How to Tackle Interference in MIMO Interference Channel

Ethan Hill, Rodriguez Hugo and Sonia Cirino

***Abstract*—Multiple Input Multiple Output Interference Channel is investigated in this paper. We focus on how to tackle the interference when different users try to send their code words to their corresponding receivers. We propose a strategy to remove the interference while allowing different users transmit at the same time. Our strategy is low-complexity while the performance is good. Mathematical analysis is provided and simulations are given based on our system.**

***Index Terms*—MIMO, Interference Channel, Alamouti Codes, Diversity, Interference Cancellation, Complexity**

I. Introduction

The development of wireless communication systems for high bit rate data transmission and high-quality information exchange between terminals is becoming one of the new challenging targets in telecommunications research. Multiple input multiple output (MIMO) systems are currently stimulating considerable interest across the wireless industry because they appear to be a key technology for future wireless generations [1]–[9]. An (N,M)-MIMO wireless system can be generally defined as a MIMO system in which N signals are transmitted by N antennas at the same time using the same bandwidth and, thanks to effective processing at the receiver side based on the M received signals by M different antennas, is able to distinguish the different transmitted signals. The processing at the receiver is essentially efficient co-channel interference cancellation on the basis of the collected multiple information. This permits improving system performance whether the interest is to increase the single link data rate or increase the number of users in the whole system.

An interference channel is a network consisting N senders and N receivers. There exists a one-to-one correspondence between senders and receivers. Each sender only wants to communicate with its corresponding receiver, and each receiver only cares about the information from its corresponding sender. However, each channel interferers the others. So an interference channel has N principal links and N(N − 1) interference links. This scenario often occurs, when several sender-receiver pairs share a common media. For example, in satellite communication, two satellites send information to its corresponding ground station simultaneously. Each ground

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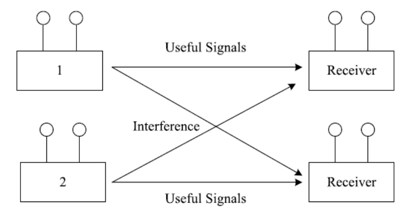

Fig. 1. Channel Model

station can receive the signals from both of the two satellites and its communication is interfered by the other pair's communication. The study of this kind of channel was initiated by Shannon in 1961. However, this channel has not been solved in general case even in the general Gaussian case.

In this paper, we focus on MIMO interference channels [10]–[18]. Since each user transmits at the same time, how to deal with the co-channel interference is an interesting question. Schemes to cancel the co-channel interference when channel knowledge is known at the transmitter are proposed in [19]–[30]. In this paper, we propose and analyze a scheme when channel knowledge is not known at the transmitter, a scenario which is more practical. The article is organized as follows. In the next section the system model is introduced. Detailed interference cancellation procedures are provided and performance analysis is given. Then simulation results are presented. Concluding remarks are given in the final section.

II. Interference Cancellation and Performance Analysis

Assume there are 2 transmitters each with 2 transmit antennas and 2 receivers each equipped with 2 receive antennas. Each transmit sends codewords to different receivers. So this is an interference channel. Let $c_{t,n}(j)$ denote the transmitted symbol from the n-th antenna of user j at transmission interval t and $r_{t,m}$ be the received word at the receive antenna m at the first receiver. We only need to consider receiver 1, because the analysis for receiver 2 is similar. Then, for the received symbols we will have

$$r_{t,m} = \sum_{j=1}^{J} \sum_{n=1}^{N} \alpha_{n,m}(j) c_{t,n}(j) + \eta_{t,m} \qquad (1)$$

It is well-known that one can separate signals sent from J different users each equipped with N transmit antennas, with enough receive antennas. We can simply form a decoding matrix that is orthogonal to the space spanned by channel coefficients of the users to be eliminated. For example, if we let

$$R_t = C_t H + N_t \tag{2}$$

where

$$C_t = (C_t(1), C_t(2), \dots, C_t(J)) \tag{3}$$

$$R_t = (r_{t,1}, r_{t,2}, \dots, C_{t,M}) \tag{4}$$

$$N_t = (\eta_{t,1}, \eta_{t,2}, \dots, \eta_{t,M}) \tag{5}$$

$$H = (H(1)^T | H_2^T, \dots, H(J)^T) \tag{6}$$

with

$$C_t(j) = (c_{t,1}(j), c_{t,2}(j), \dots, c_{t,N}(j)) \tag{7}$$

and

$$H(j) = \begin{pmatrix} \alpha_{1,1}(j) & \alpha_{1,2}(j) & \cdots & \alpha_{1,M}(j) \\ \alpha_{2,1}(j) & \alpha_{2,2}(j) & \cdots & \alpha_{2,M}(j) \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{N,1}(j) & \alpha_{N,2}(j) & \cdots & \alpha_{N,M}(j) \end{pmatrix} \tag{8}$$

