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Interference Cancellation Anddetection for More Than Two Users

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ABSTRACT
We consider interference cancellation for a system with more than two users when users know each other channels. The goal is to utilize multiple antennas to cancel the interference without sacrificing the diversity or the complexity of the system. in the literature, it was shown how a receiver with two receive antennas can completely cancel the interference of two users and provide a diversity of 2 for users with two transmit antennas. Unfortunately, the scheme only works for two users. Recently it was shown that a system to achieve interference cancellation and full diversity with low complexity for any number of users and with any number of transmit and receive antennas In this paper our main idea is to design precoders, using the channel information, to make it possible for different users to transmit over orthogonal directions. Then, using the orthogonality of the transmitted signals, the receiver can separate them and decode the signals independently. Next, we extend the result for limited feedback systems to improve the diversity in the applied conditions. Simulation results show that the proposed precoder outperforms the previous work and improved diversity results using limited feedback.
Key words:-Multi-user detection, multiple antennas, interference cancellation, precoder, orthogonal designs

I. INTRODUCTION

Recently, a lot of attention has been given to multi-user detection schemes with simple receiver structures. Multiple transmit and receive antennas have been used to increase rate and improve the reliability of wireless systems. In this paper, we consider a multiple-antenna multi-access scenario where interference cancellation is achieved by utilizing channel information. When there is no channel information at the transmitter, simple array processing methods using orthogonal space-time block codes (OSTBC) and quasi-orthogonal space-time block codes (QOSTBC) have been proposed.

A receiver can completely cancel the interference of the two users andprovide full diversity for each user. Unfortunately, the scheme only works for two users. For that we extend cancel the interference of the more than two usersandprovide full diversity for each user.

To design precoders, using the channel information, to make it possiblefor different users to transmit over orthogonal directions. Then,using the orthogonality of the transmitted signals, the receivercan separate them and decode the signals independently.

The existing multi-user systems are the small number of required receiveantennas and the low complexity of the array-processing decoding.However, as mentioned before, full diversity for eachuser is only achieved using maximum-likelihood detection. Onthe other hand, maximum-likelihood detection is usually notpractical, because its complexity increases exponentially asa function of the number of antennas, the number of users, and the bandwidth efficiency. the dis advantages of existing system are High complexity, High interference, Limited users Our main idea is to design precoders, using the channel information, to make it possiblefor different users to transmit over orthogonal directions. Then,using the orthogonality of the transmitted signals, the receivercan separate them and decode the signals independently. Wehave analytically proved that the system provides full diversityto each user and extended the results to any number of userseach with any number of transmit antennas and one receiverwith any number of receive antennas.

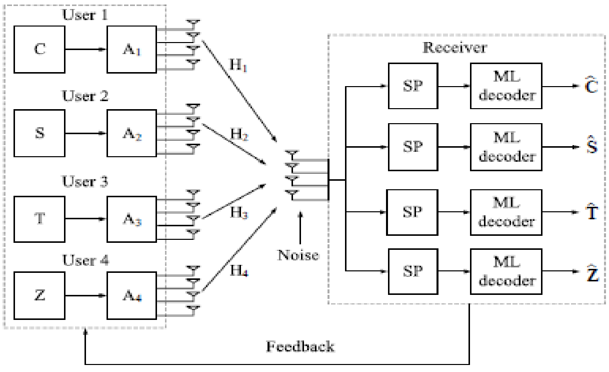

Fig:1 Block diagram of the system

The advantages of the proposed system are Full diversity achieved, High interference cancellation,It is applied to many no of users,Low complexity.

We provide the details ofand show our scheme can be extended to any number of users each with any number of transmit antennas and any number of receiveas well as we have shown the Extension of our scheme with limited feedback. Lastly we have shown the Simulation result sand and concludes the paper.

A lot of attention has been given to multi-userdetection schemes with simple receiver structures. Multiple transmit and receive antennas have been used to increaserate and improve the reliability of wireless systems. In this paper, we consider a multiple-antenna multi-access scenariowhere interference cancellation is achieved by utilizing channel information.We assume a quasi-static flat Rayleighfading channel model. The path gains are independent complex Gaussian random variables and are fixed during thetransmission of one block. In addition, a short-term powerconstraint is assumed. For the sake of simplicity, we onlypresent the scheme for four users each with four transmitantennas and one receiver with four receive antennas. Byadjusting the dimensions of channel matrices, our proposedscheme can be easily applied to Jusers with Jtransmitantennas and one receiver with Jreceive antennas.

