract

Interference cancellation scheme without feedback is proposed for *X* channels with four antennas at each user. Space-time codeword with Alamouti structure is designed for each user. Codewords are combined according a certain rule. The unwanted codewords are cancelled by linear operation on the received signals. Then, multi-user interference is mitigated by the orthogonal property of the Alamouti code. Comparing with the existing scheme for the same scene, feedback information is not required in the proposed scheme. So the transmission efficiency is improved.

Keywords

X Channel, Space-Time Codeword, Multi-User Interference, Transmission Efficiency, Feedback Information

1. Introduction

Multi-input multi-output (MIMO) systems have the ability to improve the reliability and the effectiveness by transmitting independent data stream simultaneously. There are single user MIMO and multi-user MIMO [1] [2]. For multi-user MIMO system, each user transmits signals to one or more receivers simultaneously using the same band. Since these users can't cooperate with each other, there is serious interference at each receiver, which seriously affects the system performance [3] [4].

Interference alignment is the most studied interference cancellation method [5] [6]. Interference alignment aligns the interference signals along the same subspace while the wanted signals occupy linearly independent signal dimensions, such that the wanted signals can be separated [7] [8]. Later, interference alignment and space-time code are combined to obtain diversity gain [9] [10]. For example, interference alignment and space-time code are introduced into two users MIMO X channels, in which multi-user interference is eliminated by interference alignment and linear processing at the receivers [11]. In [11], the transmission efficiency and the diversity gain are 8/3 symbol/channel and 2, respectively. The idea in [11] is extended into [12], in which 4×4 space-time code is used at each user and two columns of the zero vector are introduced into each codeword. [13] proposes a method of interference cancellation using space-time and pre-coding for MIMO X channels, where each user has four antennas. However, in [12] and [13], channel station information (CSI) is required at the two users. Since some time slots are required to send CSI, the transmission efficiency needs to be improved.

Interference cancellation method without feedback is proposed for X channels with 4 antennas at each user. Codewords with Alamouti structure are designed, which contain 4 independent modulated symbols, and then the codewords are combined with a certain rule. The unwanted codewords are eliminated by linear operation on the received signals, and then the interference between wanted codewords is cancelled using the orthogonal property of the Alamouti code. So the multi-user interference is mitigated. Compared with the same scheme for the same scene, our proposed scheme greatly reduces feedback amount, while keeping the same diversity gain. Simulation results demonstrate the validity of the proposed scheme.

2. System Model

The system model proposed in this paper is shown in **Figure 1**. Consider a two-user and two-receiver X channel, where each node has four antennas. Use $R_i\left(i=1,2\right)$ to denote the two receivers. Both users want to send different codewords to R_1 and R_2 on the same frequency band at the same time. As shown in **Figure 1**, $\boldsymbol{C}_1$ and $\boldsymbol{S}_1$ are the wanted codewords for R_1, hence they become interference for R_2. $\boldsymbol{C}_2$ and $\boldsymbol{S}_2$ are the wanted codewords for R_2, hence they become interference for R_1. $\boldsymbol{C}_i\left(i=1,2\right)$ and $\boldsymbol{S}_i$ can be written as

$$\begin{aligned}\boldsymbol{C}_i &= \begin{bmatrix} c_{4i-3}+e^{j\theta}c_{4i-1} & -c_{4i-2}^{*}-e^{-j\theta}c_{4i}^{*} \\ c_{4i-2}+e^{j\theta}c_{4i} & c_{4i-3}^{*}+e^{-j\theta}c_{4i-1}^{*} \end{bmatrix} \\ \boldsymbol{S}_i &= \begin{bmatrix} s_{4i-3}+e^{j\theta}s_{4i-1} & -s_{4i-2}^{*}-e^{-j\theta}s_{4i}^{*} \\ s_{4i-2}+e^{j\theta}s_{4i} & s_{4i-3}^{*}+e^{-j\theta}s_{4i-1}^{*} \end{bmatrix}\end{aligned} \tag{1}$$

where $c_k\left(k=1,2,\cdots,8\right)$ and s_k are the modulated signals. The elements of $\boldsymbol{C}_i$ and $\boldsymbol{S}_i$ are un-zero with the proper value of θ. $\left(\cdot\right)^{*}$ denotes the conjugate.

