Performance Evolution of Different Space Time Block Codes With Linear Receiver

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Abstract –

We document the performance of space–time block codes, which provide a new paradigm for transmission over Rayleigh fading channels using multiple transmit antennas. It has been shown that a complex orthogonal design that provides full diversity and full transmission rate for a space–time block code is not possible for more than two antennas. The objective of this paper is to provide the description of different type of space time block codes and to provide the performance analysis of these codes without channel knowledge at the transmitter with different schemes for four transmit and one receive antenna. We propose a new space time block code and compare it with other codes.

***Keywords* -** MIMO systems, diversity, bit error rate, linear receivers, OSTBC, Q-OSTBC.

I. INTRODUCTION

Wireless communication is based on radio signals. Traditionally, wireless applications were voice-centric and demanded only moderate data rates, while most high-rate applications such as file transfer or video streaming were wireline applications. In the last decade,, however, there has been a shift to wireless multimedia applications, there has been a dramatic increase in the demand for higher data rates. However, with regard to the ever-growing demands of wireless services, the time is now ripe for evolving the antenna part of the radio system. One of the most significant and promising advances in wireless communications that can meet the demand for higher data rate is the use of multiple antennas at the transmitter and receiver. Deploying multiple antennas at the transmitter and receiver creates a multiple-input multiple-output (MIMO) channel that not only offers higher transmission rates, but it can also decreases error rates that improve the system's reliability and robustness to noise compared to single antenna systems. In addition to this, multiple antennas can also be utilized in order to mitigate co-channel interference, which is another major source of disruption in (cellular) wireless communication systems.

A major problem in the wireless channel is that out-of-phase reception of multipaths causes deep attenuation in the received signal, known as multipath fading. The distortion induced by the time-varying fading is caused by the superposition of delayed, reflected, scattered and diffracted signal components from different objects in the environment, before it reaches the receiver antenna. At the receiver due to multipath fading, the receiver cannot correctly detect the transmitted signal unless some less attenuated replica of the signal is provided to the receiver. This technique is called diversity, which can be provided using temporal, frequency, polarization, and spatial resources. In many situations, however, the wireless channel is neither significantly time variant nor highly frequency selective. This forces the system engineers to consider the possibility of deploying multiple antennas at both the transmitter and receiver to achieve spatial diversity.

1.1 Transmit and Receive Diversity

A practical, effective and, hence, a widely applied technique for reducing the effect of multipath fading in wireless systems is antenna diversity. The classical approach is to use multiple antennas at the receiver and perform combining or selection and switching in order to improve the quality of the received signal.

In many systems, though, additional antennas may be expensive or impractical at the remote or even at the base station. The major problem with using the receive diversity approach is the cost, size, and power of the remote units. In these cases, transmit diversity can be used to provide diversity benefit at a receiver with multiple transmit antennas only. With transmit diversity, multiple antennas transmit delayed versions of a signal, creating frequency-selective fading, which is equalized at the receiver to provide diversity gain. A base station often serves hundreds to thousands of remote units. It is therefore more economical to add equipment to base stations rather than the remote units. For this reason, transmit diversity [1] schemes are very attractive.

1.2 Space Time Coding

The term Space-Time Code (STC) was originally coined in 1998 by Tarokh et al. to describe a new two-dimensional way of encoding and decoding signals transmitted over wireless fading channels using multiple transmit antennas [2]. STC make use of both the space (different antennas) and the time domain while encoding and decoding information symbols. It uses multiple transmit antennas and (optionally) multiple receive antennas to provide high data rates and reliable communications over fading channels, this concept combines coding, modulation and spatial diversity into a two-dimensional coded modulation technique. Examples of space-time coding include space-time trellis codes, space-time block codes, super-orthogonal space-time codes and linear-dispersion (LD) codes. Space-time trellis codes provide full diversity and coding gain at the cost of a complex receiver. Space-time block codes provide full diversity and simple decoding, but no coding gain.

1.3 Focus and Outline of the paper

The objective of this paper is to provide the basics of space time block codes and propose a new scheme. This paper is organized as follows. In Section II, we describe the model of space time block codes. In Section III, we present the different type of space time block codes and their property. In section IV, We give the simulation result and performance comparison of different space time block codes with different schemes. In Section V, Some conclusions are offered. Although the list of references is not intended to be exhaustive, the cited papers (as well as the references therein) will serve as a good starting point for further reading.

