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Interference Cancellation Scheme for Multiuser Detection

Khushboo P. Waghade, Vandana B. Bagde
P.I.E.T, Nagpur, P.I.E.T, Nagpur, INDIA

Abstract— In multiple access channels, when users know each other channels, precoders can be designed utilizing channel information to cancel the interference at the receiver without sacrificing the diversity or the complexity of the system. In a recent work, it was shown that when there are only two users, a receiver can completely cancel the interference and provides full diversity for each user. Unfortunately, the scheme only works for two users. In this paper, we extend the scheme to 4 users. In other words, we propose a system to achieve interference cancellation and full diversity with low complexity for 4 users. We also provide simulation results that confirm our analysis.

Keywords— Multi-user detection, multiple antennas, interference cancellation, precoder, orthogonal designs.

I. INTRODUCTION

Multiple-input multiple-output (MIMO) wireless channels created by deploying antenna arrays at both the transmitter and receiver, promise high capacity and high quality wireless communication links [1], [2]. A lot of attention has been given to multi user detection schemes with simple receiver structures. The multiple transmit and receive antennas are used to improve the gain rate and reliability of wireless system. In this paper we consider a multiple antenna multi access scenario where interference cancellation is achieved by channel information. When there is no channel information at the transmitter, simple array processing methods using orthogonal space-time codes are used.

MIMO stands for multiple-input multiple-output and means multiple antennas at both link ends of a communication system, i.e., at the transmit and at the receive side. Multiple transmit and receive antennas have been used to increase rate and improve the reliability of wireless systems. A multiple-antenna multi-access scenario is considered 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 (OSTBCs) and quasi-orthogonal space-time block codes (QOSTBCs) have been proposed. For J users each with N transmit antennas, it has been shown that in order to achieve interference cancellation, a receiver does not need more than J receive antennas. In addition, the diversity of each user is equal to NM using maximum likelihood detection and $N(M-J+1)$ using low complexity array-processing schemes.

However by using maximum likelihood detection we achieve full diversity for each user. But maximum likelihood detection is usually not a practical, as number of transmit and receive antennas increases the number of users and bandwidth. To overcome this drawback channel information is utilized at the transmitters to increase the diversity of the system while keeping the low complexity of the decoding. Receive antennas are not used to cancel the interference. Instead, channel information at the transmitter is used to design precoders that align different groups of signals along orthogonal directions. Then, using the orthogonality of the transmitted signals, the receiver can separate them and decode the signals independently. Analytically it is proved that the system provides full diversity to both users. Maximum-likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection. This uses the orthogonal structure of the space-time block code. Space-time block codes are designed to achieve the maximum diversity order for a given number of transmit and receive antennas. (Tarokh 1999).

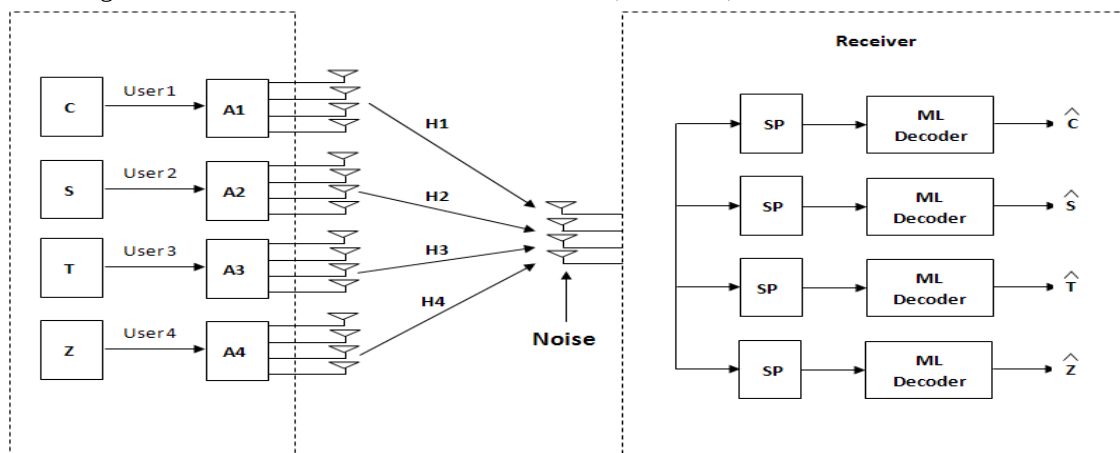


Figure 1 : System Model

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

In this paper, we have taken flat Rayleigh fading channel model. The path gains are independent complex Gaussian random variables and are fixed during the transmission of one block. We only present the scheme for four users each with four transmit and one receive with four 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:

$$\begin{aligned} H_1 &= [h_1(i,j)]_{4 \times 4}, \quad H_2 = [h_2(i,j)]_{4 \times 4}, \\ H_3 &= [h_3(i,j)]_{4 \times 4}, \quad H_4 = [h_4(i,j)]_{4 \times 4}, \end{aligned} \quad (1)$$

respectively. At the l^{th} time slots $l=1, 2, 3, 4$ the precoders for user 1,2,3,4 are

$$\begin{aligned} A^l_1 &= [a^l_1(i,j)]_{4 \times 4}, \quad A^l_2 = [a^l_2(i,j)]_{4 \times 4}, \\ A^l_3 &= [a^l_3(i,j)]_{4 \times 4}, \quad A^l_4 = [a^l_4(i,j)]_{4 \times 4}, \end{aligned} \quad (2)$$

In every 4 time slots, Users 1, 2, 3, 4 send QOSTBCs

$$\begin{aligned} c &= \begin{bmatrix} c_1 & -c_2^* & c_3 & -c_4^* \\ c_2 & c_1^* & c_4 & c_3^* \\ c_3 & -c_4^* & c_1 & -c_2^* \\ c_4 & c_3^* & c_2 & c_1^* \end{bmatrix} \\ T &= \begin{bmatrix} t_1 & -t_2^* & t_3 & -t_4^* \\ t_2 & t_1^* & t_4 & t_3^* \\ t_3 & -t_4^* & t_1 & -t_2^* \\ t_4 & t_3^* & t_2 & t_1^* \end{bmatrix} \\ s &= \begin{bmatrix} s_1 & -s_2^* & s_3 & -s_4^* \\ s_2 & s_1^* & s_4 & s_3^* \\ s_3 & -s_4^* & s_1 & -s_2^* \\ s_4 & s_3^* & s_2 & s_1^* \end{bmatrix} \\ Z &= \begin{bmatrix} z_1 & -z_2^* & z_3 & -z_4^* \\ z_2 & z_1^* & z_4 & z_3^* \\ z_3 & -z_4^* & z_1 & -z_2^* \\ z_4 & z_3^* & z_2 & z_1^* \end{bmatrix} \end{aligned}$$

III. ENCODING

According to our block diagram of system shown in fig.1, we have encoding and decoding block along with the channel, as a flat Rayleigh fading channel. In this paper we are going to use 4 users i.e. 4 user with one receiver with 4 receiving antennas.

As we are having 4 users, assuming the channel matrices and they transmit at different time slots as: $l = 1, 2, 3, 4$

At time slot l , $l = 1, 2, 3, 4$, we have the following input output Equation.

$$\begin{aligned} y' &= \sqrt{E_s} (H_1 A^l_1 c(l) + H_2 A^l_2 c(l) + H_3 A^l_3 c(l) + H_4 A^l_4 c(l)) + n^l \\ y' &= \sqrt{E_s} (H'_1 c(l) + H'_2 c(l) + H'_3 c(l) + H'_4 c(l)) + n^l \end{aligned} \quad (3)$$

Where y' denotes the received signals of the four receive antennas at time slot.

E_s denotes the transmit energy of each user.

n' denotes the noise at the receiver at time slot

Rearranging Equation (3), we have

$$\bar{y} = \sqrt{E_s} \left(\bar{H}_1 \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix} + \bar{H}_2 \begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{pmatrix} + \bar{H}_3 \begin{pmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \end{pmatrix} + \bar{H}_4 \begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{pmatrix} \right) + \bar{n}$$

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

$$\bar{y} = \begin{pmatrix} y^1 \\ (y^2)^* \\ y^3 \\ (y^4)^* \end{pmatrix}, \quad \bar{n} = \begin{pmatrix} n^1 \\ (n^2)^* \\ n^3 \\ (n^4)^* \end{pmatrix}$$