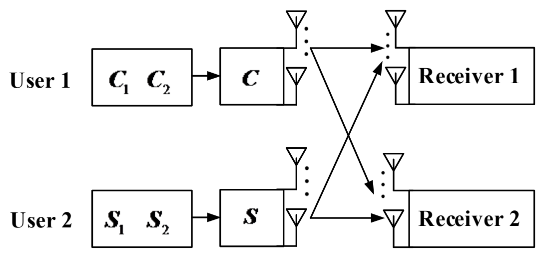

Figure 1. System model of the proposed X channel.

The two users combine $\boldsymbol{C}_i$ and $\boldsymbol{S}_i$ respectively to get $\boldsymbol{C}$ and $\boldsymbol{S}$ as follows

$$\boldsymbol{C} = \begin{bmatrix} \boldsymbol{C}_1 + \boldsymbol{C}_2 & \boldsymbol{C}_1 - \boldsymbol{C}_2 \\ \boldsymbol{C}_1 - \boldsymbol{C}_2 & \boldsymbol{C}_1 + \boldsymbol{C}_2 \end{bmatrix}$$
$$\boldsymbol{S} = \begin{bmatrix} \boldsymbol{S}_1 + \boldsymbol{S}_2 & \boldsymbol{S}_1 - \boldsymbol{S}_2 \\ \boldsymbol{S}_1 - \boldsymbol{S}_2 & \boldsymbol{S}_1 + \boldsymbol{S}_2 \end{bmatrix} \quad (2)$$

Let $\boldsymbol{H}_i$ and $\boldsymbol{G}_i$ to denote the 4 × 4 channel matrices from user 1 to R_i and from user 2 to R_i, respectively. These two users transmit $\boldsymbol{C}$ and $\boldsymbol{S}$ respectively at the same time. The received signals at R_1 and R_2, denoted by $\boldsymbol{Y}$ and $\boldsymbol{Z}$ with dimension 4 × 4 respectively, which are written as follows

$$\boldsymbol{Y} = \boldsymbol{H}_1 \begin{bmatrix} \boldsymbol{C}_1 + \boldsymbol{C}_2 & \boldsymbol{C}_1 - \boldsymbol{C}_2 \\ \boldsymbol{C}_1 - \boldsymbol{C}_2 & \boldsymbol{C}_1 + \boldsymbol{C}_2 \end{bmatrix} + \boldsymbol{G}_1 \begin{bmatrix} \boldsymbol{S}_1 + \boldsymbol{S}_2 & \boldsymbol{S}_1 - \boldsymbol{S}_2 \\ \boldsymbol{S}_1 - \boldsymbol{S}_2 & \boldsymbol{S}_1 + \boldsymbol{S}_2 \end{bmatrix} + \boldsymbol{N} \quad (3)$$

$$\boldsymbol{Z} = \boldsymbol{H}_2 \begin{bmatrix} \boldsymbol{C}_1 + \boldsymbol{C}_2 & \boldsymbol{C}_1 - \boldsymbol{C}_2 \\ \boldsymbol{C}_1 - \boldsymbol{C}_2 & \boldsymbol{C}_1 + \boldsymbol{C}_2 \end{bmatrix} + \boldsymbol{G}_2 \begin{bmatrix} \boldsymbol{S}_1 + \boldsymbol{S}_2 & \boldsymbol{S}_1 - \boldsymbol{S}_2 \\ \boldsymbol{S}_1 - \boldsymbol{S}_2 & \boldsymbol{S}_1 + \boldsymbol{S}_2 \end{bmatrix} + \boldsymbol{W} \quad (4)$$

where, $\boldsymbol{N}$ and $\boldsymbol{W}$ are 4 × 4 Gaussian noise matrices.