Therefore, one can rewrite Equation (2) as follows:

$$R_t = \sum_{j=1}^{J} C_t(j) H(j) + N_t \tag{9}$$

To decode user 1, one can simply find a zero-forcing(ZF) matrix Z such as

$$H(1)Z \neq 0 \tag{10}$$

and

$$H(j)Z = 0 \quad \text{for} \quad j \neq 1 \tag{11}$$

In other words, Z should null the space spanned by the row vectors of all $H(j)$s, for $j = 2, 3, \dots, J$. Also, it should not null at least one row vector of $H(1)$. Since all the rows of $H(j)$s might be linearly independent, the dimension of Z, i.e. M, must be at least equal to the number of these rows, or $(J-1)N+1$. Each antenna group (user) can employ a modulation scheme to benefit transmit diversity; as if it is the only group that is sending data.

In order to reduce the number of required receive antennas, we propose a scheme to cancel the interference with less number of receive antennas.

Consider 2 users each transmitting Alamouti code, i.e. Orthogonal Space-Time Block Code (OSTBC)

$$\begin{pmatrix} a_1 & a_2 \\ -a_2^* & a_1^* \end{pmatrix} \tag{12}$$

to receivers each equipped with at least 2 receive antennas. The received signal at the first receive antenna of the first receiver can be written in the following format:

$$\begin{pmatrix} r_{1,1}(1) \\ r_{2,1}(1) \end{pmatrix} = \begin{pmatrix} s_1(1) & s_2(1) \\ -s_2(1)^* & s_1(1)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,1}(1,1) \\ \alpha_{2,1}(1,1) \end{pmatrix} + \begin{pmatrix} s_1(2) & s_2(2) \\ -s_2(2)^* & s_1(2)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,1}(2,1) \\ \alpha_{2,1}(2,1) \end{pmatrix} + \begin{pmatrix} \eta_{1,1}(1) \\ \eta_{2,1}(1) \end{pmatrix} \tag{13}$$

where $r_{i,j}(k)$ denotes the received signal at the jth antenna of receiver k at time slot i. $\alpha_{i,j}(k,l)$ denotes the channel coefficient from transmit antenna i from transmitter k to the receive antenna j from receiver l. $\eta_{i.i}(k)$ denotes the noise at the jth antenna of receiver k at time slot i.At the second receive antenna of the first receiver, we have

$$\begin{pmatrix} r_{1,2}(1) \\ r_{2,2}(1) \end{pmatrix} = \begin{pmatrix} s_1(1) & s_2(1) \\ -s_2(1)^* & s_1(1)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,2}(1,1) \\ \alpha_{2,2}(1,1) \end{pmatrix} + \begin{pmatrix} s_1(2) & s_2(2) \\ -s_2(2)^* & s_1(2)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,2}(2,1) \\ \alpha_{2,2}(2,1) \end{pmatrix} + \begin{pmatrix} \eta_{1,2}(1) \\ \eta_{2,2}(1) \end{pmatrix} \tag{14}$$

Similarly, the received signal at the first receive antenna of the second receiver can be written in the following format:

$$\begin{pmatrix} r_{1,1}(2) \\ r_{2,1}(2) \end{pmatrix} = \begin{pmatrix} s_1(1) & s_2(1) \\ -s_2(1)^* & s_1(1)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,1}(1,2) \\ \alpha_{2,1}(1,2) \end{pmatrix} + \begin{pmatrix} s_1(2) & s_2(2) \\ -s_2(2)^* & s_1(2)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,1}(2,2) \\ \alpha_{2,1}(2,2) \end{pmatrix} + \begin{pmatrix} \eta_{1,1}(2) \\ \eta_{2,1}(2) \end{pmatrix} \tag{15}$$

At the second receive antenna of the second receiver, we have

$$\begin{pmatrix} r_{1,2}(2) \\ r_{2,2}(2) \end{pmatrix} = \begin{pmatrix} s_1(1) & s_2(1) \\ -s_2(1)^* & s_1(1)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,2}(1,2) \\ \alpha_{2,2}(1,2) \end{pmatrix} + \begin{pmatrix} s_1(2) & s_2(2) \\ -s_2(2)^* & s_1(2)^* \end{pmatrix} \begin{pmatrix} \alpha_{1,2}(2,2) \\ \alpha_{2,2}(2,2) \end{pmatrix} + \begin{pmatrix} \eta_{1,2}(2) \\ \eta_{2,2}(2) \end{pmatrix} \tag{16}$$