II. INTERFERENCE CANCELLATION FOR FOUR USERS EACH WITH FOUR TRANSMIT ANTENNAS

In this paper, we assume a quasi-static flat Rayleigh fading channel model. The path gains are independent complex Gaussian random variables and are fixed during the transmission of one block. In addition, a short-term power constraint is assumed. For the sake of simplicity, we only present the scheme for four users each with four transmit antennas and one receiver with four receive antennas. By adjusting the dimensions of channel matrices, our proposed scheme can be easily applied to *J*users with *J*transmit antennas and one receiver with *J*receive antennas.

The block diagram of the system is shown in Figure 1. We assume the channel matrices for Users 1, 2, 3, 4 are

$$H_1 = [h_1(i,j)]_{4\times4} \quad H_2 = [h_2(i,j)]_{4\times4}$$
$$H_3 = [h_3(i,j)]_{4\times4} \; H_4 = [h_4(i,j)]_{4\times4} \_\_\_\_\_\_ [1]$$

respectively. At the l th time slot, l= 1, 2, 3, 4, the precoders for Users 1, 2, 3, 4 are

$$A_1^l = [a_1^l(i,j)]_{4\times4}, \quad A_2^l = [a_2^l(i,j)]_{4\times4}$$
$$A_3^l = [a_3^l(i,j)]_{4\times4}, \quad A_4^l = [a_4^l(i,j)]_{4\times4} \_\_\_\_\_\_\_\_\_\_ [2]$$

respectively. In every four time slots, Users 1, 2, 3, 4 send Quasi Orthogonal Space-Time Block Codes (QOSTBCs) [2]

$$C = \begin{pmatrix} c_1 & -c_2^* & c_3 & -c_4^* \\ c_2 & c_1^* & c_4 & c_3^* \\ c_3 & -c_4^* & c_1 & -c_2^* \\ c_4 & c_3^* & c_2 & c_1^* \end{pmatrix} S = \begin{pmatrix} s_1 & -s_2^* & s_3 & -s_4^* \\ s_2 & s_1^* & s_4 & s_3^* \\ s_3 & -s_4^* & s_1 & -s_2^* \\ s_4 & s_3^* & s_2 & s_1^* \end{pmatrix}$$

$$T = \begin{pmatrix} t_1 & -t_2^* & t_3 & -t_4^* \\ t_2 & t_1^* & t_4 & t_3^* \\ t_3 & -t_4^* & t_1 & -t_2^* \\ t_4 & t_3^* & t_2 & t_1^* \end{pmatrix},$$

$$Z = \begin{pmatrix} z_1 & -z_2^* & z_3 & -z_4^* \\ z_2 & z_1^* & z_4 & z_3^* \\ z_3 & -z_4^* & z_1 & -z_2^* \\ z_4 & z_3^* & z_2 & z_1^* \end{pmatrix} \qquad [3]$$

respectively.

At time slot *l*, *l*= 1, 2, 3, 4, we have the followi

$$y^l = \sqrt{E_s}\left(H_1A_1^lc(l) + H_2A_2^ls(l) + H_3A_3^lt(l) + H_4A_4^lz(l)\right) + n^l$$

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$$= \sqrt{E_s}\left(H_1^lc(l) + H_2^ls(l) + H_3^lt(l) + H_4^lz(l)\right) + n^l \qquad [4]$$

Where $H_i^l = H_iA_i^l$ and $y^l = \begin{pmatrix} y_1^l \\ y_2^l \\ y_3^l \\ y_4^l \end{pmatrix}$ denotes the received signals of the four receive antennas at time slot *l*. $E_s$denotesthe transmit energy of each user.

$n^l = \begin{pmatrix} n_1^l \\ n_2^l \\ n_3^l \\ n_4^l \end{pmatrix}$ denotes thenoise at the receiver at time slot *l*. We assume that $n_1^l, n_2^l, n_3^l, n_4^l$ are i.i.d complex Gaussian noises with mean 0 and variance 1.

