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Performance Analysis of Alamouti and Orthogonal Space -Time Block Codes In MIMO System under Rayleigh Fading Scenario

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ABSTRACT: In this paper, an analysis for the bit error rate (BER) performance of space-time block codes (STBC) from generalized orthogonal designs for QAM modulation has been presented. Space-time block codes (STBC) offer high diversity gain and among which orthogonal STBCs are very attractive due to its relatively simpler design and low decoding complexity. Performance of Alamouti STBC and Orthogonal STBC with rate ½ for different transmitting and receiving antennas under Rayleigh fading situation has been analyzed. The decoding techniques used for this analysis are ZF, MMSE and ML. In all the cases, the bit error rate has been treated as the figure of merit and its change with SNR are observed due to different parameter variations of the channel distribution as well as different antenna configurations.

KEYWORDS: STBC, QAM, ZF, OSTBC, ALAMOUTI, BER.

I. INTRODUCTION

Wireless communications has facilitated people the freedom to communicate from almost anywhere, as it relies on the propagation of electromagnetic waves in free space. However the wireless channel constitutes a hostile propagation medium, which suffers from fading (caused by destructive addition of multipath components), shadowing, noise and interference from other users. Path loss, or large-scale path loss, significantly reduces the strength of transmitted signals such that the signal-to-noise-ratio (SNR) at the receiver can be very low. MIMO systems provide different replicas of transmitted symbols to the receiver by using multiple receiver antennas with sufficient separation between each so that the fading for each receiver is independent of others. Such diversity can also be achieved at the transmitter by spacing the transmitter antennas sufficiently and introducing a code for the transmitted symbols distributed over transmitter antennas (space) and symbol periods (time), i.e., space-time coding [1]–[4]. Full diversity is achieved when the total degree of freedom available in the multiple-antenna system is utilized. Over the past several years, various space-time coding schemes have been developed to take advantage of the MIMO communication channel. Using a linear processor, orthogonal space-time block codes [2], [3], [5]–[8] can provide maximum diversity achievable by a maximum-likelihood (ML) detector.

II. SPACE TIME BLOCK CODES

Two different space-time coding methods, namely space-time trellis codes (STTCs) and space-time block codes (STBCs) have been proposed. STTC has been introduced in [3] as a coding technique that promises full diversity and substantial coding gain at the price of a quite high decoding complexity. To avoid this disadvantage, STBCs have been proposed by the pioneering work of Alamouti. The Alamouti code promises full diversity and full data rate (on data symbol per channel use) in case of two transmit antennas. The key feature of this scheme is the orthogonality between the signal vectors transmitted over the two transmit antennas. This scheme was generalized to an arbitrary number of transmit antennas by applying the theories of orthogonal design. The generalized schemes are referred to as space-time block codes. However, for more than two transmit antennas no complex valued STBCs with full diversity and full data

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rate exist. In a general form, an STBC can be seen as a mapping of n_N complex symbols $\{s_1, s_2, \ldots s_N\}$ onto a matrix **S** of dimension $n_t \times N$:

$$\{s_1, s_2, \ldots s_N\} \rightarrow \mathrm{S}$$

An STBC code matrix **S** taking on the following form:

$$\boldsymbol{S} = \sum_{n=1}^{n_N} (\bar{s_n} \boldsymbol{A_n} + j\tilde{s}_n \boldsymbol{B_n}),$$

Where $\{s_1, s_2, \ldots s_{n_N}\}$ is a set of symbols to be transmitted with $\bar{s_n} = Re\{s_n\}$ and $\tilde{s}_n = Im\{s_n\}$, and with fixed code matrices $\{\boldsymbol{A_n}, \boldsymbol{B_n}\}$ of dimension $n_t \times N$ are called linear STBCs. The following STBCs can be regarded as special cases of these codes.

