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Performance Analysis of STBC and Precoded OSTBC for MIMO

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***Abstract*— Orthogonal space-time block codes (OSTBCs) are simple space-time codes that can be used for transmit diversity systems. OSTBCs are a class of easily decoded space-time codes that achieve full diversity order in Rayleigh fading channels. OSTBCs exist only for certain numbers of transmit antennas and do not provide array gain like diversity techniques that exploit transmit channel information. When channel state information is available at the transmitter, though, precoding the space-time codeword can be used to support different numbers of transmit antennas. This paper involves a transmitted signal consists of a precode followed by an orthogonal space-time block code (OSTBC), such as Alamouti code. A new design criterion and a corresponding design method of precoders are proposed which shows comparison of bit error rate (BER) performance of Precoded Alamouti and Precoded OSTBC in Zero Forcing and MMSE equalization techniques.**

***Keywords* – OSTBC, Precoding, Alamouti, BER, Zero Forcing, MMSE.**

I. INTRODUCTION

Multiple-Input multiple-output (MIMO) wireless channels have considerably higher capacities than traditional channels. Fading makes it extremely difficult for the receiver to recover the transmitted signal unless the receiver is provided with some form of diversity, i.e. replicas of the same transmitted signal with uncorrelated attenuation. In fact, diversity combining technology has been one of the most important contributors to reliable wireless communications. Consider transmit diversity by deploying multiple antennas at the base station. Moreover, in economic terms, the cost of multiple transmit antennas at the base station can be amortized over numerous mobile users. Hence transmit diversity has been identified as one of the key contributing technologies to the downlinks of 3G wireless systems such as W-CDMA and CDMA2000.

WE have analysed the full diversity condition in MIMO to achieve the better BER performance. We take Alamouti, OSTBC, (with 2, 4, and 8) transmit antenna to show that BER performance will improve when antenna size improved. But the cost of device improve make it practically impossible and power consumption will more for mobile device, so alternate is using same MIMO with turbo code so same will give better result, with two antenna.

Transmit Diversity

Transmit diversity improves the signal quality and achieves a higher SNR ratio at the receiver side; it involves transmitting data stream through multiple antennas and receiving by single antenna or more. Transmit diversity can effectively mitigate multipath fading effects as multiple antennas afford a receiver several observations of the same data stream. Each antenna will experience a different interference environment and if one antenna experienced a deep fade, then it is likely that another has a sufficient signal. Thus, transmit diversity can help improve the reliability of the data reception and data decoding as well. The most popular examples of these transmit diversity techniques include Alamouti code [1] and orthogonal codes and orthogonal codes proposed by Taroukh [2]. Figure 1 shows the whole system for an exemplary Nt transmit antenna system.

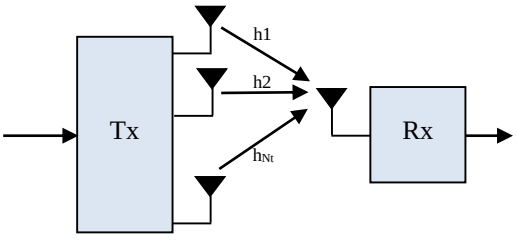

Figure 1: Transmit diversity

Receive Diversity

Receive diversity are widely used in wireless communication systems; it can be achieved by receiving redundant copies of the same signal. The idea behind receive diversity is that each antenna at the receive end can observe an independent copy of the same signal. Therefore the probability that all

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signals are in deep fade simultaneously is significantly reduced.

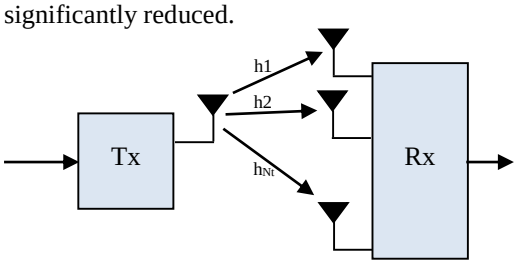


Figure 2: Receive diversity

The paper is organized as follows: Section 2 describes the different space time coding schemes. Section 3 presents simulation results. The conclusions are offered in Section 4.