Applying some simple algebra to Equation (4), we have

[5]

Where

$$H_i^{'}=\begin{pmatrix} h_i^1(1,1) & h_i^1(1,2) & h_i^1(1,3) & h_i^1(1,4) \\ h_i^1(2,1) & h_i^1(2,2) & h_i^1(2,3) & h_i^1(2,4) \\ h_i^1(3,1) & h_i^1(3,2) & h_i^1(3,3) & h_i^1(3,4) \\ h_i^1(4,1) & h_i^1(4,2) & h_i^1(4,3) & h_i^1(4,4) \\ \left(h_i^2(1,2)\right)^* & -\left(h_i^2(1,1)\right)^* & \left(h_i^2(1,4)\right)^* & -\left(h_i^2(1,3)\right)^* \\ \left(h_i^2(2,2)\right)^* & -\left(h_i^2(2,1)\right)^* & \left(h_i^2(2,4)\right)^* & -\left(h_i^2(2,3)\right)^* \\ \left(h_i^2(3,2)\right)^* & -\left(h_i^2(3,1)\right)^* & \left(h_i^2(3,4)\right)^* & -\left(h_i^2(3,3)\right)^* \\ \left(h_i^2(4,2)\right)^* & -\left(h_i^2(4,1)\right)^* & \left(h_i^2(4,4)\right)^* & -\left(h_i^2(4,3)\right)^* \\ h_i^3(1,3) & h_i^3(1,4) & h_i^3(1,1) & h_i^3(1,2) \\ h_i^3(2,3) & h_i^3(2,4) & h_i^3(2,1) & h_i^3(2,2) \\ h_i^3(3,3) & h_i^3(3,4) & h_i^3(3,1) & h_i^3(3,2) \\ h_i^3(4,3) & h_i^3(4,4) & h_i^3(4,1) & h_i^3(4,2) \\ \left(h_i^4(1,4)\right)^* & -\left(h_i^4(1,3)\right)^* & \left(h_i^4(1,2)\right)^* & -\left(h_i^4(1,1)\right)^* \\ \left(h_i^4(2,4)\right)^* & -\left(h_i^4(2,3)\right)^* & \left(h_i^4(2,2)\right)^* & -\left(h_i^4(2,1)\right)^* \\ \left(h_i^4(3,4)\right)^* & -\left(h_i^4(3,3)\right)^* & \left(h_i^4(3,2)\right)^* & -\left(h_i^4(3,1)\right)^* \\ \left(h_i^4(4,4)\right)^* & -\left(h_i^4(4,3)\right)^* & \left(h_i^4(4,2)\right)^* & -\left(h_i^4(4,1)\right)^* \end{pmatrix}$$

$$y'=\begin{pmatrix} y^1 \\ \left(y^2\right)^* \\ y^3 \\ \left(y^4\right)^* \end{pmatrix}, \qquad n'=\begin{pmatrix} n^1 \\ \left(n^2\right)^* \\ n^3 \\ \left(n^4\right)^4 \end{pmatrix}$$

Now we choose precoders that can realize full diversity and interference cancellation for each user. First, we illustrate our main idea.

To realize interference cancellation, a straightforward idea is to transmit the symbols of the four users along four orthogonal directions. By doing so, it is easy to achieve interference cancellation at the receiver using zero-forcing. However, the difficulty lies in how to achieve

$$y^{'}=\sqrt{E_s}\left(H_1^{'}\begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix}+H_2^{'}\begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{pmatrix}+H_3^{'}\begin{pmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \end{pmatrix}+H_4^{'}\begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{pmatrix}\right)+n^{'} \qquad [6]$$

full iversity as well. In [17] a scheme based on Alamouti structure has been proposed to achieve interference cancellation and full diversity for two users. When we have four users, the method does not work because four-dimensional rate-one complex orthogonal designs do not exist. An alternative is to use the quasi orthogonal structure, but it cannot achieve full interference cancellation for each user due to its non-orthogonality.

To tackle all the above problems together, we propose a new precoder design scheme as follows. At each of the first 2 time slots, we design precoders such that symbols of User 1 and symbols of User 2 are transmitted along two orthogonal directions, respectively, as illustrated in Figure 2. In addition, because of the characteristic of our designed precoders, each element of the equivalent channel matrices for Users 1 and 2 is still Gaussian. This property is critical to achieve full diversity or Users 1 and 2 as we will show later. Then we design precoders for Users 3 and 4, such that the transmit directions of their signals are orthogonal to each other. Note that it is impossible to obtain this orthogonalstructure and make each element of the equivalent channel matrices for Users 3 and 4 still Gaussian. This is the main difference between the precoders for Users 1, 2 and the precoders for Users 3, 4, at the first 2 time slots.