A. Alamouti Code

The Alamouti space time block code provides full diversity at full data rate for two transmit antennas. Two modulated symbols s_1 and s_2 are encoded in each encoding operation and hands it to the transmit antennas according to the code matrix

$$\boldsymbol{S} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix}$$

The first row represents the first transmission period and the second row the second transmission period. During the first transmission, the symbol s_1 and s_2 are transmitted simultaneously from antenna one and antenna two respectively. In the second transmission period, the symbol $-s_2^*$ is transmitted from antenna one and the symbol s_1^* from transmit antenna two. It is clear that the encoding is performed in both time (two transmission intervals) and space domain (across two transmit antennas). The two rows and columns of $\boldsymbol{S}$ are orthogonal to each other and the code matrix is orthogonal:

$$\boldsymbol{SS^H} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} s_1^* & -s_2 \\ s_2^* & s_1 \end{bmatrix}$$

$$\boldsymbol{SS^H} = \begin{bmatrix} |s_1|^2 + |s_2|^2 & 0 \\ 0 & |s_1|^2 + |s_2|^2 \end{bmatrix}$$

$$\boldsymbol{SS^H} = (|s_1|^2 + |s_2|^2)\, I_2$$

Where I_2 is a (2×2) identity matrix. This property enables the receiver to detect s_1 and s_2 by a simple linear signal processing operation. Let us look at the receiver side now. Only one receive antenna is assumed to be available. The channel at time t may be modeled by a complex multiplicative distortion $h_1(t)$ for transmit antenna one and $h_2(t)$ for transmit antenna two. Assuming that the fading is constant across two consecutive transmit periods of duration T, we can write

$$h_1(t) = h_1(t + T) = h_1 = |h_1|e^{j\theta_1}$$

$$h_2(t) = h_2(t + T) = h_1 = |h_2|e^{j\theta_2}$$

where $|h_i|$ and $\theta_i, i = 1{,}2$ are the amplitude gain and phase shift for the path from transmit antenna i to the receive antenna. The received signals at the time t and $t + T$ can then be expressed as

$$r_1 = s_1 h_1 + s_2 h_2 + n_1$$

$$r_2 = -s_2^* h_1 + s_1^* h_2 + n_2$$

Where r_1 and r_2 are the received signals at time t and $t + T$, n_1 and n_2 are complex random variables representing receiver noise and interference. This can be written in matrix form as:

$$\boldsymbol{r} = \boldsymbol{Sh} + \boldsymbol{n}$$

Where $h = [h_1, h_2]^T$ is the complex channel vector and n is the noise vector at the receiver.

III.ORTHOGONAL SPACE-TIME BLOCK CODES (OSTBCS)

Space–time block coding is a technique used to improve the performance of a wireless transmission system, where the receiver is provided with multiple signals carrying the same information. The concept behind space-time block coding is to transmit multiple copies of the same data through multiple antennas in order to improve the reliability of the data-transfer through the noisy channel. The pioneering work of Alamouti has been a basis to create OSTBCs for more than two transmit antennas Orthogonal STBCs are an important subclass of linear STBCs that guarantee that the ML detection of different symbols $\{s_n\}$ is decoupled and at the same time the transmission scheme achieves a diversity

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order equal to $n_t n_r$. The main disadvantage of OSTBCs is the fact that for more than two transmit antennas and complex-valued signals, OSTBCs only exist for code rates smaller than one symbol per time slot.

A. Orthogonal Design

An OSTBC is a linear space-time block code $\boldsymbol{S}$ that has the following unitary property:

$$\boldsymbol{S}^H\boldsymbol{S} = \sum_{n=1}^{N} |s_n|^2 \boldsymbol{I}$$

The i-th row of $\boldsymbol{S}$ corresponds to the symbols transmitted from the i -th transmit antenna in N transmission periods, while the j-th column of $\boldsymbol{S}$ represents the symbols transmitted simultaneously through transmit antennas at time j.

According to the columns of the transmission matrix $\boldsymbol{S}$ are orthogonal to each other. That means that in each block, the signal sequences from any two transmit antennas are orthogonal. The orthogonality enables us to achieve full transmit diversity and at the same time, it allows the receiver by means of simple MRC to decouple the signals transmitted from different antennas and consequently, it allows a simple ML decoding.