II. SPACE TIME BLOCK CODES

2.1 Transmission Model

We consider a wireless communication system with N antennas at the base station and M antennas at the remote. At each time slot t, signals, C_t^i $i=1,2,\ldots N$ are transmitted Simultaneously from the N transmit antennas. The channel is assumed to be a flat fading channel and the path gain from transmit antenna i to receive antenna j is defined to be α_{ij} . The path gains are modeled as samples of independent complex Gaussian random variables with variance 0.5 per real dimension. This assumption can be relaxed without any change to the method of encoding and decoding [2]. The wireless channel is assumed to be quasi-static i.e the path gains are constant over a frame of length and vary from one frame to another. At time t the signal r_t^j , received at antenna j , is given by

$$r_t^{\,j} = \sum_{i=1}^{n} \alpha_{ij} c_t^{\,j} + n_t^{\,j} \quad \ldots\ldots (1)$$

where the noise samples n_t^j are independent samples of a zero-mean complex Gaussian random variable with variance $n/(2\ \mathrm{SNR})$ per complex dimension. The average energy of the symbols transmitted from each antenna is normalized to be one, so that the average power of the received signal at each receive antenna is n and the signal-to-noise ratio is SNR.

Assuming perfect channel state information is available, the receiver computes the decision metric

$$\sum_{t} \sum_{j}^{n_r} \left| r_t^j - \sum_{i=1}^{n} \alpha_{ij}\, c_t^j + n_t^j \right|^2 \quad \ldots\ldots (2)$$

over all codeword

$$c_1^1 c_1^2 \ldots c_1^n c_2^1 c_2^2 \ldots c_2^n c_l^1 c_l^2 \ldots c_l^n$$

and decides in favor of the code word that minimizes the sum.

2.2 Encoding Algorithm

A space–time block code is defined by a $P\times N$ transmission matrix G. The entries of the matrix are linear combinations of the variables $X_1 X_2 \ldots\ldots X_k$ and their conjugates. The number of transmission antennas is N and we usually use it to separate different codes from each other. For example, Alamouti code [3] which utilizes two transmit antennas and is defined by

$$X_2 = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \quad \ldots\ldots\ldots\ldots (3)$$

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 $S_1 S_2 S_3 \ldots\ldots S_K$. Setting for $S_i = X_i$ for i=1,2,3…. in G, we arrive at a matrix C with entries linear combinations of $S_1 S_2 S_3 \ldots\ldots S_K$ and their conjugates. So, while G contains indeterminate $X_1 X_2 \ldots\ldots X_k$, C contains specific constellation symbols (or their linear combinations) which are transmitted from N antennas for each kb bits as follows. 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 , and the orthogonality of G's columns allows a simple decoding scheme.

Since P time slots are used to transmit K symbols, we define the rate of the code to be R=K/P. For example, the rate of G_2 is one. Next we review the decoding of these codes.

2.3 The Decoding Algorithm

The ML detector is optimal in the sense of minimum error probability when all transmitted data vectors are equally probable. However, this optimality is obtained at the cost of an exponentially increasing computational complexity depending on the symbol constellation size and the number of transmit antennas.

Linear receivers (Zero Forcing (ZF) and Mean Squared Error (MMSE) receiver) can reduce the decoding complexity but they typically suffer from noise enhancement. Linear detection can be described by

$$\hat{s} = (\mathbf{H}_v^H \mathbf{H}_v + \mu \mathbf{I})^{-1} z \quad \ldots\ldots(4)$$

Where H_v is EVCM for S, H_v^H is its Hermitian matrix, I is Identity matrix and $\mu = 0$ for the ZF receiver and $\mu = \sigma_n^2$ for the MMSE receiver. The MMSE receiver behaves similar to the ZF receiver, however with an additional term in the matrix inverse proportional to the noise variance. In practice it can be difficult to obtain correct values of σ_n^2 . But only for correct values a small improvement compared to the ZF receiver can be obtained. Therefore, the MMSE technique is not used in practice

III. TYPES OF SPACE TIME BLOCK CODES

First I explained ALAMOUTI code which are full rate and full diversity code.

3.1 ALAMOUTI Code

Historically, the ALAMOUTI code is the first STBC that provides full diversity at full data rate for two transmit antennas [3]. The information bits are first modulated using an M-ary modulation scheme. The encoder takes the block of two modulated symbols S_1 and S_2 in each encoding operation and hands it to the transmit antennas according to the code matrix

$$S = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad \ldots\ldots\ldots (5)$$

The first row represents the first transmission period and the second row the second transmission period. During the first transmission, the symbols 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 S are orthogonal to each other and the code matrix is orthogonal.