At the second 2 time slots, we also design precoders to make the transmit directions of signals orthogonal to each other. However, we design the precoders for Users 3 and 4 first, such that each element of the equivalent channel matrices for Users 3 and 4 is Gaussian. Then we design the precoders for Users 1 and 2 to obtain the orthogonal structure. As a result, elements of the equivalent channel matrices for Users 1 and 2 will not be Gaussian at the second 2 time slots. Later we w[6] prove that by using such precoders, we can achieve interference cancellation and full diversity for each user. In what follows, we will describe the details of our precoder designs.

At time slot 1, in order to have orthogonality between User 1 and User 2, we design the precoders such that

$$\begin{pmatrix} h_2^1(1,1) \\ h_2^1(2,1) \\ h_2^1(3,1) \\ h_2^1(4,1) \end{pmatrix}=\eta\begin{pmatrix} -h_1^1(2,1) \\ h_1^1(1,1) \\ -h_1^1(4,1) \\ h_1^1(3,1) \end{pmatrix}^* \qquad [7]$$

Where $h_1^1(i,j)$ and $h_2^1(i,j)$ are elements of the equivalentchannel matrices in Equation (6). Equation (7) can be rewritten as

$$H_2=\begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix}=\hat{H}_1^*\begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix}^* \qquad [8]$$

where

$$\hat{H}_1 = \begin{pmatrix} -h_1(2,1) & -h_1(2,2) & -h_1(2,3) & -h_1(2,4) \\ h_1(1,1) & h_1(1,2) & h_1(1,3) & h_1(1,4) \\ -h_1(4,1) & -h_1(4,2) & -h_1(4,3) & -h_1(4,4) \\ h_1(3,1) & h_1(3,2) & h_1(3,3) & h_1(3,4) \end{pmatrix} \quad [9]$$

Now let,

$$Q = H_2^{-1}\hat{H}_1^* = U\sum V^H \quad [10]$$

Where we have made the singular value decomposition.

$$\begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix} = v(i)^* \quad , \quad \begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix} = u(i)^* \quad ,$$

$$\eta = \frac{1}{\sum(i,i)} \quad [11]$$

where$i$= 1, 2, 3, 4, will satisfy Equation (8). There are fourdifferent choices for

$$\begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix} \text{and} \begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix}$$

Depending on which iwe pick. Different choices of $i$result in different performances. For given channel matrices H_1 and H_2, at time slot 1, we let **v**′ = **v**(i)*, i∈ {1, 2, 3, 4}, such that the norm of $\mathbf{H_1 v'}$ is the largest, i.e.,

$$v' = \arg_{v(i)^*} \max_{i=1,2,3,4} \left\| H_1 v(i)^* \right\|_F^2 \quad [12]$$

Then for User 1, at time slot 1, we let

$$\begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix} = \frac{v'}{\sqrt{1+\sum_{j=1}^{3} k_j^2}} \quad ,$$

$$\begin{pmatrix} a_1^1(1,i') \\ a_1^1(2,i') \\ a_1^1(3,i') \\ a_1^1(4,i') \end{pmatrix} = k_{i'-1} \cdot \begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix} \quad [13]$$

wherei'= 2, 3, 4. For User 2, at time slot 1, we let

$$\begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix} = \frac{u(i)}{\sqrt{1+\sum_{j=1}^{3} k_j^2}} \quad ,$$

$$\begin{pmatrix} a_2^1(1,i') \\ a_2^1(2,i') \\ a_2^1(3,i') \\ a_2^1(4,i') \end{pmatrix} = k_{i'-1} \cdot \begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix} \quad [14]$$

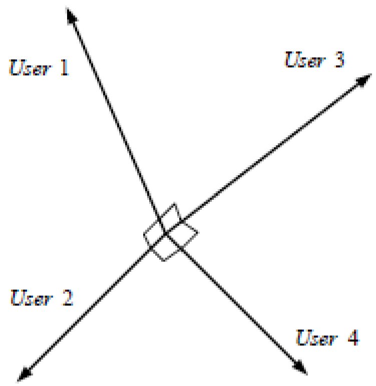

Figure 2: Orthogonal structure of signal vectors in 4-dimensional space.