The idea behind interference cancellation arises from separate decodability of each symbol; at each receive antenna we perform the decoding algorithm as if there is only one user. This user will be the one the effect of whom we want to cancel out. Then, we simply subtract the soft-decoded value of each symbol in one of the receive antennas from the rest and as a result remove the effect of that user. This procedure is presented in the following. At the first antenna of receiver 1, we have

$$\begin{pmatrix} r_{1,1}(1) \\ r_{2,1}(1)^* \end{pmatrix} = \begin{pmatrix} \alpha_{1,1}(1,1) & \alpha_{2,1}(1,1) \\ \alpha_{2,1}(1,1)^* & -\alpha_{1,1}(1,1)^* \end{pmatrix} \begin{pmatrix} s_1(1) \\ s_2(1) \end{pmatrix} + \begin{pmatrix} \alpha_{1,1}(2,1) & \alpha_{2,1}(2,1) \\ \alpha_{2,1}(2,1)^* & -\alpha_{1,1}(2,1)^* \end{pmatrix} \begin{pmatrix} s_1(2) \\ s_2(2) \end{pmatrix} + \begin{pmatrix} \eta_{1,1}(1) \\ \eta_{2,1}^*(1) \end{pmatrix} \tag{17}$$

At the second antenna of receiver 1, we have

$$\begin{pmatrix} r_{1,2}(1) \\ r_{2,2}(1)^* \end{pmatrix} = \begin{pmatrix} \alpha_{1,2}(1,1) & \alpha_{2,2}(1,1) \\ \alpha_{2,2}(1,1)^* & -\alpha_{1,2}(1,1)^* \end{pmatrix} \begin{pmatrix} s_1(1) \\ s_2(1) \end{pmatrix} + \begin{pmatrix} \alpha_{1,2}(2,1) & \alpha_{2,2}(2,1) \\ \alpha_{2,2}(2,1)^* & -\alpha_{1,2}(2,1)^* \end{pmatrix} \begin{pmatrix} s_1(2) \\ s_2(2) \end{pmatrix} + \begin{pmatrix} \eta_{1,2}(1) \\ \eta_{2,2}(1)^* \end{pmatrix} \tag{18}$$

In order to cancel the signals s_1^1 and s_2^1 from User 1, we first multiply both sides of Equation (17) with $\begin{pmatrix} \alpha_{1,1}(1,1) & \alpha_{2,1}(1,1) \\ \alpha_{2,1}(1,1)^* & -\alpha_{1,1}(1,1)^* \end{pmatrix}^\dagger$ and multiply both sides of Equation (18) with $\begin{pmatrix} \alpha_{1,2}(1,1) & \alpha_{2,2}(1,1) \\ \alpha_{2,2}(1,1)^* & -\alpha_{1,2}(1,1)^* \end{pmatrix}^\dagger$ Then we have Equations (25) and (26) in the next page, where $\eta'_{1,1}$, $\eta'_{2,1}$, $\eta'_{1,2}$, $\eta'_{2,2}$ are given by

$$\begin{pmatrix} \eta_{1,1}(1)' \\ \eta_{2,1}(1)' \end{pmatrix} = \begin{pmatrix} \alpha_{1,1}^*(1,1) & \alpha_{2,1}(1,1) \\ \alpha_{2,1}^*(1,1) & -\alpha_{1,1}(1,1) \end{pmatrix} \begin{pmatrix} \eta_{1,1}(1) \\ \eta_{2,1}(1) \end{pmatrix} \tag{19}$$

$$\begin{pmatrix} \eta_{1,2}(1)' \\ \eta_{2,2}(1)' \end{pmatrix} = \begin{pmatrix} \alpha_{1,2}^*(1,1) & \alpha_{2,2}(1,1) \\ \alpha_{2,2}^*(1,1) & -\alpha_{1,2}(1,1) \end{pmatrix} \begin{pmatrix} \eta_{1,2}(1) \\ \eta_{2,2}(1)^* \end{pmatrix} \tag{20}$$