3. The Method of Interference Cancellation

The interference alignment method is presented, taking R_1 as example. Let $\boldsymbol{H}_1 = [\boldsymbol{H}_{11} \quad \boldsymbol{H}_{21}]$, $\boldsymbol{G}_1 = [\boldsymbol{G}_{11} \quad \boldsymbol{G}_{21}]$, $\boldsymbol{N} = [\boldsymbol{N}_{11} \quad \boldsymbol{N}_{21}]$ and $\boldsymbol{Y} = [\boldsymbol{Y}_{11} \quad \boldsymbol{Y}_{21}]$. The dimension of $\boldsymbol{H}_{i1}$, $\boldsymbol{G}_{i1}$, $\boldsymbol{Y}_{i1}$ and $\boldsymbol{N}_{i1}$ are all 4 × 2. From (2) (3) (5) and (6) can be obtained.

$$\boldsymbol{Y}_{11} = \boldsymbol{H}_{11}(\boldsymbol{C}_1 + \boldsymbol{C}_2) + \boldsymbol{H}_{21}(\boldsymbol{C}_1 - \boldsymbol{C}_2) + \boldsymbol{G}_{11}(\boldsymbol{S}_1 + \boldsymbol{S}_2) + \boldsymbol{G}_{21}(\boldsymbol{S}_1 - \boldsymbol{S}_2) + \boldsymbol{N}_{11} \quad (5)$$

$$\boldsymbol{Y}_{21} = \boldsymbol{H}_{11}(\boldsymbol{C}_1 - \boldsymbol{C}_2) + \boldsymbol{H}_{21}(\boldsymbol{C}_1 + \boldsymbol{C}_2) + \boldsymbol{G}_{11}(\boldsymbol{S}_1 + \boldsymbol{S}_2) + \boldsymbol{G}_{21}(\boldsymbol{S}_1 + \boldsymbol{S}_2) + \boldsymbol{N}_{21} \quad (6)$$

From (5) (6), (7) can be obtained.

$$\underbrace{\boldsymbol{Y}_{11} + \boldsymbol{Y}_{21}}_{\boldsymbol{Y}_1} = \underbrace{2(\boldsymbol{H}_{11} + \boldsymbol{H}_{21})}_{\boldsymbol{H}_1}\boldsymbol{C}_1 + \underbrace{2(\boldsymbol{G}_{11} + \boldsymbol{G}_{21})}_{\boldsymbol{H}_2}\boldsymbol{S}_1 + \underbrace{\boldsymbol{N}_{11} + \boldsymbol{N}_{21}}_{\boldsymbol{N}_1} \quad (7)$$

The wanted codewords of R_1 are included in (7), while the unwanted codewords are not included. Thus, the unwanted codewords are mitigated through linear operation on the received signals, and the number of interfering codewords is reduced. However, interference between $\boldsymbol{C}_1$ and $\boldsymbol{S}_1$ still exists, as shown in (7). In what follows, the method to separate $\boldsymbol{C}_1$ and $\boldsymbol{S}_1$ is presented.

Let $\boldsymbol{H}_1 = \begin{bmatrix} h_{11}^1 & h_{12}^1 \\ h_{21}^1 & h_{22}^1 \end{bmatrix}$ and $\boldsymbol{H}_2 = \begin{bmatrix} h_{11}^2 & h_{12}^2 \\ h_{21}^2 & h_{22}^2 \end{bmatrix}$. Use y_{ij} and n_{ij} to denote the elements of $\boldsymbol{Y}_1$ and $\boldsymbol{N}_1$, respectively, $i = 1,2,3,4$, $j = 1,2$. From (7), we have

$$\underbrace{\begin{bmatrix} y_{11} \\ y_{12}^* \end{bmatrix}}_{\boldsymbol{y}_1} = \boldsymbol{Z}_1 \begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix} + \boldsymbol{Z}_2 \begin{bmatrix} s_1 + e^{j\theta} s_3 \\ s_2 + e^{j\theta} s_4 \end{bmatrix} + \underbrace{\begin{bmatrix} n_{11} \\ n_{12}^* \end{bmatrix}}_{\boldsymbol{n}_1} \quad (8)$$

$$\underbrace{\begin{bmatrix} y_{21} \\ y_{22}^* \end{bmatrix}}_{\boldsymbol{y}_2} = \boldsymbol{Z}_3 \begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix} + \boldsymbol{Z}_4 \begin{bmatrix} s_1 + e^{j\theta} s_3 \\ s_2 + e^{j\theta} s_4 \end{bmatrix} + \underbrace{\begin{bmatrix} n_{21} \\ n_{22}^* \end{bmatrix}}_{\boldsymbol{n}_2} \quad (9)$$