3.2 ORTHOGONAL SPACE TOME BLOCK CODE

The theory of orthogonal designs is an arcane branch of mathematics which was studied by several great number theorists including Radon and Hurwitz. Radon determined the set of dimensions for which an orthogonal design exists [4]. Radon's results are only concerned with real square orthogonal designs. The results of orthogonal design by Radon is extended by Tarokh [5] to both non square and complex orthogonal designs and introduce a *theory of generalized orthogonal designs*. Using this theory, they construct space–time block codes for any number of transmit antennas.

3.3 QUASI-ORTHOGONAL SPACE TIME BLOCK CODE

The main characteristic of the codes designed in [5] is the orthogonality property of the codes. The codes are designed using *orthogonal designs* which are transmission matrices with orthogonal columns. It is shown how simple decoding which can separately recover transmit symbols, is possible using an orthogonal design. In Quasi orthogonal space time block code (JAFARKHANI code) [6], we propose structures that are not orthogonal designs and, therefore, at the decoder, cannot separate all transmitted symbols from each other. Instead, in Quasi OSTBC structure, the transmission matrix columns are divided into groups. While the columns within each group are not orthogonal to each other, different groups are orthogonal to each other. We call such a structure a quasi-orthogonal design. It is shown that using a quasi-orthogonal design, pairs of transmitted symbols can be decoded separately. The application of such a structure is in designing codes which provide higher transmission rates while sacrificing the full diversity. By using the orthogonality of the transmitted symbols, ALAMOUTI [3] first defined a space time transmission matrix as

$$A_{12} = \begin{bmatrix} X_1 & X_2 \\ -X_2^* & X_1^* \end{bmatrix} \quad \ldots (5)$$

Where the subscript A_{12} indicates the indeterminate X_1 and X_2 existing in the transmission matrix. Based on ALAMOUTI orthogonal STBC, JAFARKHANI [6] gave a quasi orthogonal STBC form for four transmit antennas as

$$C_J = \begin{bmatrix} A_{12} & A_{34} \\ -A_{34}^* & A_{12}^* \end{bmatrix} = \begin{bmatrix} X_1 & X_2 & X_3 & X_4 \\ -X_2^* & X_1^* & -X_4^* & X_3^* \\ -X_3^* & -X_4^* & X_1^* & X_2^* \\ X_4 & -X_3 & -X_2 & X_1 \end{bmatrix} \quad \ldots\ldots\ldots\ldots (6)$$

Where A_{12} and A_{34} are ALAMOUTI codes. Further, different from JAFARKHANI scheme, the TBH case [7] has

$$S_{ABBA} = \begin{bmatrix} S_{12} & S_{34} \\ S_{34} & S_{12} \end{bmatrix} = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ s_3 & s_4 & s_1 & s_2 \\ -s_4^* & s_3^* & -s_2^* & s_1^* \end{bmatrix} \quad \ldots\ldots\ldots\ldots (7)$$

Using a unitary pattern idea introduced in [8] to investigate the distribution of conjugates in the transmission matrices, we find that it is related to the positions of correlated values. By changing the distribution of conjugates, we can obtain matrices with different positions of correlated values.

3.3.1 JAFARKHANI Case with TBH Correlated Position

We change the conjugates' distribution of JAFARKHANI matrix, and let

$$C_{JT}^H = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ x_4 & -x_3 & -x_2 & x_1 \\ -x_3^* & -x_4^* & x_1^* & x_2^* \end{bmatrix} \quad \ldots\ldots\ldots (8)$$

3.3.2 TBH case with JAFARKHANI-correlated positions

Similar to the above modification, we exchange the last row and the third row from eqn. (7) and let

$$C_{Tj}^{H} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ x_2^* & -x_1^* & x_4^* & -x_3^* \\ x_4^* & -x_3^* & x_2^* & -x_1^* \\ x_3 & x_4 & x_1 & x_2 \end{bmatrix} \quad \ldots.. (9)$$

3.5 Proposed Code

We proposed a new space time block code matrix whose performance is better than other space time block codes. This space time block code is quasi-orthogonal in nature. We use zero-forcing technique for the analysis of this code. Channel is assumed to be quasi-static Rayleigh flat fading channel. The matrix of the proposed code is given by

$$A = \begin{bmatrix} A_{12} & A_{34} \\ A_{34} & -A_{12} \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ x_3 & x_4 & -x_1 & -x_2 \\ -x_4^* & x_3^* & x_2^* & -x_1^* \end{bmatrix} \quad \ldots(10)$$

IV. SIMULATION RESULT AND PERFORMANCE COMPARISION

In simulation result, first we give the comparison of ALAMOUTI space time block codes with 1×1 scheme. We also provide comparison with 1×2 MRC scheme. The comparison of analytical and simulation result is also given. ALAMOUTI scheme is better than other schemes but there is 3-dB difference between ALAMOUTI scheme and (1×2) MRC scheme. Reason is that in ALAMOUTI scheme the signal power is divided in 2 antennas equally.