Now we choose precoders that can realize full diversity and interference cancellation for each user. To realize interference cancellation, a straight forward 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 full diversity as well. Here comes the concept of precoding technique this helps in improving the diversity and also removes the interference for four users, At each of the first 2 time slots, 1, 2, 3 and 4, we design precoders such that symbols of User 1 and symbols of User 2 are transmitted along two orthogonal directions, respectively 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 for Users 1 and 2. Summarily we design precoders for Users 3 and 4, such that the transmit directions of their signals are not orthogonal to each other this kind of placing will helps in obtaining cancelation of interference. Finally after combining 1, 2, 3, 4 they all will not interfere because of the individual choosing of precoders symbols for 1, 2 and 3, 4 as shown in the figure they are placed in orthogonal structure in vector space.

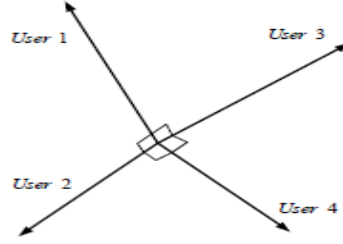


Fig 2: Orthogonal structure of signal vectors in 4-dimensional space.

The matrix H_1 , H_2 , H_3 , and H_4 represents,

$$\mathbf{H}_1 \begin{pmatrix} a_1^1(1,1) \\ a_1^1(2,1) \\ a_1^1(3,1) \\ a_1^1(4,1) \end{pmatrix}, \quad \mathbf{H}_2 \begin{pmatrix} a_2^1(1,1) \\ a_2^1(2,1) \\ a_2^1(3,1) \\ a_2^1(4,1) \end{pmatrix}, \quad \mathbf{H}_3 \begin{pmatrix} a_3^1(1,1) \\ a_3^1(2,1) \\ a_3^1(3,1) \\ a_3^1(4,1) \end{pmatrix}, \quad \mathbf{H}_4 \begin{pmatrix} a_4^1(1,1) \\ a_4^1(2,1) \\ a_4^1(3,1) \\ a_4^1(4,1) \end{pmatrix} \quad (4)$$

VI. DECODING

Using our precoders, Equation (3) becomes,

$$\bar{\mathbf{y}} = \sqrt{E_s} \left(\bar{\mathbf{H}}_1 \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix} + \bar{\mathbf{H}}_2 \begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{pmatrix} + \bar{\mathbf{H}}_3 \begin{pmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \end{pmatrix} + \bar{\mathbf{H}}_4 \begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{pmatrix} \right) + \bar{\mathbf{n}} \quad (5)$$

Here $\mathbf{y}$ and $\mathbf{n}$ are the same with $\mathbf{y}'$ and $\mathbf{n}'$ in Equation (3). Note that using our precoders, each column of matrix $\bar{\mathbf{H}}_1$ is orthogonal to each column of matrices $\bar{\mathbf{H}}_2$, $\bar{\mathbf{H}}_3$, $\bar{\mathbf{H}}_4$.

In order to decode symbols from User 1, we multiply both sides of Equation (5) by matrix $\bar{\mathbf{H}}_1^+$ to achieve,

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

Similarly for user 2, 3, 4 we can multiply both sides of the equation (5) with matrix $\bar{\mathbf{H}}_2^+$, $\bar{\mathbf{H}}_3^+$ and $\bar{\mathbf{H}}_4^+$ respectively to remove the signals of other user and use Maximum Likelihood Decoding to complete the decoding. Here, we can prove that we can achieve full diversity using our precoding scheme. We present the proof for User 1, since the proof for Users 2, 3, 4 is the same. Diversity is defined as:

$$d = - \lim_{\rho \rightarrow \infty} \frac{\log P_e}{\log \rho}$$

Where ' P_e ' denotes the SNR and ' ρ ' represents the probability of error.

VI. CONCLUSION

In this paper, we consider interference cancellation for a system with 4 users each with 4 transmits antennas and one receiver with 4 receive antennas. When users know all channels, we propose a scheme to achieve Interference cancellation and achieve maximum possible diversity with low complexity. Our main idea is that each user transmits signals along a direction that is orthogonal to direction of other users. This is achieved by designing precoders. Then the receiver can separate signals of different users using the orthogonality of the transmitted

signals and Maximum Likelihood Decoding. Simulation results show that our proposed scheme out performs better than other existing schemes.