In order to eliminate the effect of user 1, we need to divide both sides of Equation (25) by

$$\frac{1}{(|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2)} \tag{21}$$

and divide both sides of Equation (26) by

$$\frac{1}{(|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2)} \tag{22}$$

Equations (25) and (26) becomes Equations (27) and (28). Then we can subtract both sides of Equation (27) from Equation (28). The resulting terms are shown by

$$\widehat{y}(1)=\widehat{H}(1)\begin{pmatrix}s_1(2)\\ s_2(2)\end{pmatrix}+\begin{pmatrix}\eta_{1,2}(1)''\\ \eta_{2,2}(1)''\end{pmatrix} \tag{23}$$

where $\widehat{y}(1)$ and $\widehat{H}(1)$ are given by Equations (29) and (30). $\eta_{1,2}(1)''$, $\eta_{2,2}(1)''$ are given by

$$\begin{pmatrix}\eta_{1,2}(1)''\\ \eta_{2,2}(1)''\end{pmatrix}=\frac{1}{(|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2)}\begin{pmatrix}\eta_{1,2}(1)'\\ \eta_{2,2}(1)'\end{pmatrix}-\frac{1}{(|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2)}\begin{pmatrix}\eta_{1,1}(1)'\\ \eta_{2,1}(1)'\end{pmatrix} \tag{24}$$

The distribution of $\eta_{1,2}(1)''$, $\eta_{2,2}(1)''$ are Gaussian white noise. In Equation (25), $\widehat{H}(1)$ can be written as the following structure:

$$\widehat{H}(1)=\begin{pmatrix}a(1) & b(1)\\ b(1)^* & -a(1)^*\end{pmatrix} \tag{33}$$

where $a(1)$ and $b(1)$ are given by Equations (31) and (32). In order to decode the s_1^2, we can multiply both sides of the Equation (23) with $\begin{pmatrix}a(1)\\ b(1)^*\end{pmatrix}^\dagger$, we have

$$\begin{aligned}\begin{pmatrix}a(1)\\ b(1)^*\end{pmatrix}^\dagger\widehat{y}(1)&=\begin{pmatrix}|a(1)|^2+|b(1)|^2 & 0\end{pmatrix}\begin{pmatrix}s_1(2)\\ s_2(2)\end{pmatrix}\\ &\quad+\begin{pmatrix}a(1)\\ b(1)^*\end{pmatrix}^\dagger\begin{pmatrix}\eta_{1,2}(1)''\\ \eta_{2,2}(1)''\end{pmatrix}\\ &=(|a(1)|^2+|b(1)|^2)s_1(2)+\begin{pmatrix}a(1)\\ b(1)^*\end{pmatrix}^\dagger\begin{pmatrix}\eta_{1,2}^{(}1)''\\ \eta_{2,2}(1)''\end{pmatrix}\end{aligned} \tag{34}$$

In order to keep the Gaussian white noise, we need

$$\begin{aligned}\frac{1}{\sqrt{|a(1)|^2+|b(1)|^2}}\begin{pmatrix}a(1)\\ b(1)^*\end{pmatrix}^\dagger\widehat{y}(1)&=\\ \sqrt{|a(1)|^2+|b(1)|^2}s_1(2)&\\ +\frac{1}{\sqrt{|a(1)|^2+|b(1)|^2}}\begin{pmatrix}a(1)\\ b(1)^*\end{pmatrix}^\dagger\begin{pmatrix}\eta_{1,2}(1)''\\ \eta_{2,2}(1)''\end{pmatrix}&\end{aligned} \tag{35}$$

Maximum likelihood decoding can be used to decode s_1^2:

$$\widehat{s}_1^2=\arg\min_{s_1^2}\left|\frac{1}{\sqrt{|a(1)|^2+|b(1)|^2}}\begin{pmatrix}a(1)\\ b(1)^*\end{pmatrix}^\dagger\widehat{y}(1)-\sqrt{|a(1)|^2+|b(1)|^2}s_1(2)\right|_F^2 \tag{36}$$

So the decoding is symbol-by-symbol. In order to decode the s_2^2, we can multiply both sides of the Equation (23) with $\begin{pmatrix}b(1)\\ -a(1)^*\end{pmatrix}^\dagger$, we have

$$\begin{aligned}\begin{pmatrix}b(1)\\ -a(1)^*\end{pmatrix}^\dagger\widehat{y}(1)&=\begin{pmatrix}0 & |a(1)|^2+|b(1)|^2\end{pmatrix}\begin{pmatrix}s_1(2)\\ s_2(2)\end{pmatrix}\\ &\quad+\begin{pmatrix}b(1)\\ -a(1)^*\end{pmatrix}^\dagger\begin{pmatrix}\eta_{1,2}(1)''\\ \eta_{2,2}(1)''\end{pmatrix}\\ &=(|a(1)|^2+|b(1)|^2)s_2(2)+\begin{pmatrix}b(1)\\ -a(1)^*\end{pmatrix}^\dagger\begin{pmatrix}\eta_{1,2}(1)''\\ \eta_{2,2}(1)''\end{pmatrix}\end{aligned} \tag{37}$$