B. OSTBC with a rate of 1/2 symbol per time slot

For any arbitrary complex signal constellation, there are OSTBCs that can achieve a rate of 1/2 for any given number of n_t transmit antennas. For example, the code matrix s_3 is OSTBCs for three transmit antennas, respectively and they have the rate 1/2.

$$\boldsymbol{S_3} = \begin{bmatrix} s_1 & s_2 & s_3 \\ -s_2 & s_1 & -s_4 \\ -s_3 & s_4 & s_1 \\ -s_4 & -s_3 & s_2 \\ s_1^* & s_2^* & s_3^* \\ -s_2^* & s_1^* & -s_4^* \\ -s_3^* & s_4^* & s_1^* \\ -s_4^* & -s_3^* & s_2^* \end{bmatrix}$$

With the code matrix s_3, four complex symbols are taken at a time and transmitted via three transmit antennas in eight time slots.

IV.SIMULATION PARAMETERS

QAM modulation technique has been employed on MIMO system for evaluating the bit error rate performance of alamouti STBC and OSTBC with different equalization techniques.
The parameters are shown in table below:

S.No	Parameter	Value
1	Technology	MIMO
2	Data Bits	$3x10^4$
3	Number of Transmitter	1,2,3
4	Number of Receiver	1,2,3
5	Decoding Algorithm	ZF, MMSE,ML
6	Modulation Technique	QAM
7	Channel	Rayleigh
8	SNR	0-40

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V.SIMULATION RESULTS

Case 1:

Here the MIMO system is considered for 2X1 antennas using Rayleigh channel. In this scheme two transmitter antennas are selected to transmit the whole data while one receiver antenna is selected for the reception. In the Graph, for QAM modulation technique using Alamouti STBC, the values of bit error rate at 5 dB and at 30 dB for ZF, MMSE & ML equalizer are found to be 0.57 ,0.12, 0.06 and 0.001,0.0004,0.0002 respectively.

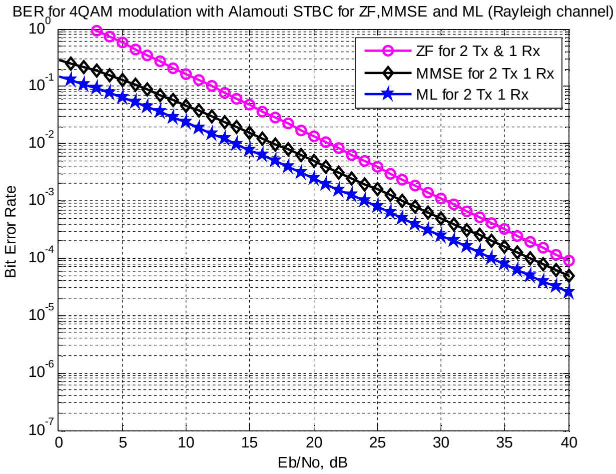

Fig 1. BER for 4QAM modulation with Alamouti STBC for 2x1 system

Case 2:

Here the MIMO system is considered for 2X2 antennas using Rayleigh channel. In this scheme two transmitter antennas are selected to transmit the whole data while two receiver antennas are selected for the reception. In the Graph, for QAM modulation technique using Alamouti STBC, the values of bit error rate at 5 dB and at 30 dB for ZF, MMSE & ML equalizer are found to be 0.28, 0.0128, 0.0513 and 0.0004, 0.00049, 0.000199 respectively.