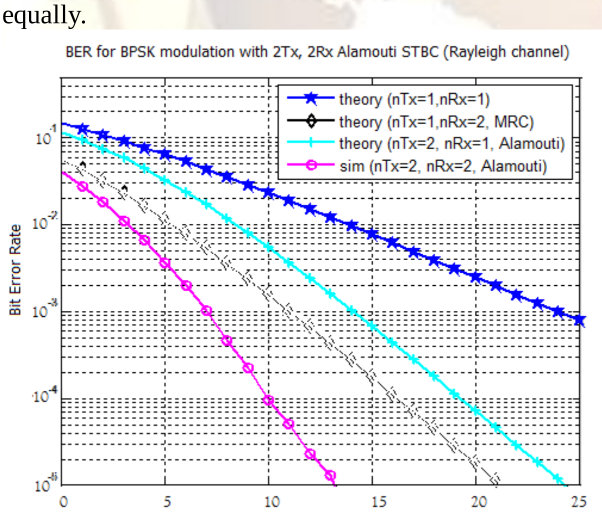

FIG 1: BER performance of ALAMOUTI STBC with different scheme

In next results, we give comparisons of all the space time block codes explained in this paper. The codes are compared under the different modulation schemes like BPSK, QPSK, 8PSK, 16 PSK, 32PSK, 64PSK, 128PSK. We see that the proposed code has better performance than other codes under different modulation schemes. Linear receiver techniques like zero forcing are used in simulation model. Channel is assumed to be quasi-static flat fading Rayleigh channel.