In order to keep the Gaussian white noise, we need

$$\begin{aligned}\frac{1}{\sqrt{|a(1)|^2+|b(1)|^2}}\begin{pmatrix}b(1)\\ -a(1)^*\end{pmatrix}^\dagger\widehat{y}(1)&=\\ \sqrt{|a(1)|^2+|b(1)|^2}s_2(2)&\\ +\frac{1}{\sqrt{|a(1)|^2+|b(1)|^2}}\begin{pmatrix}b(1)\\ -a(1)^*\end{pmatrix}^\dagger\begin{pmatrix}\eta_{1,2}(1)''\\ \eta_{2,2}(1)''\end{pmatrix}&\end{aligned} \tag{38}$$

Maximum likelihood decoding can be used to decode s_2^2:

$$\widehat{s}_2^2=\arg\min_{s_2^2}\left|\frac{1}{\sqrt{|a(1)|^2+|b(1)|^2}}\begin{pmatrix}b(1)\\ -a(1)^*\end{pmatrix}^\dagger\widehat{y}(1)-\sqrt{|a(1)|^2+|b(1)|^2}s_2(2)\right|_F^2 \tag{39}$$

The decoding is also symbol-by-symbol. Now we analyze the diversity. From Equation (34), we know that the diversity is determined by factor $\sqrt{|a(1)|^2+|b(1)|^2}$. The diversity is defined as

$$d=-\lim_{\rho\to\infty}\frac{\log P_e}{\log\rho} \tag{40}$$

where ρ denotes the SNR and P_e represents the probability of error. It is known that the error probability can be written as

$$\begin{aligned}&P(s_1(2)\to error|a(1),b(1))\\ &=Q\left(\sqrt{\frac{\rho|\sqrt{|a(1)|^2+|b(1)|^2}\mathbf{e}|_F^2}{4}}\right)\\ &\le\exp\left(-\frac{\rho(|a(1)|^2+|b(1)|^2)\mathbf{e}^\dagger\mathbf{e}}{4}\right)\\ &=\exp\left(-\frac{\rho(|a(1)|^2+|b(1)|^2)e^2}{4}\right)\end{aligned} \tag{41}$$

where e is the error. We need to analyze $a(1)$ and $b(1)$. Conditioned on $\alpha_{1,2}(1,1),\alpha_{2,2}(1,1),\alpha_{1,1}(1,1),\alpha_{2,1}(1,1)$, then $a(1)$ and $b(1)$ are both Gaussian random variables. It is easy to verify that

$$E[a(1)\cdot b(1)|\alpha_{1,2}(1,1),\alpha_{2,2}(1,1),\alpha_{1,1}(1,1),\alpha_{2,1}(1,1)]=0 \tag{42}$$

$$\begin{pmatrix}\alpha_{1,1}^*(1,1) & \alpha_{2,1}(1,1)\\ \alpha_{2,1}^*(1,1) & -\alpha_{1,1}(1,1)\end{pmatrix}\begin{pmatrix}r_{1,1}(1)\\ r_{2,1}(1)^*\end{pmatrix} = (|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2)\begin{pmatrix}s_1^1\\ s_2^1\end{pmatrix} + \begin{pmatrix}\alpha_{1,1}^*(1,1) & \alpha_{2,1}(1,1)\\ \alpha_{2,1}^*(1,1) & -\alpha_{1,1}(1,1)\end{pmatrix}\begin{pmatrix}\alpha_{1,1}(2,1) & \alpha_{2,1}(2,1)\\ \alpha_{2,1}^*(2,1) & -\alpha_{1,1}^*(2,1)\end{pmatrix}\begin{pmatrix}s_1(2)\\ s_2(2)\end{pmatrix} + \begin{pmatrix}\eta_{1,1}(1)'\\ \eta_{2,1}(1)'\end{pmatrix} \quad (25)$$