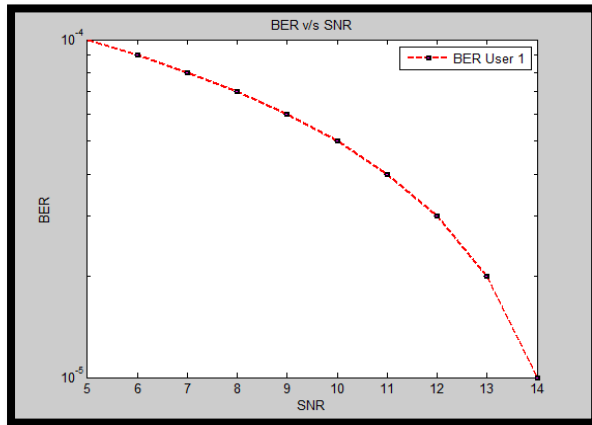


Figure 4.1. Bit error rate vs. SNR per transmit antenna, Maximum Likelihood Decoding technique for user1.

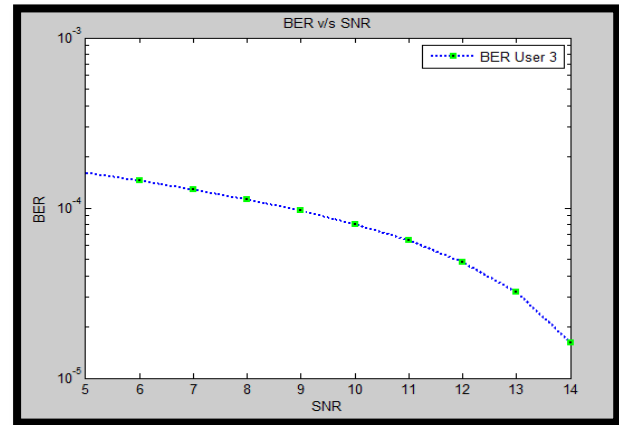


Figure 4.3. Bit error rate vs. SNR per transmit antenna, Maximum Likelihood Decoding technique for user3.

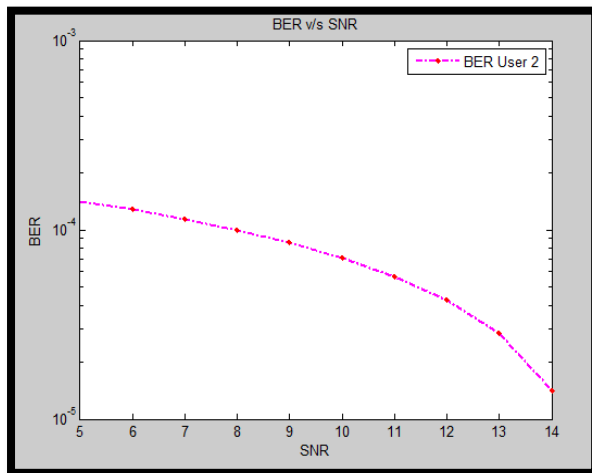


Figure 4.2. Bit error rate vs. SNR per transmit antenna, Maximum Likelihood Decoding technique for user2.

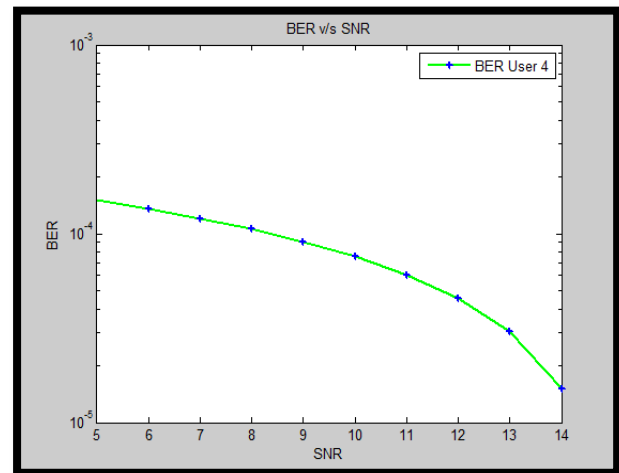


Figure 4.4. Bit error rate vs. SNR per transmit antenna, Maximum Likelihood Decoding technique for user4.

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