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Performance Evaluation of Orthogonal Space-Time Block Codes in MIMO Wireless Communications

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Abstract—
With the integration of voice, Internet and multimedia applications in next generation wireless mobile communication, the demand for reliable high data rate and quality of service is growing at a very rapid pace. The increasing requirements on the service quality and data flow in wireless mobile communication system call for new approaches to improve the bandwidth efficiency and reliability of the systems. Recently, MIMO systems with multiple antenna elements at both link ends have received great attention for future wireless communications systems as they provide high data rates by exploiting the spatial domain under the constraints of limited bandwidth and transmit power and thus have capabilities to improve the overall system performance. In MIMO wireless mobile communications, space-time block coding (STBC) is an attractive approach to achieve high bit rate and reliable transmission over fading channels. Space-Time Block Coding (STBC) exploits transmit diversity and high reliability. Although STBC has full diversity gain but no coding gain. Usually, STBCs are of two types i.e. Orthogonal Space-Time Block Codes (OSTBCs) and Non-Orthogonal Space-Time Block Codes (NOSTBCs). This paper presents the bit error rate performance evaluation of orthogonal space-time block codes with multiple transmit antennas in wireless mobile communication systems with the help of computer simulation. The research study shows that combined use of multiple transmit antennas and Orthogonal Space-Time Block Codes (OSTBCs) results in the significant overall system performance without any extra signal processing.

Keywords— Space time block codes, Diversity, MIMO systems, Bit Error Rate (BER) and Multipath fading, Rayleigh fading channels, Orthogonal Space-Time Block Codes**.**

I. INTRODUCTION

In modern times, communication technologies have become a very vital part of human life. Wireless communication systems have opened new dimensions in communications. People can be reached at any time and at any place. Presently, the wireless communication research community and industry are exploring standards for the fourth generation (4G) of mobile communication. There are many drawbacks in the wireless communication environments, such as multipath fading, Doppler frequency shifting and channel change. In order to ensure the stable transmission, many useful technologies have been provided. The research community has generated a number of promising solutions for significant improvements in system performance. Wireless communication is highly challenging due to the complex, time varying propagation medium. If we consider a wireless link with one transmitter and one receiver, the transmitted signal that is launched into wireless environment arrives at the receiver along a number of diverse paths, referred to as multi-paths. These paths occur from scattering and rejection of radiated energy from objects like buildings, hills, trees etc. and each path has a different and time-varying delay, angle of arrival, and signal amplitude. Because of this, the received signal can vary as a function of frequency, time and space. These variations are referred to as fading and cause deterioration of the system quality [1,2]. Therefore, wireless systems must be designed to mitigate fading and interference to guarantee a reliable communication.

A successful method to improve reliable communication over a wireless link is to use multiple antennas at the transmitter and at the receiver. Multiple antennas play an important role in improving radio communications. Multiple antenna systems have the potential of achieving high rate data access and increased capacity of mobile services. MIMO stands for multiple-input multiple-output and means multiple antennas at both link ends of a communication system, i.e., at the transmit and at the receive side. The multiple-antennas at the transmitter and/or at the receiver in a wireless communication can improve the system performance substantially. The idea behind MIMO is that the transmit antennas at one end and the receive antennas at the other end are “connected and combined” in such a way that the quality (the bit error rate (BER), or the data rate) for each user is improved. The core idea in MIMO transmission is space-time signal processing in which signal processing in time is complemented by signal processing in the spatial dimension by using multiple, spatially distributed antennas at both link ends [3,4]. In case of multiple antennas at both link ends, utilization of diversity requires a combination of the receive and transmit diversity. The diversity order is bounded by the product of the number of transmit and receive antennas [5,6].