$$\begin{pmatrix}\alpha_{1,2}^*(1,1) & \alpha_{2,2}(1,1)\\ \alpha_{2,2}^*(1,1) & -\alpha_{1,2}(1,1)\end{pmatrix}\begin{pmatrix}r_{1,2}(1)\\ r_{2,2}(1)^*\end{pmatrix} = (|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2)\begin{pmatrix}s_1^1\\ s_2^1\end{pmatrix} + \begin{pmatrix}\alpha_{1,2}^*(1,1) & \alpha_{2,2}(1,1)\\ \alpha_{2,2}^*(1,1) & -\alpha_{1,2}(1,1)\end{pmatrix}\begin{pmatrix}\alpha_{1,2}(2,1) & \alpha_{2,2}(2,1)\\ \alpha_{2,2}^*(2,1) & -\alpha_{1,2}^*(2,1)\end{pmatrix}\begin{pmatrix}s_1(2)\\ s_2(2)\end{pmatrix} + \begin{pmatrix}\eta_{1,2}(1)'\\ \eta_{2,2}(1)'\end{pmatrix} \quad (26)$$

$$\frac{1}{(|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2)}\begin{pmatrix}\alpha_{1,1}^*(1,1) & \alpha_{2,1}(1,1)\\ \alpha_{2,1}^*(1,1) & -\alpha_{1,1}(1,1)\end{pmatrix}\begin{pmatrix}r_{1,1}(1)\\ r_{2,1}(1)^*\end{pmatrix} = \begin{pmatrix}s_1^1\\ s_2^1\end{pmatrix} + \frac{1}{(|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2)}\begin{pmatrix}\eta_{1,1}(1)'\\ \eta_{2,1}(1)'\end{pmatrix} + \left(\frac{1}{(|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2)}\begin{matrix}\alpha_{1,1}^*(1,1) & \alpha_{2,1}(1,1)\\ \alpha_{2,1}^*(1,1) & -\alpha_{1,1}(1,1)\end{matrix}\right)\begin{pmatrix}\alpha_{1,1}(2,1) & \alpha_{2,1}(2,1)\\ \alpha_{2,1}^*(2,1) & -\alpha_{1,1}^*(2,1)\end{pmatrix}\begin{pmatrix}s_1(2)\\ s_2(2)\end{pmatrix} \quad (27)$$

$$\frac{1}{(|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2)}\begin{pmatrix}\alpha_{1,2}^*(1,1) & \alpha_{2,2}(1,1)\\ \alpha_{2,2}^*(1,1) & -\alpha_{1,2}(1,1)\end{pmatrix}\begin{pmatrix}r_{1,2}(1)\\ r_{2,2}(1)^*\end{pmatrix} = \begin{pmatrix}s_1^1\\ s_2^1\end{pmatrix} + \frac{1}{(|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2)}\begin{pmatrix}\eta_{1,2}(1)'\\ \eta_{2,2}(1)'\end{pmatrix} + \frac{1}{(|\alpha_{1,2}(1)|^2+|\alpha_{2,2}(1)|^2)}\begin{pmatrix}\alpha_{1,2}^*(1,1) & \alpha_{2,2}(1,1)\\ \alpha_{2,2}^*(1,1) & -\alpha_{1,2}(1,1)\end{pmatrix}\begin{pmatrix}\alpha_{1,2}(2) & \alpha_{2,2}(2)\\ \alpha_{2,2}^*(2) & -\alpha_{1,2}^*(2)\end{pmatrix}\begin{pmatrix}s_1(2)\\ s_2(2)\end{pmatrix} \quad (28)$$

$$\widehat{y}(1) = \frac{1}{|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2}\begin{pmatrix}\alpha_{1,2}^*(1,1) & \alpha_{2,2}(1,1)\\ \alpha_{2,2}^*(1,1) & -\alpha_{1,2}(1,1)\end{pmatrix}\begin{pmatrix}r_{1,2}(1)\\ r_{2,2}(1)^*\end{pmatrix} - \frac{1}{|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2}\begin{pmatrix}\alpha_{1,1}^*(1,1) & \alpha_{2,1}(1,1)\\ \alpha_{2,1}^*(1,1) & -\alpha_{1,1}(1,1)\end{pmatrix}\begin{pmatrix}r_{1,1}(1)\\ r_{2,1}(1)^*\end{pmatrix} \quad (29)$$

