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Exploiting Channel State Information of OSTBC-MIMO System for Improving System Performance

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Abstract – Orthogonal Space Time Block Codes (OSTBC) have shown remarkable performance for Multiple Inputs Multiple Output (MIMO) systems. The performance of OSTBC can be further enhance by knowing transmit channel side information. This paper investigates how to exploit the channel side information at the transmitter end for OSTBC-MIMO system using pre-coding methods. Then the BER performance of the precoded OSTBC Alamouti coding scheme has been evaluated.

Keywords - MIMO ,OSTBC,CSI ,BER,FDD,TDD

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) is seen as one of the key technologies in wireless communication industry that offers significant increase in data throughput and link range without additional bandwidth or increased transmit power. Such systems have the potential to spread the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency and/or to achieve a diversity gain that improves the link reliability. The availability of Channel State Information (CSI) at the transmitter end in MIMO system has been a popular research topic in recent years. The knowledge of accurate and timely CSI at the transmitter is becoming increasingly important in wireless communication systems. While it is often assumed that the receiver needs to know the channel for accurate power control, scheduling, and data demodulation, it is now known that the transmitter (especially, the base station) can also benefit greatly from this information.

In general only the receiver is used to track the channel. In this paper, we will use transmission techniques that can be used to exploit the channel state information (CSI) on the transmitter side. The CSI can be known completely or partially. Sometimes, only statistical information of the channel state is available. We will exploit of such information allows for increasing the channel capacity, error performance, while reducing hardware requirements. CSI for the time-varying channel cannot be tracked completely by the transmitter and thus, only partial information can be exploited. This paper first presents the techniques to obtain channel information. Then precoding techniques is used to exploit CSI on the transmitter side.

II. CHANNEL ESTIMATION ON THE TRANSMITTER SIDE

In general, a transmitter does not have direct access to its own channel state information. Therefore, some indirect means are required for the transmitter. In time division duplexing (TDD) system, we can exploit the channel reciprocity between opposite links (downlink and uplink). Based on the signal received from the opposite direction, it allows for indirect channel estimation. In frequency division duplexing (FDD) system, which usually does not have reciprocity between opposite directions, the transmitter relies on the channel feedback information from the receiver. In other words, CSI must be estimated at the receiver side and then feedback to the transmitter side.

2.1 Exploring the Use of Channel Reciprocity

As long as the channel gains in both directions are reciprocal as shown in Figure 2.1. The channel condition in one direction can be implicitly known from the other direction. In TDD systems, forward and backward channels are almost reciprocal and there exists a non-negligible difference in their transmission time. If the difference is small compared to the coherence time, the reciprocity can be a useful property to exploit. On the other side, in FDD systems, the two channels use different radio frequencies and hence channel reciprocity does not hold.

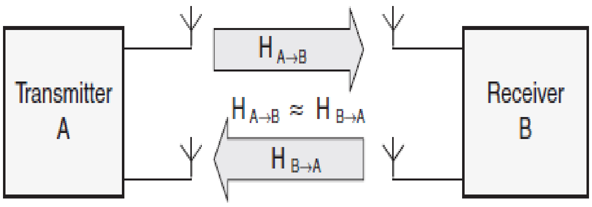

Figure 2.1 Reciprocity of wireless channel.

2.2 The use of CSI Feedback

One important approach in obtaining the channel condition in the transmitter side is to use the feedback from the receiver side, as shown in Figure 5.2. In this case compensation for the RF difference is not necessary. But the feedback delay Δ_t must be less than the coherence time $T_{c.}$,

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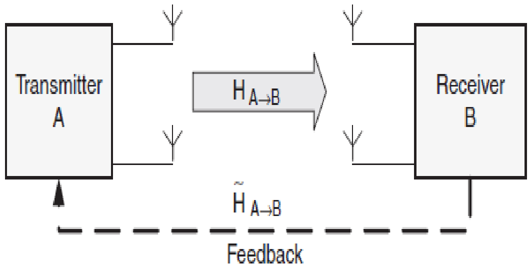

Figure 2.2 Feedback of channel state information.