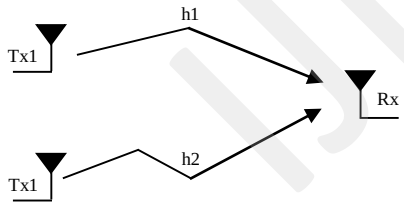
II. SPACE TIME BLOCK CODES

Alamouti STBC

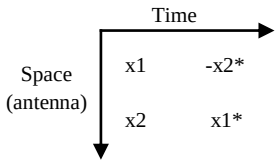
It is simple method for achieving spatial diversity with two transmit antennas. The scheme is as follows:
Consider that we have a transmission sequence, for example

$$\{x_1, x_2, x_3, \ldots\ldots, x_n\}$$

In normal transmission, we will be sending x_1 in the first time slot, x_2 in the second time slot, x_3 and so on.



(a)



(b)

Figure 3: (a) Transmit, (b) Receive Alamouti STBC coding

However, Alamouti suggested that we group the symbols into groups of two. In the first time slot, send x_1 and x_2 from the first and second antenna. In second time slot send $-x_2^*$ and x_1^* from the first and second antenna. In the third time slot send x_3 and x_4 from the first and second antenna. In fourth time slot, send $-x_4^*$ and x_3^* from the first and second antenna and so on.

Notice that though we are grouping two symbols, we still need two time slots to send two symbols. Hence, there is no change in the data rate. This forms the simple explanation of the transmission scheme with Alamouti Space Time Block coding.

Alamouti scheme is an example of a full-rate full-diversity complex space–time block code.

Tarokh Scheme

A space–time block code is defined by an m×n transmission matrix G_T. The entries of the matrix G_T are linear combinations of the variables $x_1, x_1, \ldots\ldots x_k$ and their conjugates. The number of transmission antennas is n and we usually use it to separate different codes from each other. For example, G_{T_2} represents a code which utilizes two transmit antennas and is defined by:

$$G_{T_2} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}$$

We assume that transmission at the baseband employs a signal constellation A with 2^b elements. At time slot 1, kb bits arrive at the encoder and select constellation signals $s_1, s_2 \ldots\ldots s_k$. Setting $x_i = s_i$ for i = 1, 2… k in G_T we arrive at a matrix C with entries linear combinations of $s_1, s_2 \ldots\ldots s_k$ and their conjugates. So, while G_T contains in-determinates $x_1, x_1, \ldots\ldots x_k$ C contains specific constellation symbols (or their linear combinations) which are transmitted from n antennas for each kb bits as follows. If C_t^i represents the element in the t^{th} row and the i^{th} column of C, the entries C_t^i, i = 1,2,……,n are are transmitted simultaneously from transmit antennas 1,2,……,n at each time slot 1,2,……,m. So, the i^{th} column of C represents the transmitted symbols from the i^{th} antenna and the t^{th} row of C represents the transmitted symbols at time slot t Note that C is basically defined using G_T, and the orthogonality of G_T's columns allows a simple decoding scheme which will be explained in the sequel. Since m time slots are used to transmit k symbols, we define the rate R of the code to be R=k/p. For example, the rate of G_{T_2} is one.
In this work, we consider the performance of the following rate half space–time block codes:

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$$G_{T_3} = \begin{bmatrix} x_1 & x_2 & x_3 \\ -x_2 & x_1 & -x_4 \\ -x_3 & x_4 & x_1 \\ -x_4 & -x_3 & x_2 \\ x_1^* & x_2^* & x_3^* \\ -x_2^* & x_1^* & -x_4^* \\ -x_3^* & x_4^* & x_1^* \\ -x_4^* & -x_3^* & x_2^* \end{bmatrix}$$