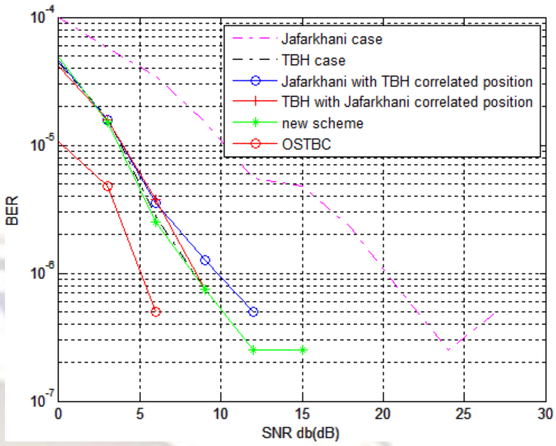

FIG 2: BER performance comparisons of different STBC under BPSK scheme

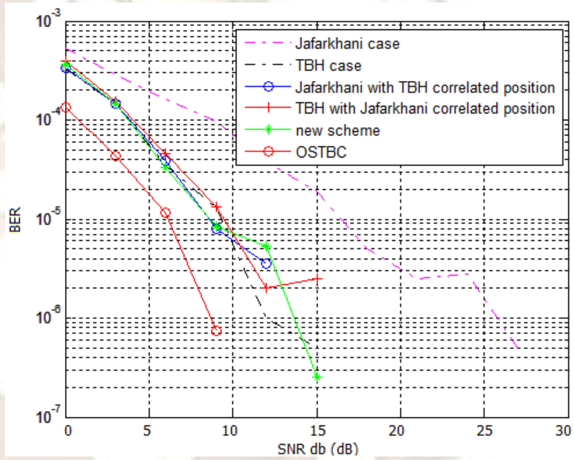

FIG 3: BER performance comparisons of different STBC under QPSK scheme

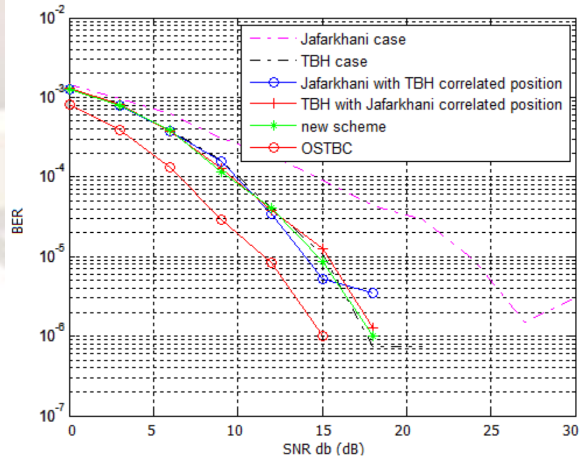

FIG 4: BER performance comparisons of different STBC under 8PSK scheme

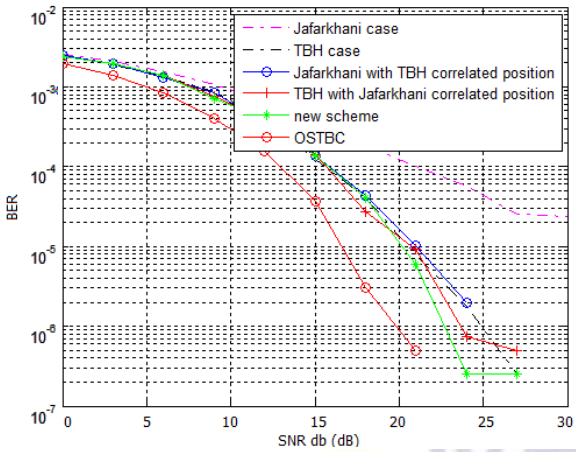

FIG 5: BER performance comparisons of different STBC under 16PSK scheme

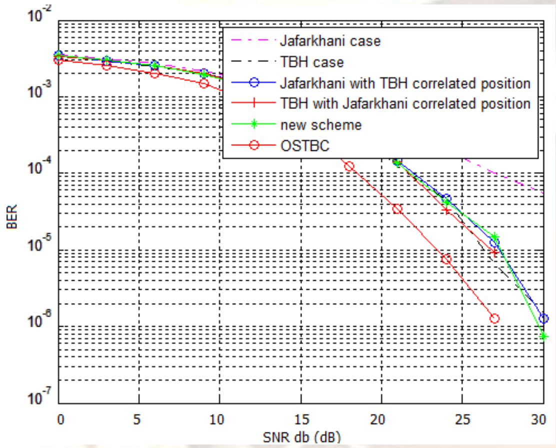

FIG 6: BER performance comparisons of different STBC under 32PSK scheme

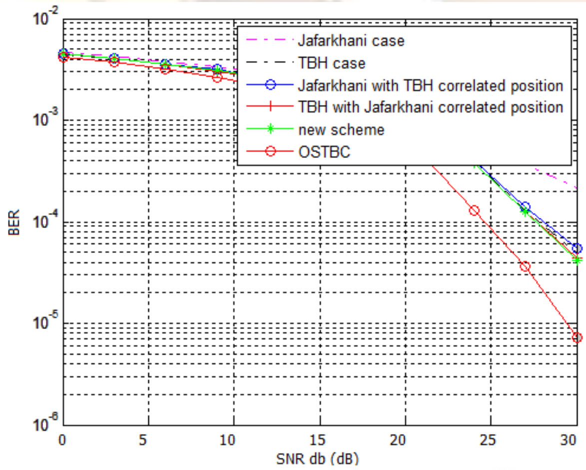

FIG 7: BER performance comparisons of different STBC under 64PSK scheme

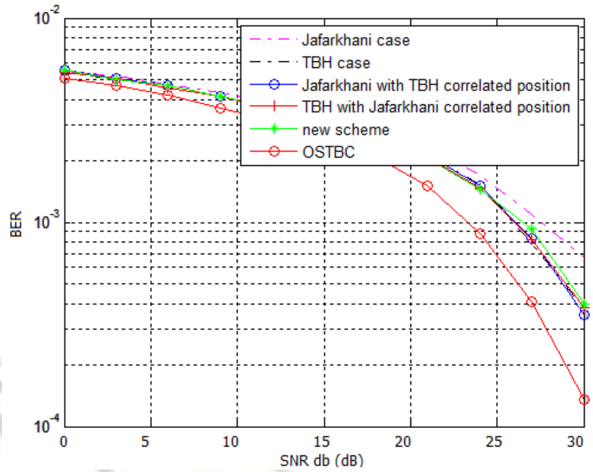

FIG 7: BER performance comparisons of different STBC under 128PSK scheme

Analyzing all the results, we find that proposed code has better result than other space time block codes under linear receiver.

V. CONCLUSION

In this paper we give the modeling of space time block codes. ALAMOUTI space time block code is based upon this modeling. We explain different space time block codes with their code matrix. Finally we give comparisons of the different space time block codes and show that proposed space time block code is showing better results comparing with different cases. Further, there is a scope of research in M×N space time block codes.

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