Its main drawback is that additional bits are required for transmitting the feedback information. The amount of feedback data increases with the number of antennas. Hence, the overhead problem becomes severe for multiple antenna systems. Also, when channels are subject to fast fading i.e. the coherence time is small, which results in the requirement of more frequent feedback to meet the constraint in Equation (2.1). One method to overcome this problem is to compress the estimated CSI at the receiver resulting in reduction in the feedback overhead.

Let $Q_{quan}(\mathrm{H})$ represent the quantization function of the channel gain H. Then, the channel gain can be quantized using minimum mean square approach as $\mathrm{E}\left\{\left\| H - Q_{quan}(\mathrm{H}) \right\|^2\right\}$. Another approach is to use the codebook that is shared by the transmitter and receiver. The codebook is a set of codewords, which are the quantized vectors to represent the states of channel condition. In this approach, channel gains are estimated at the receiver side. Then, the index of the appropriate codeword is selected to represent a state of estimated channel gain. Rather than the full CSI, only the corresponding index is fed back to the transmitter side. Each index can be represented with FB bits, which allows for a total number of $L = 2^{F_s}$ codewords in the codebook. Where L is referred to as a codebook size. Let W_i denote the i[th] codeword, $i = 1, 2, \cdots, L$ For a given codebook $F = \{W_1, W_2, W_3, \cdots, W_L\}$, the codeword is selected by a mapping function $f(\cdot)$. For a given channel condition H, the codebook method can be represented as

$$W_{opt} = f(\mathrm{H}) \in \mathrm{F} = \{W_1, W_2, W_3, \cdots, W_L\} \qquad (2.1)$$

Where W_{opt} is the codeword that best represents H for a given mapping function $f(\cdot)$. However, the issue of designing a codebook remains. We are supposed to determine the code words that quantize the channel space with the least distortion. Let us discuss the codebook design methods in the following sections.

2.3 Using Precoded OSTBC

Let us have a MISO system with N_T antennas, that is, $h \in \Re^{1 \times N_T}$. Let $C \in \Re^{M \times T}$ denote a space time codeword with a length of M, and is represented as

$$C = [c_1 c_2 \cdots c_T] \qquad (2.2)$$

where $c_k = \left[c_{k,1} c_{k,2} \cdots c_{k,M}\right]^T, k = 1, 2, \cdots, T,$ and $M \le N_T$. In the precoded OSTBC systems, the space-time codeword C is multiplied by a precoding matrix $W \in \Re^{N_T \times M}$, where W is chosen from the codebook $F = \{W_1, W_2, W_3, \cdots, W_L\}$. W is chosen such that the codeword improves channel capacity or error performance. Assuming that N_T channels remain static over T, the received signal $y \in \Re^{l \times T}$ can be expressed as

$$y = \sqrt{\frac{E_X}{N_T}} hWC + z \qquad (2.3)$$

In Equation (2.3), the length of each vector is $M \le N_T$ while the space time codeword is composed of T column vectors. For a given channel h and precoding matrix W, we consider the pairwise codeword error probability $\Pr\left(C_i \to C_j \,|\, H\right)$. This is the probability that the space-time codeword C_i is transmitted whereas C_j with $j \ne i$ is decoded. After few mathematic a manipulations, the upper bound of the pair wise error probability can be derived as

$$\Pr\left(C_i \to C_j | H\right) = Q\left(\sqrt{\frac{\rho \left\| HWE_{i,j} \right\|_F^2}{2N_T}}\right) \le \exp\left(-\frac{\rho \left\| HWE_{i,j} \right\|_F^2}{4N_T}\right)$$

(2.4)

where ρ is the signal-to-noise ratio (SNR) and is given as $\rho = E_X / N_0$, and $E_{i,j} = C_i - C_j$ is the error matrix between the codewords C_i and C_j. From Equation (2.4), we can interpret that in order to minimize the pairwise error probability [1, 2] $\left\| HWE_{i,j} \right\|_F^2$ needs to be maximized, which leads us to the following codeword selection criterion

$$\begin{aligned} W_{opt} &= \underset{W \in F, i \ne j}{\arg\max} \left\| HWE_{i,j} \right\|_F^2 \\ &= \underset{W \in F, i \ne j}{\arg\max}\, Tr\left(HWE_{i,j} E_{i,j}^H W^H H^H\right) \qquad (2.5) \\ &= \underset{W \in F}{\arg\max}\, Tr\left(HWE^H H^H\right) \\ &= \underset{W \in F}{\arg\max} \left\| HW \right\|_F^2 \end{aligned}$$