Where i′ = 2, 3, 4 and $i$is the same as that in Equation (12). As we will discuss later, we choose parameters k_1, k_2*and* k_3 to maximize the coding gain. The choice of k_1,k_2, k_3 will complete the precoder design for Users 1 and 2 at time slot 1. Note that the designed precoders A_1^1, A_2^1 satisfy $\left\|A_1^1\right\|_F^2$ = $\left\|A_1^1\right\|_F^2$ = 1 and the signals of User 1 and User 2 will be transmitted along two orthogonal directions as shown in Figure 2.

In order to derive the orthogonality among Users 1, 2, 3 at time slot 1, we design precoder A_3^1 to satisfy the following properties:

1.Complex vectors $H_1 \begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix}$,

$$H_2 \begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix}, H_3 \begin{pmatrix} a_3^1(1,1) \\ a_3^1(2,1) \\ a_3^1(3,1) \\ a_3^1(4,1) \end{pmatrix}$$

Are orthogonal to each other.

$$\begin{pmatrix} a_3^1(1,i) \\ a_3^1(2,i) \\ a_3^1(3,i) \\ a_3^1(4,i) \end{pmatrix} = k_{i'-1}.\begin{pmatrix} a_3^1(1,1) \\ a_3^1(2,1) \\ a_3^1(3,1) \\ a_3^1(4,1) \end{pmatrix}, \quad \text{i=2,3,4} \qquad [15]$$

3. The Frobenius norm of complex matrix A_3^1 is equal to 1.

In order to maximize the coding gain, A_3^1 can be further chosen numerically such that the norm of $H_3 A_3^1$ is maximized. Similarly, for User 4, at time slot 1, in order to derive the orthogonality as shown in Figure 2, we choose precoder A_4^1 to satisfy the following properties

1. Complex vectors $H_1\begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix}$,

$H_2\begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix}$, $H_3\begin{pmatrix} a_3^1(1,1) \\ a_3^1(2,1) \\ a_3^1(3,1) \\ a_3^1(4,1) \end{pmatrix}$

$H_4\begin{pmatrix} a_4^1(1,1) \\ a_4^1(2,1) \\ a_4^1(3,1) \\ a_4^1(4,1) \end{pmatrix}$ are orthogonal to each other,

2. $$\begin{pmatrix} a_4^1(1,i) \\ a_4^1(2,i) \\ a_4^1(3,i) \\ a_4^1(4,i) \end{pmatrix} = k_{i'-1}.\begin{pmatrix} a_4^1(1,1) \\ a_4^1(2,1) \\ a_4^1(3,1) \\ a_4^1(4,1) \end{pmatrix}, \quad \text{i=2,3,4} \qquad [16]$$

3. The Frobenius norm of complex matrix A_4^1 is equal to 1. Similarly, in order to improve the coding gain, A_4^1 can be further chosen numerically such that the norm of $\mathbf{H}_4 A_4^1$ is maximized. By choosing A_1^1, A_2^1, A_3^1, A_4^1, the precoder design at time slot 1 is complete.

At time slot 2, the precoder design is similar to that attime slot 1The difference is that we choose $\mathbf{u}' = \mathbf{u}(i)$, $i \in \{1, 2, 3, 4\}$, such that $\|H_2 u'\|_F$ is the largest, i.e.,

$$u' = \arg_{u(i)^*} \max_{i=1,2,3,4} \left\| H_1 u(i)^* \right\|_F^2 \quad [17]$$

Then we let $\begin{pmatrix} a_2^2(1,1) \\ a_2^2(2,1) \\ a_2^2(3,1) \\ a_2^2(4,1) \end{pmatrix} = \dfrac{u'}{\sqrt{1+\sum_{j=1}^{3} k_j^2}}$,

$$\begin{pmatrix} a_2^1(1,i') \\ a_2^1(2,i') \\ a_2^1(3,i') \\ a_2^1(4,i') \end{pmatrix} = k_{i'-1}.\begin{pmatrix} a_2^2(1,1) \\ a_2^2(2,1) \\ a_2^2(3,1) \\ a_2^2(4,1) \end{pmatrix}$$

[18]

Where I'=2,3,4. For User 1,at time slot 2,we choose

$$\begin{pmatrix} a_1^2(1,1) \\ a_1^2(2,1) \\ a_1^2(3,1) \\ a_1^2(4,1) \end{pmatrix} = \frac{v(i)}{\sqrt{1+\sum_{j=1}^{3} k_j^2}} ,$$

$$\begin{pmatrix} a_1^2(1,i') \\ a_1^2(2,i') \\ a_1^2(3,i') \\ a_1^2(4,i') \end{pmatrix} = k_{i'-1}.\begin{pmatrix} a_1^2(1,1) \\ a_1^2(2,1) \\ a_1^2(3,1) \\ a_1^2(4,1) \end{pmatrix} \qquad [19]$$

wherei' = 2, 3, 4 and $i$is the same with that in Equation (17)

Design of A_3^2, A_4^2 is similar to that of A_3^1, A_4^1. By switching the terms related to Users 1 and 2 with those of Users 3 and 4, respectively, we can design the precoders at time slots 3 and 4.