$$\widehat{H}(1) = \Bigg[\frac{1}{|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2}\begin{pmatrix}\alpha_{1,2}^*(1,1) & \alpha_{2,2}(1,1)\\ \alpha_{2,2}^*(1,1) & -\alpha_{1,2}(1,1)\end{pmatrix}\begin{pmatrix}\alpha_{1,2}(2,1) & \alpha_{2,2}(2,1)\\ \alpha_{2,2}^*(2,1) & -\alpha_{1,2}^*(2,1)\end{pmatrix} - \frac{1}{|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2}\begin{pmatrix}\alpha_{1,1}^*(1,1) & \alpha_{2,1}(1,1)\\ \alpha_{2,1}^*(1,1) & -\alpha_{1,1}(1,1)\end{pmatrix}\begin{pmatrix}\alpha_{1,1}(2,1) & \alpha_{2,1}(2,1)\\ \alpha_{2,1}^*(2,1) & -\alpha_{1,1}^*(2,1)\end{pmatrix}\Bigg] \quad (30)$$

$$a(1) = \frac{1}{|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2}[\alpha_{2,1}^*(1,1)\alpha_{1,2}(2,1)+\alpha_{2,2}(1,1)\alpha_{2,2}^*(2,1)] - \frac{1}{|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2}[\alpha_{1,1}^*(1,1)\alpha_{1,1}(2,1)+\alpha_{2,1}(1,1)\alpha_{2,1}^*(2,1)] \quad (31)$$

$$b(1) = \frac{1}{|\alpha_{1,2}(1,1)|^2+|\alpha_{2,2}(1,1)|^2}[\alpha_{1,2}^*(1,1)\alpha_{2,2}(2,1)-\alpha_{2,2}(1,1)\alpha_{1,2}^*(2,1)] - \frac{1}{|\alpha_{1,1}(1,1)|^2+|\alpha_{2,1}(1,1)|^2}[\alpha_{1,1}^*(1,1)\alpha_{2,1}(2,1)-\alpha_{2,1}(1,1)\alpha_{1,1}^*(2,1)] \quad (32)$$

So $a(1)$ and $b(1)$ are independent Gaussian random variables

$$\begin{aligned}
&P(s_1(2)\rightarrow error)\\
&= E[E[P(s_1(2)\rightarrow error|a(1),b(1))]|\\
&\qquad \alpha_{1,2}(1,1),\alpha_{2,2}(1,1),\alpha_{1,1}(1,1),\alpha_{2,1}(1,1)]\\
&\leq E[E[\exp\left(-\frac{\rho(|a(1)|^2+|b(1)|^2)e^2}{4}\right)\Bigg|\\
&\qquad \alpha_{1,2}(1,1),\alpha_{2,2}(1,1),\alpha_{1,1}(1,1),\alpha_{2,1}(1,1)]]\\
&= E[\frac{1}{\prod_{j=1}^2[1+\frac{\rho e^2}{4})]}|\\
&\qquad \alpha_{1,2}(1,1),\alpha_{2,2}(1,1),\alpha_{1,1}(1,1),\alpha_{2,1}(1,1)]\\
&= \frac{1}{\prod_{i=1}^2[1+\frac{\rho e^2}{4})]}
\end{aligned} \quad (43)$$

When ρ is large, Equation (43) becomes

$$P(s_1(2)\rightarrow error) \leq \rho^{-2}\left(\frac{e^2}{4}\right)^{-2} \quad (44)$$

By Equation (40), the diversity is 2. Now we analyze the diversity for $s_2(2)$. We know that the diversity is determined by factor $\sqrt{|a(1)|^2+|b(1)|^2}$. The error probability can be written as

$$
\begin{aligned}
&P(s_2(2) \to error|a(1), b(1)) \\
&= Q\left(\sqrt{\frac{\rho|\sqrt{|a(1)|^2+|b(1)|^2}\mathbf{e}|_F^2}{4}}\right) \\
&\leq \exp\left(-\frac{\rho(|a(1)|^2+|b(1)|^2)\mathbf{e}^\dagger\mathbf{e}}{4}\right) \\
&= \exp\left(-\frac{\rho(|a(1)|^2+|b(1)|^2)e^2}{4}\right) \qquad (45)
\end{aligned}
$$

where e is the error. We need to analyze $a(1)$ and $b(1)$. Conditioned on $\alpha_{1,2}(2), \alpha_{2,2}(2,1), \alpha_{1,1}(2,1), \alpha_{2,1}(2,1)$, then $a(1)$ and $b(1)$ are both Gaussian random variables. It is easy to verify that

$$
E[a(1)\cdot b(1)|\alpha_{1,2}(2,1), \alpha_{2,2}(2,1), \alpha_{1,1}(2,1), \alpha_{2,1}(2,1)] = 0 \qquad (46)
$$