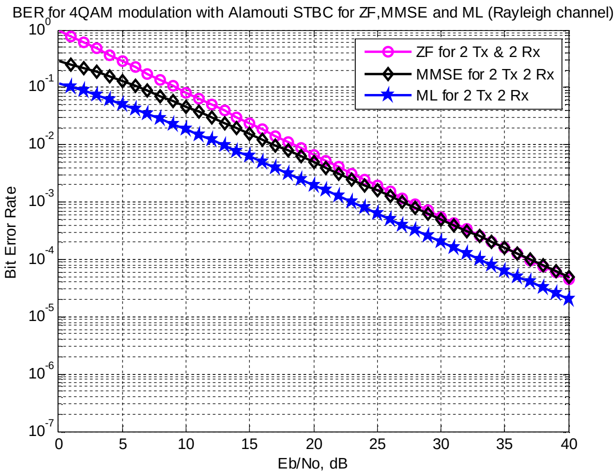

Fig 2. BER for 4QAM modulation with Alamouti STBC for 2x2 system

Case 3:

Here the MIMO system is considered for 3X1 antennas using Rayleigh channel. In this scheme three transmitter antennas are selected to transmit the whole data while one receiver antenna is selected for the reception. In the Graph, for QAM modulation technique using Alamouti STBC, the values of bit error rate at 5 dB and at 30 dB for ZF, MMSE & ML equalizer are found to be 0.022, 0.0113, 0.0060 and 0.000000498, 0.000000187, 0.000000128 respectively.

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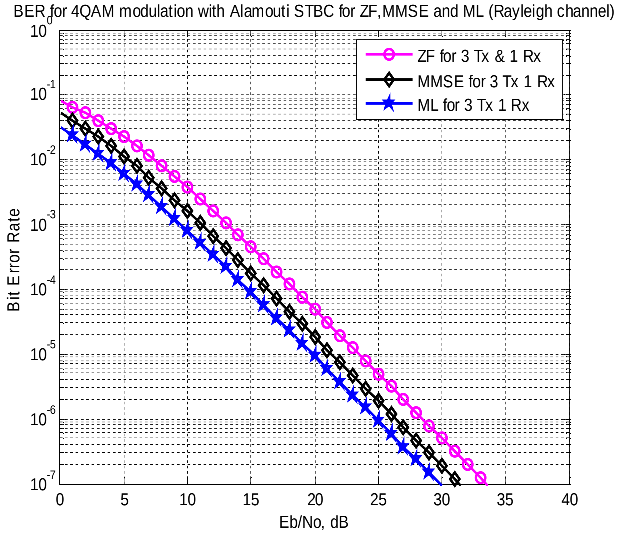

Fig 3. BER for 4QAM modulation with Alamouti STBC for 3x1 system

Case 4:

Here the MIMO system is considered for 3X2 antennas using Rayleigh channel. In this scheme three transmitter antennas are selected to transmit the whole data while two receiver antennas are selected for the reception. In the Graph, for QAM modulation technique using Alamouti STBC, the values of bit error rate at 5 dB and at 25 dB for ZF, MMSE & ML equalizer are found to be 0.0143, 0.0065, 0.0024 and 0.0000013, 0.00000044, 0.00000044 respectively.

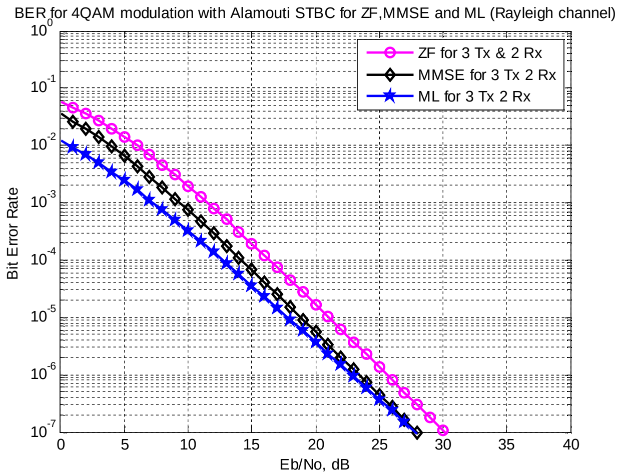

Fig 4. BER for 4QAM modulation with Alamouti STBC for 3x2 system

Case 5:

Here the MIMO system is considered for 2X2 antennas using Rayleigh channel. In this scheme two transmitter antennas are selected to transmit the whole data while two receiver antennas are selected for the reception. In the Graph, for QAM modulation technique using orthogonal STBC with code rate ½ , the values of bit error rate at 5 dB and at 30 dB for ZF, MMSE & ML equalizer are found to 0.1433, 0.045, 0.02268 and 0.00027,0.000176, 0.000088 respectively.