Till now, the precoder design for each user at the first 4 time slots is complete. When there are Jusers, at time slots $2k-1$ and $2k$, we first design precoders for Users $2k-1$ and $2k$similar to what we do for Users 1 and 2. Then we design precoders for other users such that all of them transmit along orthogonal directions. Therefore, the above idea for 4 users can be easily extended to any number of users. In the nexttwo sections, we will illustrate how to decode and why our scheme can realize interference cancellation and full diversity for each user.

III. DECODING

Using our precoders in (5) becomes

$$\bar{y} = \sqrt{E_s}\left(\bar{H}_1\begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix} + \bar{H}_2\begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{pmatrix} + \bar{H}_3\begin{pmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \end{pmatrix} + \bar{H}_3\begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{pmatrix}\right) + \bar{n} \quad [20]$$

$$\bar{H}_i = \begin{pmatrix}
h_i^1(1,1) & k_1 h_i^1(1,1) & k_2 h_i^1(1,1) & k_3 h_i^1(1,1) \\
h_i^1(2,1) & k_1 h_i^1(2,1) & k_2 h_i^1(2,1) & k_3 h_i^1(2,1) \\
h_i^1(3,1) & k_1 h_i^1(3,1) & k_2 h_i^1(3,1) & k_3 h_i^1(3,1) \\
h_i^1(4,1) & k_1 h_i^1(4,1) & k_2 h_i^1(4,1) & k_3 h_i^1(4,1) \\
k_1(h_i^2(1,1))^* & -(h_i^2(1,1))^* & k_3(h_i^2(1,1))^* & -k_2(h_i^2(1,1))^* \\
k_1(h_i^2(2,1))^* & -(h_i^2(2,1))^* & k_3(h_i^2(2,1))^* & -k_2(h_i^2(2,1))^* \\
k_1(h_i^2(3,1))^* & -(h_i^2(3,1))^* & k_3(h_i^2(3,1))^* & -k_2(h_i^2(3,1))^* \\
k_1(h_i^2(4,1))^* & -(h_i^2(4,1))^* & k_3(h_i^2(4,1))^* & -k_2(h_i^2(4,1))^* \\
k_2 h_i^3(1,1) & k_3 h_i^3(1,1) & h_i^3(1,1) & k_1 h_i^3(1,1) \\
k_2 h_i^3(2,1) & k_3 h_i^3(2,1) & h_i^3(2,1) & k_1 h_i^3(2,1) \\
k_2 h_i^3(3,1) & k_3 h_i^3(3,1) & h_i^3(3,1) & k_1 h_i^3(3,1) \\
k_2 h_i^3(4,1) & k_3 h_i^3(4,1) & h_i^3(4,1) & k_1 h_i^3(4,1) \\
k_3(h_i^4(1,1))^* & -k_2(h_i^4(1,1))^* & k_1(h_i^4(1,1))^* & -(h_i^4(1,1))^* \\
k_3(h_i^4(2,1))^* & -k_2(h_i^4(2,1))^* & k_1(h_i^4(2,1))^* & -(h_i^4(2,1))^* \\
k_3(h_i^4(3,1))^* & -k_2(h_i^4(3,1))^* & k_1(h_i^4(3,1))^* & -(h_i^4(3,1))^* \\
k_3(h_i^4(4,1))^* & -k_2(h_i^4(4,1))^* & k_1(h_i^4(4,1))^* & -(h_i^4(4,1))^*
\end{pmatrix}$$

Here $\bar{y}$ and $\bar{n}$ are the same with **y**′ and **n**′ in Equation (5). Note that using our precoders, each column of matrix $\bar{H}_1$ isorthogonal to each column of matrices $\bar{H}_2, \bar{H}_3, \bar{H}_4$.