And

$$G_{T_4} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{bmatrix}$$

Precoded OSTBC

Consider the MISO system with N_T antennas, that is $\mathbf{h} \in C^{1\times N_T}$. Let $C \in C^{M\times T}$ denote a space-time codeword with a length of M, which is represented as

$$\mathbf{C} = [c_1 c_2 \dots \dots c_T]$$

Where $\mathbf{c}_k = [c_{k,1} c_{k,2} \dots \dots c_{k,M}]^T$, $k = 1,2, \dots, T$ And $M \leq N_T$. In the precoded OSTBC systems, the space-time codeword **C** is multiplied by a precoding matrix $\mathbf{W} \in C^{N_T\times M}$, which is chosen from the codebook $F = \{\mathbf{W}_1, \mathbf{W}_2, \mathbf{W}_3 \dots, \mathbf{W}_L\}$. The objective is to choose an appropriate codeword that improves the overall system performance such as channel capacity or error performance. Assuming that N_T channels remain static over T, the received signal $\mathbf{y} \in C^{1\times T}$ can be expressed as,

$$\mathbf{y} = \sqrt{\frac{E_X}{N_T}}\mathbf{hWC} + \mathbf{z} \tag{1}$$

In above equation the length of each vector is $M \leq N_T$. The probability of codeword error can be derived as follows: For a given channel **h** and precoding matrix **W**, we consider the pairwise codeword error probability $P_r(C_i \to C_j|\mathbf{H})$. The upper bound of the pairwise error probability is given as

$$P_r(C_i \to C_j|\mathbf{H}) = Q\left(\sqrt{\frac{\rho||\boldsymbol{HWE}_{i,j}||_F^2}{2N_T}}\right) \leq exp\left(-\frac{\rho||\boldsymbol{HWE}_{i,j}||_F^2}{4N_T}\right) \tag{2}$$

Where ρ is the signal-to-noise ratio (SNR), given as $\rho = E_x/N_0$ and $E_{i,j}$ is the error matrix between the codewords C_i and C_j which is defined as $E_{i,j} = C_i - C_j$ for a given STBC scheme. From equation above we see that $||\boldsymbol{HWE}_{i,j}||_F^2$ needs to be maximized in order to minimize the pairwise error probability. This leads us to the following codeword selection criterion:

$$\begin{aligned} \boldsymbol{W}_{opt} &= \underbrace{\arg max}_{W\in F, i\neq j} ||\boldsymbol{HWE}_{i,j}||_F^2 \\ &= \underbrace{\arg max}_{W\in F, i\neq j} Tr(\boldsymbol{HWE}_{i,j}\boldsymbol{E}_{i,j}^H\boldsymbol{W}^H\boldsymbol{H}^H) \\ &= \underbrace{\arg max}_{W\in F} Tr(\boldsymbol{HWW}^H\boldsymbol{H}^H) \\ &= \underbrace{\arg max}_{W\in F} ||\boldsymbol{HW}||_F^2 \end{aligned} \tag{3}$$

In the course of deriving equation (3), we have used the fact that the error matrix of OSTBC has the property of $\boldsymbol{E}_{i,j}\boldsymbol{E}_{i,j}^H = a\boldsymbol{I}$ with constant a. When the constraint $\boldsymbol{W}\epsilon F$ is not imposed, the above optimum solution $\boldsymbol{W}_{opt}$ is not unique, because $||\boldsymbol{HW}_{opt}||_F^2 = ||\boldsymbol{HW}_{opt}\boldsymbol{Z}||_F^2$. Where **Z** is a unitary matrix. The unconstrained optimum solution of equation (3) can be obtained by a singular value decomposition (SVD) of channel $\boldsymbol{H} = \boldsymbol{U\Sigma V}^H$, where the diagonal entry of S is in descending order. It is shown that the optimum solution of above equation is given by the leftmost M columns of **V**, that is,

$$\boldsymbol{W}_{opt} = [v_1 v_1 \dots . v_M] \triangleq \bar{\boldsymbol{V}} \tag{4}$$

Since $\bar{\boldsymbol{V}}$ is unitary, $\lambda_i(\boldsymbol{W}_{opt}) = 1, i = 1,2, \dots, M$ where $\lambda_i(\boldsymbol{A})$ denotes the i^{th} largest eigenvalue of the matrix $\boldsymbol{A}$. In case that a channel is not deterministic, the following criterion is used for the codebook design:

$$E\left\{\underbrace{min}_{W\in F}\left(||\boldsymbol{HW}_{opt}||_F^2 - ||\boldsymbol{HW}||_F^2\right)\right\} \tag{5}$$