The key feature of all diversity methods is to provide a low bit error rate. Usually, the system performance with diversity techniques depends on signal replicas combined at the receiver end to increase the value of signal to noise ratio. Basically, there are four main types of signal combining techniques at the receiver. These are: selection combining, switched combining, equal-gain combining and maximum ratio combining (MRC). More information about combining techniques can be found in [7, 8]. Because of the enormous capacity increase MIMO systems offer, such systems gained a lot of interest in mobile communication research [9,10]. Several transmission schemes have been proposed that utilize the MIMO channel in different ways, *e.g*., spatial multiplexing, space-time coding or beam forming. Space-time coding (STC), introduced first by Tarokh at el. [11], is a promising method where the number of the transmitted code symbols per time slot are equal to the number of transmit antennas. These code symbols are generated by the space-time encoder in such a way that diversity gain, coding gain, as well as high spectral efficiency are achieved.

There are various coding methods as space-time trellis codes (STTC), space-time block codes (STBC), space-time turbo trellis codes and layered space-time codes [13]. This paper explains the concept of orthogonal space-time block coding in a systematic way. The paper provides an overview of OSTBCs design principles and performance. In this paper, we investigate and analyze the bit error rate (BER) performance of orthogonal space-time block codes in MIMO wireless communication systems with the help of computer simulation.

The rest of the paper is organized as follows. In section 2, we present structure of a basic wireless MIMO system. Various space-time block codes (STBC) have been introduced in section 3. In section 4, we have introduced the concept of OSTBCs. In section 5, we have formulated the simulation environments and simulation results are presented to see the performance and we conclude the paper with some remarks in section 6.

II. A BASIC MIMO COMMUNICATION SYSTEM

Wireless systems consisting of a transmitter, a radio channel and a receiver are categorized by their number of inputs and outputs. The simplest configuration is a single antenna at both sides of the wireless link, denoted as single-input/single output (SISO) system. Using multiple antennas on one or both sides of the communication link are denoted as multiple input/multiple output (MIMO) systems [14]. The difference between a SISO system and a MIMO system with N_t transmit antennas and N_r receive antennas is the way of mapping the single stream of data symbols to N_t streams of symbols and the corresponding inverse operation at the receiver side. Systems with multiple antennas on the receive side only are called single input/multiple output (SIMO) systems and systems with multiple antennas at the transmitter side and a single antenna at the receiver side are called multiple input/single output (MISO) systems [15].

The MIMO system is the most general and includes SISO, MISO, and SIMO systems as special cases. To transmit information over a single wireless link, different transmission and reception approaches can be applied. Which one of them should be used depends on the knowledge of the instantaneous MIMO channel parameters at the transmitter side.

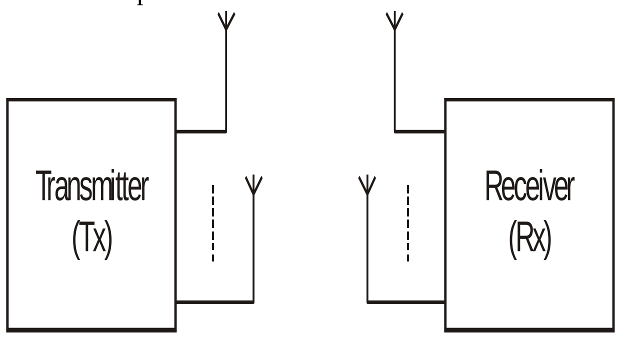

Fig. 1 A Basic MIMO Communication System

III. SPACE TIME BLOCK CODES (STBCs)

Space-time coding is a technique that promises greatly improved performance in wireless networks by using multiple antennas at the transmitter and receiver. Space-Time Codes (STCs) are widely used in cellular communications as well as in wireless local area networks. Space-time coding (STC) is performed in both spatial and temporal domain, which introduce redundancy between those signals that are transmitted from different antennas at different time instants. With the help of space-time coding (STC), transmit diversity and antenna gain can be achieved over spatially uncoded systems without any loss of bandwidth. Thus, space-time coding (STC) focuses on improving the system performance by using a few extra transmit antennas. Usually, the design of STC leads to finding transmit matrices, which can satisfy a particular optimality criterion. While designing

STC, we have to trade-off between three main aspects. These are a simple decoding scheme, minimizing the bit error rate (BER), and maximizing the information rate or data rate. For small values of total diversity and slow fading channels, the diversity and the coding gain must be maximized by choosing an appropriate code having the largest determinant of the distance matrix.