$$\underbrace{\begin{bmatrix} y_{31} \\ y_{32}^* \end{bmatrix}}_{y_3} = Z_5 \begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix} + Z_6 \begin{bmatrix} s_1 + e^{j\theta} s_3 \\ s_2 + e^{j\theta} s_4 \end{bmatrix} + \underbrace{\begin{bmatrix} n_{31} \\ n_{32}^* \end{bmatrix}}_{n_3} \tag{10}$$

$$\underbrace{\begin{bmatrix} y_{41} \\ y_{42}^* \end{bmatrix}}_{y_4} = Z_7 \begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix} + Z_8 \begin{bmatrix} s_1 + e^{j\theta} s_3 \\ s_2 + e^{j\theta} s_4 \end{bmatrix} + \underbrace{\begin{bmatrix} n_{41} \\ n_{42}^* \end{bmatrix}}_{n_4} \tag{11}$$

where, $Z_{2i-1} = \begin{bmatrix} h_{i1}^1 & h_{i2}^1 \\ h_{i2}^{1*} & -h_{i1}^{1*} \end{bmatrix}$, $Z_{2i} = \begin{bmatrix} h_{i1}^2 & h_{i2}^2 \\ h_{i2}^{2*} & -h_{i1}^{2*} \end{bmatrix}$, $i = 1,2,3,4$, y_1, y_2, y_3 and y_4 are the effective received signals. n_1, n_2, n_3 and n_4 are the effective noise. Z_i, having orthogonal characteristic, satisfies $\frac{Z_i^H Z_i}{\|Z_i\|^2} = I_2$, $i = 1,2,3,4$, where I_2 denotes the 2 × 2 unit matrix. $(\cdot)^H$ and $\|\cdot\|$ denote the conjugate-transpose and the norm, respectively. Taking operation on y_1, y_2, y_3 and y_4 according to (12)-(15), it is easy to derive z_1, z_2, z_3 and z_4.

$$z_1 = \frac{y_1 Z_2^H}{\|Z_2\|^2} - \frac{y_2 Z_4^H}{\|Z_4\|^2} = Q_1 \begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix} + \underbrace{\frac{n_1 Z_2^H}{\|Z_2\|^2} - \frac{n_2 Z_4^H}{\|Z_4\|^2}}_{P_1} \tag{12}$$

$$z_2 = \frac{y_1 Z_1^H}{\|Z_1\|^2} - \frac{y_2 Z_3^H}{\|Z_3\|^2} = Q_2 \begin{bmatrix} s_1 + e^{j\theta} s_3 \\ s_2 + e^{j\theta} s_4 \end{bmatrix} + \underbrace{\frac{n_1 Z_1^H}{\|Z_1\|^2} - \frac{n_2 Z_3^H}{\|Z_3\|^2}}_{P_2} \tag{13}$$

$$z_3 = \frac{y_3 Z_6^H}{\|Z_6\|^2} - \frac{y_4 Z_8^H}{\|Z_8\|^2} = Q_3 \begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix} + \underbrace{\frac{n_3 Z_6^H}{\|Z_6\|^2} - \frac{n_4 Z_8^H}{\|Z_8\|^2}}_{P_3} \tag{14}$$

$$z_4 = \frac{y_3 Z_5^H}{\|Z_5\|^2} - \frac{y_4 Z_7^H}{\|Z_7\|^2} = Q_4 \begin{bmatrix} s_1 + e^{j\theta} s_3 \\ s_2 + e^{j\theta} s_4 \end{bmatrix} + \underbrace{\frac{n_3 Z_5^H}{\|Z_5\|^2} - \frac{n_4 Z_7^H}{\|Z_7\|^2}}_{P_4} \tag{15}$$

where, $Q_i = \frac{Z_{2i-1} Z_{2i}^H}{\|Z_{2i}\|^2} - \frac{Z_{2i+1} Z_{2i+2}^H}{\|Z_{2i+2}\|^2}$, $i = 1,3$,

$Q_k = \frac{Z_{2k-1}^H Z_{2i}}{\|Z_{2k-1}\|^2} - \frac{Z_{2K+1}^H Z_{2k+2}}{\|Z_{2k+1}\|^2}, k = 2,4$, Q_i and Q_k are the effective channel matrices of $\begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix}$ or $\begin{bmatrix} s_1 + e^{j\theta} s_3 \\ s_2 + e^{j\theta} s_4 \end{bmatrix}$, $i = 1,2,3,4$. c_k, $k = 1,2,3,4$, the elements of C_1, are included in z_1 and z_3, while the elements of other codewords are not included in them. $s_k, k = 1,2,3,4$, the elements of S_1, are included in z_2 and z_4, while the elements of other codewords are not included in them. Therefore, C_1 and S_1 are separated. The interference between the wanted codewords is mitigated. So is the multi-user interference. Similar operations can be performed on R_2 to mitigate multi-user interference. No feedback information is required.