In order to decode symbols from User 1, we multiply bothsides of Equation (20) by matrix $\bar{H}_4^{+}$ to achieve

$$\bar{H}_1^{\dagger}\bar{y} = \sqrt{E_s}\,\bar{H}_1^{\dagger}\bar{H}_1\begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix} + \bar{H}_1^{\dagger}\bar{n}$$

Note that the noise elements of $\bar{H}_1^{+}\bar{n}$ are correlated with covariance matrix $\bar{H}_1^{+}\bar{H}_1$. We can whiten this noise vector by multiplying both sides of Equation (22) by the matrix $(\bar{H}_1^{+}\bar{H}_1)^{-1/2}$ as follows

$$\left(\bar{H}_1^{\dagger}\bar{H}_1\right)^{-\frac{1}{2}}\bar{H}_1^{\dagger}\bar{y} = \sqrt{E_s}\left(\bar{H}_1^{\dagger}\bar{H}_1\right)^{\frac{1}{2}}\begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix} + \hat{n}$$

where $\hat{n} = (\bar{H}_1^{+}\bar{H}_1)^{-1/2}(\bar{H}_1^{+}\bar{n})$ has uncorrelated elements $\sim CN(0, 1)$. Equation (23) can be further rewritten as

$$\left(\bar{H}_1^{\dagger}\bar{H}_1\right)^{-\frac{1}{2}}\bar{H}_1^{\dagger}\bar{y} = \sqrt{E_s}\begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ x_2 & x_5 & x_6 & x_7 \\ x_3 & x_6 & x_8 & x_9 \\ x_4 & x_7 & x_9 & x_{10} \end{pmatrix}^{\frac{1}{2}}\begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix} + \hat{n} \quad (20)$$

Where,

$x_1 = a + k_1^2 b + k_2^2 c + k_3^2 d$, $x_2 = k_1 a - k_1 b + k_2 k_3 c - k_2 k_3 d$

$x_3 = k_2 a + k_1 k_3 b + k_2 c + k_1 k_3 d$, $x_4 = k_3 a - k_1 k_2 b + k_1 k_2 c - k_3 d$

$x_5 = k_1^2 a + b + k_3^2 c + k_2^2 d$, $x_6 = k_1 k_2 a - k_3 b + k_3 c - k_1 k_2 d$

$x_7 = k_1 k_3 a + k_2 b + k_1 k_3 c + k_2 d$, $x_8 = k_2^2 a + k_3^2 b + c + k_1^2 d$

$x_9 = k_2 k_3 a - k_2 k_3 b + k_1 c - k_1 d$, $x_{10} = k_3^2 a + k_2^2 b + k_1^2 c + d$

$$a = \sum_{i=1}^{4}\left|h_1^1(i,1)\right|^2, \quad b = \sum_{i=1}^{4}\left|h_1^2(i,1)\right|^2$$

$$c = \sum_{i=1}^{4}\left|h_1^3(i,1)\right|^2, \quad d = \sum_{i=1}^{4}\left|h_1^4(i,1)\right|^2 \quad (21)$$

Now let, $$\hat{H} = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ x_2 & x_5 & x_6 & x_7 \\ x_3 & x_6 & x_8 & x_9 \\ x_4 & x_7 & x_9 & x_{10} \end{pmatrix}^{\frac{1}{2}} \quad (22)$$

From Equation (24), we can see that User 1 transmits 4 different codewords along 4 different equivalent channel vectors in the 4 time slots. So the rate is 1. If k_1, k_2, k_3 are all real, from (27), it is easy to see that the equivalent channel matrix $\hat{H}$ is real. So if QAM is used, Equation (24) is equivalent to the following two equations.

$$\hat{H}^{-1}\,\mathrm{Re}\left\{\bar{H}_1^{\dagger}\bar{y}\right\} = \sqrt{E_s}\,\hat{H}\begin{pmatrix} c_{1R} \\ c_{2R} \\ c_{3R} \\ c_{4R} \end{pmatrix} + \mathrm{Re}\{\hat{n}\} \quad (23)$$

$$\hat{H}^{-1}\,\mathrm{Im}\left\{\overline{H}_1^{\dagger}\overline{y}\right\} = \sqrt{E_s}\,\hat{H}\begin{pmatrix} c_{1R} \\ c_{2R} \\ c_{3R} \\ c_{4R} \end{pmatrix} + \mathrm{Im}\{\hat{n}\}$$