So $a(1)$ and $b(1)$ are independent Gaussian random variables. We have

$$
\begin{aligned}
&P(s_2(2) \to error) \\
&= E[E[P(s_2(2) \to error|a(1), b(1))]| \\
&\qquad \alpha_{1,2}(2,1), \alpha_{2,2}(2,1), \alpha_{1,1}(2,1), \alpha_{2,1}(2,1)] \\
&\leq E[E[\exp\left(-\frac{\rho(|a(1)|^2+|b(1)|^2)e^2}{4}\right)\Bigg| \\
&\qquad \alpha_{1,2}(2,1), \alpha_{2,2}(2,1), \alpha_{1,1}(2,1), \alpha_{2,1}(2,1)]] \\
&= E[\frac{1}{\prod_{j=1}^2[1+\frac{\rho e^2}{4})]}| \\
&\qquad \alpha_{1,2}(2,1), \alpha_{2,2}(2,1), \alpha_{1,1}(2,1), \alpha_{2,1}(2,1)] \\
&= \frac{1}{\prod_{j=1}^2[1+\frac{\rho e^2}{4})]} \qquad (47)
\end{aligned}
$$

When ρ is large, Equation (47) becomes

$$
P(s_2(2) \to error) \leq \rho^{-2}\left(\frac{e^2}{4}\right)^{-2} \qquad (48)
$$

By Equation (40), the diversity for s_2^2 is 2. Once we detect the signals at receiver 1. We can follow the similar procedure to detect signals from transmitter 2 at receiver 2. Because the above scheme works in the same way for receiver 2.

In summary, the interference cancellation based on Alamouti codes can achieve cancel the interference successfully and the decoding complexity is symbol-by-symbol which is the lowest and the diversity is 2, which is the best as far as we know when no channel information is available at the user side and the lowest decoding complexity is required.

III. Simulations

In order to evaluate the proposed scheme, we use a system with two users with two antennas and two receivers each with two receive antennas. This is a typical interference channel. The two users are sending signals to the receivers simultaneously. We assume alamouti codes are transmitted. So there will be co-channel interference. If the proposed interference cancellation is used, the performance is provided in Figures 2 and 3 while QPSK is used in Figure 2 and 8-PSK is used in Figure 3. In each figure, we compare the interference cancellation scheme with a TDMA scheme with beamforming scheme. That is, during each time slot, one user transmits while the other keeps silent. In order to make the rate the same for the two schemes, in Figure 2, 16-QAM is used while in Figure 3, 64-QAM is used. It is obvious that the proposed scheme has better performance which confirms the effectiveness of the interference cancellation scheme.

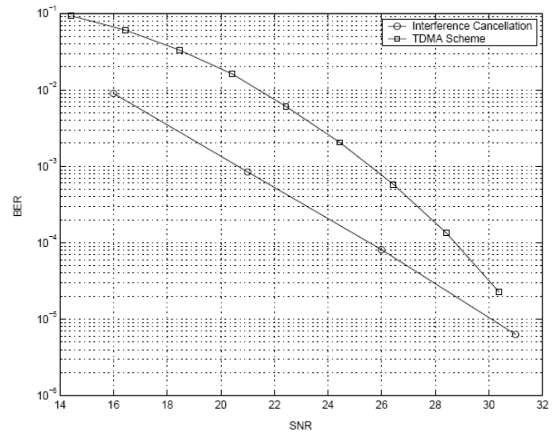

Fig. 2. QPSK constellation with interference cancellation

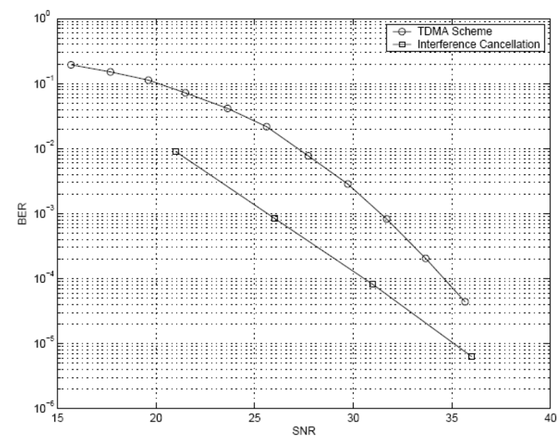

Fig. 3. 8-PSK constellation with interference cancellation

IV. Conclusions

In this paper, we discuss the interference channel. We first give detailed description on interference channel. Later we show that how to tackle interference in such a system is important. Aiming to remove the interference, a strategy for interference channel is proposed and analyzed. The complexity of the strategy is low while the performance is good. Simulations confirm the theoretical analysis.

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