Where the expectation is with regards to the random channel **H**. $\boldsymbol{W}_{opt}$ in equation (5) follows from equation (4) for the given channel H. The above expected value in equation (5) is upper-bounded as

$$\begin{aligned} &E\left\{\underbrace{min}_{W\in F}\left(\left|\left|\boldsymbol{HW}_{opt}\right|\right|_F^2 - \left|\left|\boldsymbol{HW}\right|\right|_F^2\right)\right\} \\ &\leq E\{\lambda_1^2\{\boldsymbol{H}\}\}E\left\{\underbrace{min}_{W\in F}\frac{1}{2}\left|\left|\bar{\boldsymbol{V}}\bar{\boldsymbol{V}}^H - \boldsymbol{WW}^H\right|\right|_F^2\right\} \end{aligned} \tag{6}$$

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Since $\lambda_1^2\{\boldsymbol{H}\}$ is given, the codebook must be designed so as to minimize $E\left\{\underbrace{min}_{W\in F}\frac{1}{2}\left|\left|\overline{\boldsymbol{V}}\overline{\boldsymbol{V}}^H - \boldsymbol{W}\boldsymbol{W}^H\right|\right|_F^2\right\}$ in equation (6).

III. Simulation and Results

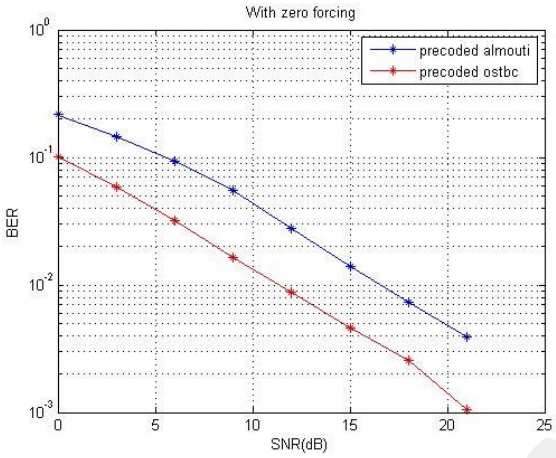

Figure 4: Comparison of BER performance of Precoded lamouti and Precoded OSTBC in Zero Forcing

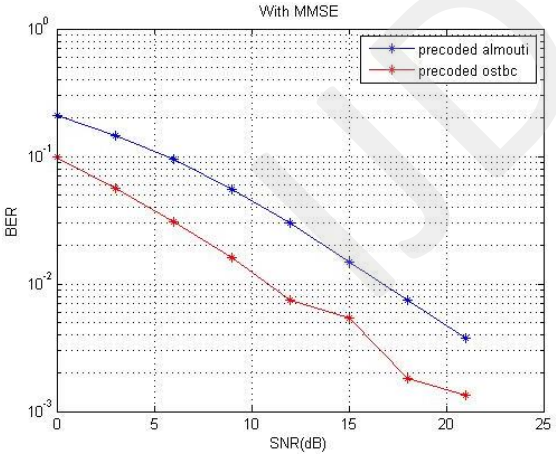

Figure 5: Comparison of BER performance of Precoded Alamouti and Precoded OSTBC in MMSE

IV. Conclusion

The most prominent space-time block codes (STBCs) are orthogonal STBCs (OSTBCs) and the most popular OSTBC is the Alamouti code. The approach in this paper has been to isolate the analysis of precoded MIMO systems. The proposed precoded OSTBC have a layered structure, which is implemented in the simplest Grassmannian precoding. Simulation results shows comparison of BER performance between Precoded Alamouti and Precoded OSTBC for Zero Forcing and MMSE equalization techniques. And finally it is found that the Precoded OSTBC shows better BER as compared to other schemes for Z-F and MMSE techniques.

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