4. Decoding and Diversity Gain

In this section, the decoding method is presented, taking R_1 as example. By calculating, we can get $Z_1 Z_2^H = \begin{bmatrix} h_{11}^1 h_{11}^{2*} + h_{12}^1 h_{12}^{2*} & h_{11}^1 h_{12}^2 - h_{12}^1 h_{11}^2 \\ h_{12}^{1*} h_{11}^{2*} - h_{11}^{1*} h_{12}^{2*} & h_{12}^{1*} h_{12}^2 + h_{11}^{1*} h_{11}^2 \end{bmatrix}$. If we consider $h_{11}^1 h_{11}^{2*} + h_{12}^1 h_{12}^{2*}$ and $h_{12}^{1*} h_{11}^{2*} - h_{11}^{1*} h_{12}^{2*}$ as the modulated signals, $Z_1 Z_2^H$ has the structure of the Alamouti code. Similarly, Q_i has the structure of Alamouti code as well, $i = 1,2,3,4$. Let $Q_1 = \begin{bmatrix} q_1 & -q_2^* \\ q_2 & q_1^* \end{bmatrix}$ and $Q_3 = \begin{bmatrix} q_3 & -q_4^* \\ q_4 & q_3^* \end{bmatrix}$, we process z_1 and z_3 according to (16)

$$Q_1^H z_1 + Q_3^H z_3 = \begin{bmatrix} q_0 & 0 \\ 0 & q_0 \end{bmatrix} \begin{bmatrix} c_1 + e^{j\theta} c_3 \\ c_2 + e^{j\theta} c_4 \end{bmatrix} + Q_1^H P_1 + Q_3^H P_3 \quad (16)$$

where $q_0 = |q_1|^2 + |q_2|^2 + |q_3|^2 + |q_4|^2$. Let $Q_1^H z_1 + Q_3^H z_3 = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix}$ and $P_1^H z_1 + P_3^H z_3 = \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$, (16) can be rewritten as

$$z_1 = q_0 \left(c_1 + e^{j\theta} c_3 \right) + p_1 \quad (17)$$

$$z_2 = q_0 \left(c_2 + e^{j\theta} c_4 \right) + p_2 \quad (18)$$

It can be seen from (17) (18) that $c_1 + e^{j\theta} c_3$ and $c_2 + e^{j\theta} c_4$ are separated. So we can decode (c_1, c_3) and (c_2, c_4), respectively. The specific steps are given as follows.

Step 1, obtain y_1, y_2, y_3 and y_4 from the received signals;

Step 2, obtain $H_1 = 2(H_{11} + H_{21})$ and $H_2 = 2(G_{11} + G_{21})$ from the channel matrices, and then obtain Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7 and Z_8;

Step 3, calculate Q_1 and Q_3 from Z_i, $k = 1,2,\cdots,8$, and let $Q_1 = \begin{bmatrix} q_1 & -q_2^* \\ q_2 & q_1^* \end{bmatrix}$ and $Q_3 = \begin{bmatrix} q_3 & -q_4^* \\ q_4 & q_3^* \end{bmatrix}$;

Step 4, obtain z_1 and z_3 by processing y_1, y_2, y_3 and y_4 using Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7 and Z_8;

Step 5, obtain $Q_1^H z_1 + Q_3^H z_3$ by combining Q_1, Q_3 with z_1, z_3, and let $Q_1^H z_1 + Q_3^H z_3 = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix}$;

Step 6, with the aid of the effective transmit signal $c_1 + e^{j\theta} c_3$, the effective channel matrix $|q_1|^2 + |q_2|^2 + |q_3|^2 + |q_4|^2$ and the effective received signal z_1, c_1 and c_3 can be estimated;

Step 7, similar operations can be performed to decode c_2 and c_4.