The optimum solution of Equation (2.5) can be given by [3],

$$W_{opt} = [V_1 V_2 \cdots V_M] \triangleq \bar{V} \qquad (2.6)$$

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Since $\bar{V}$ is unitary, $\lambda_i\left(W_{opt}\right)=1, \mathrm{i}=1,2,\cdots,\mathrm{M},$, where $\lambda_i\left(A\right)$ denotes the i[th] largest eigen value of the matrix A. For not deterministic channel codebook can be designed as [3]

$$E\left\{\min_{W\in F}\left(\left\|HW_{opt}\right\|_F^2-\left\|HW\right\|_F^2\right)\right\} \qquad (2.7)$$

W_{opt} in Equation (2.7) follows from Equation (2.6) for the given channel H. The above expected value in Equation (2.7) is upper-bounded as

$$E\left\{\min_{W\in F}\left(\left\|HW_{opt}\right\|_F^2-\left\|HW\right\|_F^2\right)\right\}\le E\left\{\lambda_1^2\left\{H\right\}\right\}E\left\{\left\|\bar{V}\bar{V}^H-WW^H\right\|_F^2\right\} \qquad (2.8)$$

Since $\lambda_1^2\left\{H\right\}$ is given, the codebook must be designed so as to minimize E min W_{opt} in Equation (2.8). The corresponding minimization problem can be formulated into the Grassmannian subspace packing problem [3–5]. The in Grassmannian subspace packing is the chordal distance is used as performance measure and is defined as

$$d\left(W_k,W_l\right)=\frac{1}{\sqrt{2}}\left\|W_kW_k^H-W_lW_l^H\right\|_F \qquad (2.9)$$

For random channels, the optimum codebook is designed so as to maximize the minimum chordal distance $\delta_{\min}=\min_{k\neq l,1\le k,l\le L} d\left(W_k,W_l\right)$ [3] as shown in Figure 2.3.

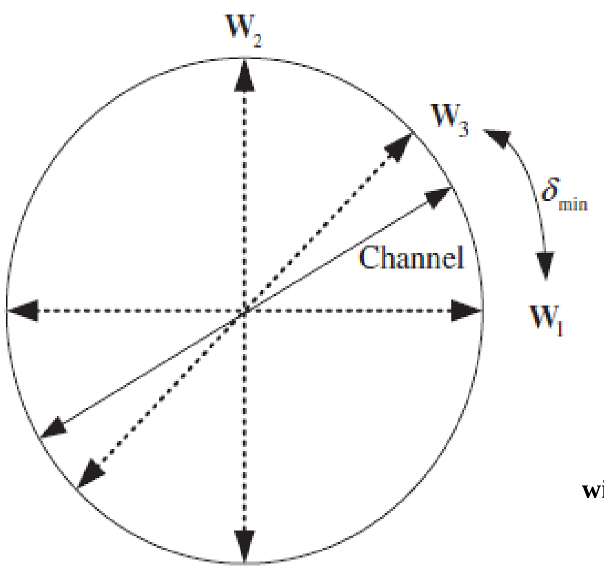

Figure 2.3 Precoding matrix and chordal distance

For N_T, codeword length M, and codebook size L Grassmannian packing problem can be solved as $F=\left\{W_{DFT},\theta W_{DFT},\cdots,\theta^{L-1}W_{DFT}\right\}$ 2.10)

Where u is the diagonal matrix and is given as

$$\theta=diag\left(\left[e^{j2\pi u_1/N_T}e^{j2\pi u_2/N_T}\cdots e^{j2\pi u_{N_T}/N_T}\right]\right) \quad (2.11)$$

$\left\{u_i\right\}_{i=1}^{N_T}$ in Equation (5.11) are determined such that the minimum chordal distance is maximized i.e.