For fast fading channels, a code with the largest minimum symbol-wise Hamming distance and the largest product distance must be chosen. Basically there are two different space-time coding methods. These are space-time trellis codes (STTCs) and space-time block codes (STBCs). STTC has been introduced in [3]. This is a coding technique that yields full diversity and sufficient coding gain at the cost of a quite high decoding complexity. To avoid this drawback, STBCs have been proposed by Alamouti [12]. Alamouti code yields full diversity and full data rate in case of two transmit antennas. The special feature of this scheme is that the signal vectors transmitted over the two transmit antennas are orthogonal to each other. This scheme can be generalized to an arbitrary number of transmit antennas with the help of orthogonal design principles.

The generalized schemes are referred to as space-time block codes. Thus, in brief, space–time block coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. In fact, space–time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.Thus, the essential feature of STBCs is the provision of full diversity with extremely low encoder/decoder complexity.

IV. ORTHOGONAL SPACE-TIME BLOCK CODES (OSTBCs)

The pioneering work of Alamouti has been a basis to create OSTBCs for more than two transmit antennas. First of all, Tarokh studied the error performance associated with unitary signal matrices. 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 order equal to $N_t N_r$. Orthogonal STBCs have received considerable attention in recent open loop multiple input multiple output (MIMO) wireless mobile communication systems because they allow low complexity maximum likelihood decoding and guarantee full diversity [13]. The main drawback 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. An OSTBC is a linear space-time block code **S** that has the following unitary property:

$$\boldsymbol{S}^H \sum_{n=1}^{N} |s_n|^2 \, \mathbf{I} \, \boldsymbol{S} \qquad \text{...(1)}$$

The i-th row of **S** corresponds to the symbols transmitted from the i-th transmit antenna in N transmission periods, while the j-th column of **S** represents the symbols transmitted simultaneously through n_t transmit antennas at time j. According to equation (1) the columns of the transmission matrix **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.

A. Few illustrations of OSTBCs

1. 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 matrices $\mathbf{S_3}$ and $\mathbf{S_4}$ are OSTBCs for three and four transmit antennas, respectively and they have the rate 1/2 [3]. With the code matrix $\mathbf{S}_3$, four complex symbols are taken at a time and transmitted via three transmit antennas in eight time slots. Thus, the symbol rate is 1/2. With the code matrix $\mathbf{S}_4$, four symbols are taken at a time and transmitted via four transmit antennas in eight time slots, resulting in a transmission rate of 1/2 as well.

$$\mathbf{S}_3 = \begin{bmatrix} s_1 & s_2 & s_3 \\ -s_2 & s_1 & -s_4 \\ -s_3 & s_4 & s_1 \\ -s_4 & -s_3 & s_2 \\ s_1^* & s_2^* & s_3^* \\ -s_2^* & s_1^* & -s_4^* \\ -s_3^* & s_4^* & s_1^* \\ -s_4^* & -s_3^* & s_2^* \end{bmatrix} \qquad \text{...(2)}$$

$$\mathbf{S_4}=\begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2 & s_1 & -s_4 & s_3 \\ -s_3 & s_4 & s_1 & -s_2 \\ -s_4 & -s_3 & s_2 & s_1 \\ s_1^* & s_2^* & s_3^* & s_4^* \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ -s_3^* & s_4^* & s_1^* & -s_2^* \\ -s_4^* & -s_3^* & s_2^* & s_1^* \end{bmatrix} \quad ...(3)$$