From (17) (18), we can see that both $c_1 + e^{j\theta} c_3$ and $c_2 + e^{j\theta} c_4$ reaches R_1 by experiencing 4 independent paths. So the diversity gain is 4.

5. Performance Analysis and Simulation Results

There are 32 modulated signals to be transmitted in 6 time slots in [12]. Before transmitting the modulated symbols, two users need to know the feedback information which are 64 plurals. The feedback information is transmitted to the two users from receivers, which takes up some time slots. 12 time slots are required to send feedback information if these receivers adopt the same transmission and adopt the same code mode as the transmitters. So, 18 time slots are required to send 32 independent modulated signals in [12], with a transmission efficiency of 16/9 symbol/channel. 16 independent modulated signals are sent over 4 time slots in [13], in which the feedback information are 8 plurals. 2 time slots are required to send feedback information if these receivers adopt the same transmission and adopt the same code mode as the transmitters. So, 6 time slots are required to send 16 independent modulated signals in [13], with a transmission efficiency of 8/3 symbol/channel. 16 independent modulated signals are sent over four time slots in the proposed scheme with a transmission efficiency of 4 symbol/channel. So the transmission efficiency of the proposed scheme is 2.25 times as much as that of Ref. [12], and is 1.5 times as much as that of Ref. [13].

There are a comparison of the transmission efficiency, diversity gain, feedback and decoding complexity of the three schemes, as shown in **Table 1**. M denotes the modulation order. As can be seen from the table, the advantage of the proposed scheme lies in improving the transmission efficiency without any feedback information. The disadvantages are that the decoding complexity is higher than that of Ref. [12] and the diversity gain is lower than that of Ref. [13].

In **Figure 2**, we simulate the average BER curves of these three schemes with 4 QAM modulation and 16 QAM modulation. We consider uncoded systems, in which the channel is independent of the Rayleigh distribution and the noise is

Table 1. Performance comparison of the three schemes.

Scheme	Proposed scheme	Ref. [12]	Ref. [13]
Transmission efficiency	4 symbol/channel	16/9 symbol/channel	8/3 symbol/channel
Diversity gain	4	4	8
Feedback amount	No	Global CSI	Global CSI
Decoding complexity	M^2	M	M^2

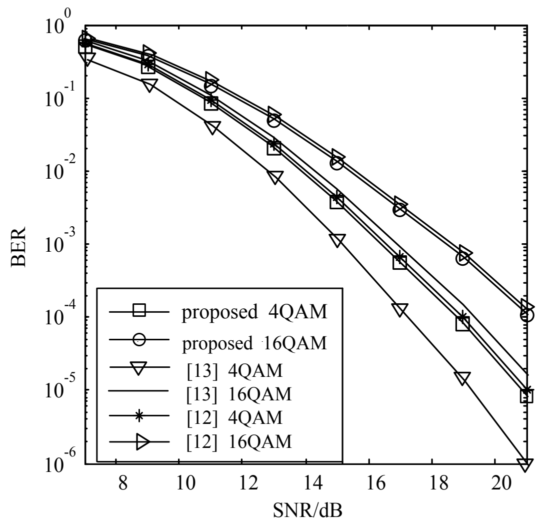

Figure 2. BER curves of the two schemes.

Gauss white noise. We can see that the reliability of the proposed scheme is not better than that of Ref. [13] with the same modulation. This is because the proposed scheme improves the transmission efficiency at the cost of decreasing of the diversity gain. The reliability of the proposed scheme is very close to that of Ref. [12], because the two schemes both have a same diversity gain of 4, which demonstrate the validity of theoretical analysis.

6. Conclusions

For X channels, where each user has four antennas, the number of interfering time slots is reduced through the combination of codewords. Then, the multi-user interference is mitigated using the orthogonal property of the Alamouti code. Compared with the existing scheme, feedback information is not required, which greatly improves the transmission efficiency. Simulation results demonstrate that the reliability of the proposed scheme is not restricted to system full-rate full-diversity space-time block code. It can be extended to the other type of perfect space-time block code. However, the scheme is limited to the two users X channels. Future work on this scheme includes extending the application scene.

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