$$u=\arg\max_{\left\{u_1,u_2\cdots u_{N_T}\right\}}\min_{l=1,2,\cdots,N-1} d\left(W_{DFT},\theta^l W_{DFT}\right) \qquad (2.12)$$

IEEE 802.16e specification for the Mobile WiMAX system uses this r design method. When $N_T=4, M=3,$, and $L=64, W_1$ is given as

$$W_1=\frac{1}{\sqrt{4}}\begin{bmatrix}1 & 1 & 1\\ 1 & e^{j2\pi\cdot1\cdot2/4} & e^{j2\pi\cdot1\cdot3/4}\\ 1 & e^{j2\pi\cdot2\cdot2/4} & e^{j2\pi\cdot2\cdot3/4}\\ 1 & e^{j2\pi\cdot3\cdot2/4} & e^{j2\pi\cdot3\cdot3/4}\end{bmatrix} \qquad (2.13)$$

The remaining precoding matrices W_i are obtained as

$$W_i=diag\left(\left[e^{j2\pi\cdot1/4}e^{j2\pi\cdot8/4}e^{j2\pi\cdot61/4}e^{j2\pi\cdot45/4}\right]\right)^{i-1}w_1, i=2,3,\cdots,64 \qquad (2.14)$$

III. Simulations and Results

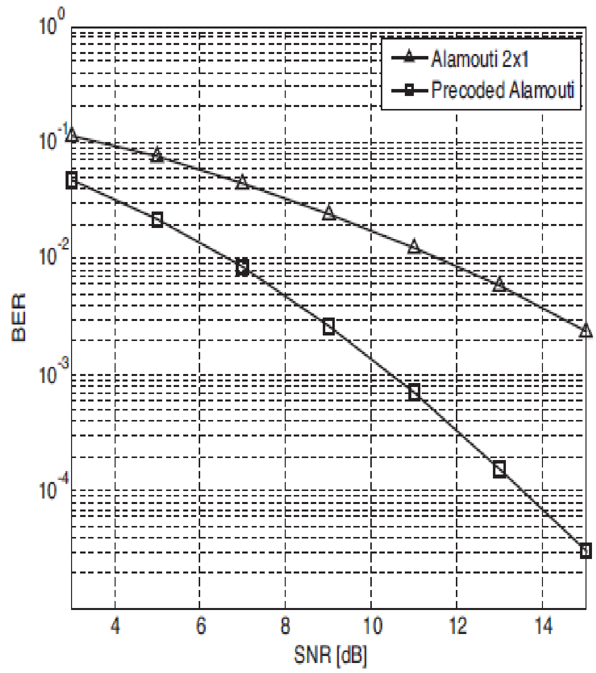

Figure 3.1 BER performance of OSTBC with and without precoding in Rayleigh fading channel

We have generated the codebook using the design method in Equation (3.1) with N_T= 4, M = 2, and L = 64. To simulate the BER performance of the precoded OSTBC the Alamouti coding scheme has been used. Comparing the performance of STBC with and without precoding for N_T= 2 and N_R= 1 in a block flat Rayleigh fading channel. It can be concluded that the precoded STBC scheme outperforms the traditional STBC scheme without increasing transmit power or increasing spectral bandwidth.

IV. Conclusion

In general only the receiver is used to track the channel. In this paper, we have used transmission techniques that can be used to exploit the channel state information (CSI) on the

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transmitter side. The CSI can be known completely or partially. Sometimes, only statistical information of the channel state is available. We have exploited such information for increasing the channel capacity, error performance, while reducing hardware requirements.

As CSI for the time-varying channel cannot be tracked completely by the transmitter and thus, only partial information can be exploited. This paper first presents the techniques to obtain channel information. Then precoding techniques is used to exploit CSI on the transmitter side.

In this paper we have generated the codebook and BER performance of the precoded OSTBC Alamouti coding scheme has been evaluated. Comparing the performance of STBC with and without precoding it has been concluded that the precoded OSTBC scheme outperforms the traditional OSTBC scheme without increasing transmit power or increasing spectral bandwidth.

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