Then we can use the Maximum-Likelihood method to detect the real and imaginary parts of these 4 codewords separately. For example, by Equation (28), we can detect $c_{1R}, \ldots, c_{4R}$ by

$$\begin{pmatrix} \hat{c}_{1R} \\ \hat{c}_{2R} \\ \hat{c}_{3R} \\ \hat{c}_{4R} \end{pmatrix} = \arg\min_{c_{1R},\ldots,c_{4R}} \left\| \hat{H}^{-1}\,\mathrm{Re}\left\{\overline{H}_1^{\dagger}\overline{y}\right\} - \sqrt{E_s}\,\hat{H}\begin{pmatrix} c_{1R} \\ c_{2R} \\ c_{3R} \\ c_{4R} \end{pmatrix} \right\|_F^2$$

Similarly, using Equation (29), we can detect ($c_{1I} c_{2I}$ c_{3I} c_{4I}). Note that the decoding complexity is pair-wise decoding. to detect codewords of Users 2, 3, 4, we can multiply both sides of Equation (20) with matrix $\overline{H_2}^{+}, \overline{H_3}^{+}$, $\overline{H_4}^{+}$, respectively, to remove the signals of other users and use a similar method to complete the decoding.

IV. SIMULATION RESULTS

In this section, we provide simulation results that confirm our analysis in the previous sections. The performance of our proposed scheme is shown in Figures 4.1 and 4.2. In Figure 4.1, we consider 4 users each equipped with 4 transmit antennas and a receiver with 4 receive antennas. Our scheme cancels the interference completely but provides a diversity of 16 by utilizing the channel information at the transmitter.

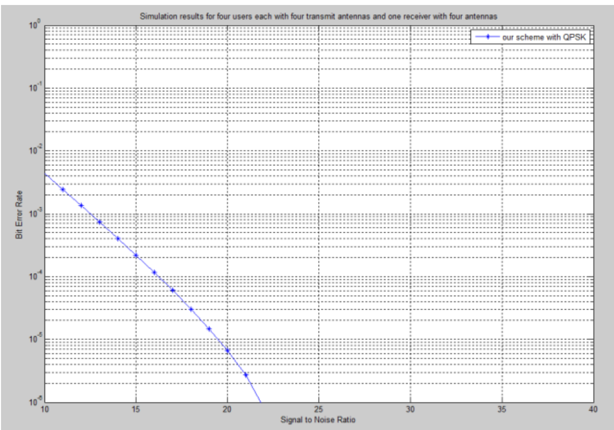

Figure 4.1 Simulation results for four users each with four transmit antenna and one receiver antenna.

In addition, in Figure 4.2, we have provided a “fixed rate" set of simulation results. In all case, what we mean by “fixed rate" is the average between the performance of two fixed-rate systems using BPSK and QPSK. we can see that adapting the rate can improve the performance compared with using a fixed rate. Also we can see that even with variable rate, our scheme provides the best performance.

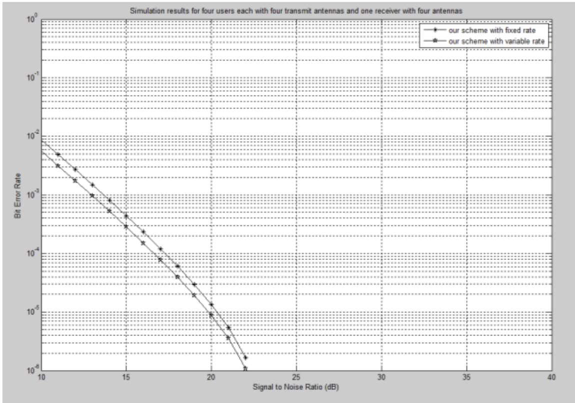

Figure4.2: Simulation results for four users each with four transmit antenna and one receiver antenna

V. CONCLUSIONS

We have considered interference cancellation for a system with more than two users when users know each other’s channels. We have proposed a system to achieve the maximum possible diversity of 16 with low complexity for 4 users each with 4 transmit antennas and one receiver with 4 receive antennas. Besides diversity, our proposed scheme also provides the best performance among all existing schemes with simple array processing decoding. Our main idea is to design precoders, using the channel information, to make it possible for different users to transmit over orthogonal directions. Then, using the orthogonality of the transmitted signals, the receiver can separate them and decode the signals independently. We have analytically proved that the system provides full diversity

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