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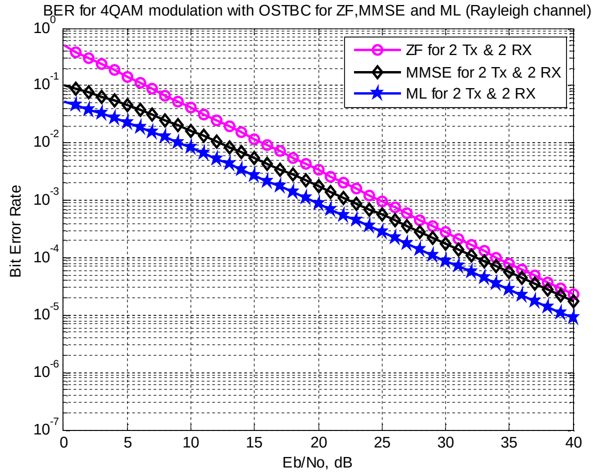

Fig 5. BER for 4QAM modulation with OSTBC for 2x2 system

Case 6:
Here the MIMO system is considered for 3X2 antennas using Rayleigh channel. In this scheme three transmitter antennas are selected to transmit the whole data while two receiver antennas are selected for the reception. In the Graph, for QAM modulation technique using orthogonal STBC with code rate ½, the values of bit error rate at 5 dB and at 30 dB for ZF, MMSE & ML equalizer are found to 0.007, 0.003995, 0.00213 and 0.00000171, 0.00000061, 0.000000329 respectively.

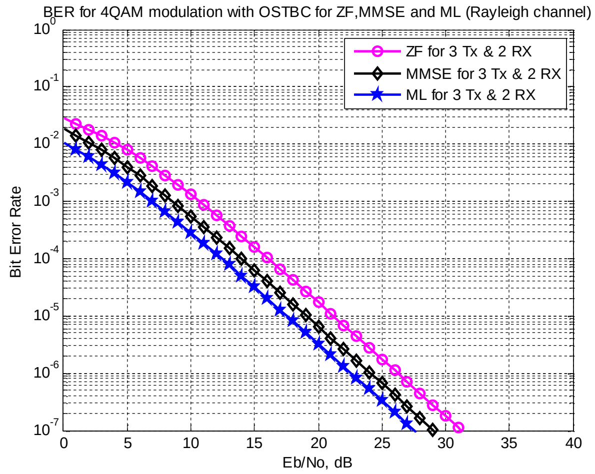

Fig 6. BER for 4QAM modulation with Alamouti STBC for 3x2 system

VI. CONCLUSION

We set our goal to analyze the performance of Alamouti STBC and OSTBC with code rate ½ scheme under MIMO fading environment with different equalization techniques. The performance parameter, we have considered is bit error rate. We have presented the BER vs Eb/No plots for the above mentioned schemes. From the simulation results, it is observed that, coding does improve the error performance, but Eb/No has dominant role for achieving full diversity. The MIMO-STBC technology is best suited for mitigating ISI in frequency selective fading channel. The most prominent space-time block codes (STBCs) are orthogonal STBCs (OSTBCs) and the most popular OSTBC is the Alamouti code. OSTBCs provide full diversity using simple detection algorithms which can separately recover transmit symbols. A complex orthogonal design of OSTBCs which provides full diversity and full transmission rate is not possible for more than two transmit antennas and the Alamouti code is the only OSTBC that provides full diversity at

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full data rate (1 symbol/time slot) for two transmit antennas. It has been observed that the BER performance of OSTBC with code rate ½ for maximum likelihood decoding performs better.

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