2. OSTBC with a rate of 3/4

The following code matrices $\mathbf{S_3}$ and $\mathbf{S_4}$ are complex generalized designs for OSTBC with rate 3/4 for three and four transmit antennas, respectively [3].

$$\mathbf{S}_3' = \begin{bmatrix} s_1 & s_2 & \frac{s_3}{\sqrt{2}} \\ -s_2^* & s_1^* & \frac{s_3}{\sqrt{2}} \\ \frac{s_3^*}{\sqrt{2}} & \frac{s_3^*}{\sqrt{2}} & \frac{(-s_1 - s_1^* + s_2 - s_2^*)}{2} \\ \frac{s_3^*}{\sqrt{2}} & -\frac{s_3^*}{\sqrt{2}} & \frac{(s_2 + s_2^* + s_1 - s_1^*)}{2} \end{bmatrix} \quad (4)$$

$$\mathbf{S}_4' = \begin{bmatrix} s_1 & s_2 & \frac{s_3}{\sqrt{2}} & \frac{s_3}{\sqrt{2}} \\ -s_2^* & s_1^* & \frac{s_3}{\sqrt{2}} & -\frac{s_3}{\sqrt{2}} \\ \frac{s_3^*}{\sqrt{2}} & \frac{s_3^*}{\sqrt{2}} & \frac{(-s_1 - s_1^* + s_2 - s_2^*)}{2} & \frac{(-s_2 - s_2^* + s_1 - s_1^*)}{2} \\ \frac{s_3^*}{\sqrt{2}} & -\frac{s_3^*}{\sqrt{2}} & \frac{(s_2 + s_2^* + s_1 - s_1^*)}{2} & \frac{(s_1 + s_1^* + s_2 - s_2^*)}{2} \end{bmatrix} \quad (5)$$

Obviously, some transmitted signal samples are scaled linear combinations of the original symbols.

V. SIMULATION RESULTS

This section provides simulation results for the codes given above. In figure 2 and figure 3, we have drawn the bit error rate (BER) curves against SNR values for the N_t x 1 configuration with Rayleigh channel coefficients using OSTBCs. Here, we consider two special cases. Figure 2 shows bit error rate (BER) for OSTBCs for an uncoded 4-PSK and for the OSTBCs using two; three, and four transmit antennas. The transmission using two transmit antennas makes use of 4-PSK constellation and the Alamouti code. For three and four transmit antennas, the 16-QAM constellation and the codes $\mathbf{S}_3'$ from equation (4) and $\mathbf{S}_4'$ from equation (5), respectively, are utilized.

The total transmission rate in each case is 6-bits/second. It may be observed that at the BER of 10^{-2}, the rate 3/4 16-QAM code $\mathbf{S}_4'$ provides about 9 dB gain over the use of an uncoded 4-PSK data transmission. For higher SNR values, the code $\mathbf{S}_4'$ for four transmit antennas provides about 6 dB gain at BER = 10^{-3} over use of the Alamouti code. Figure 3 illustrates bit error rate (BER) for OSTBCs using two, three, and four transmit antennas together with an uncoded 8-PSK transmission. The transmission using two transmit antennas employs the 8-PSK constellation and the Alamouti code. For three and four transmit antennas, the 16-QAM constellation and the codes $\mathbf{S}_3$ and $\mathbf{S}_4$, respectively, are used. Since $\mathbf{S}_3$ and $\mathbf{S}_4$ are rate 1/2 codes, the total transmission rate in each case is 4 bits/second. It may be observed that at the BER of 10^{-3} the rate 1/2 16-QAM code $\mathbf{S}_4$ gives about 8 dB gain over the use of an uncoded 4-PSK data transmission and at BER = 10^{-4} about 2 dB over the codes with two and three transmit antennas.

From simulation results, it may be observed that with increase in the number of transmit antennas; a significant performance gain can be achieved. One very important feature of OSTBCs is that if we increase the number of transmit antennas, the decoding complexity is not significantly increased, due to the fact that only linear processing is required for decoding.

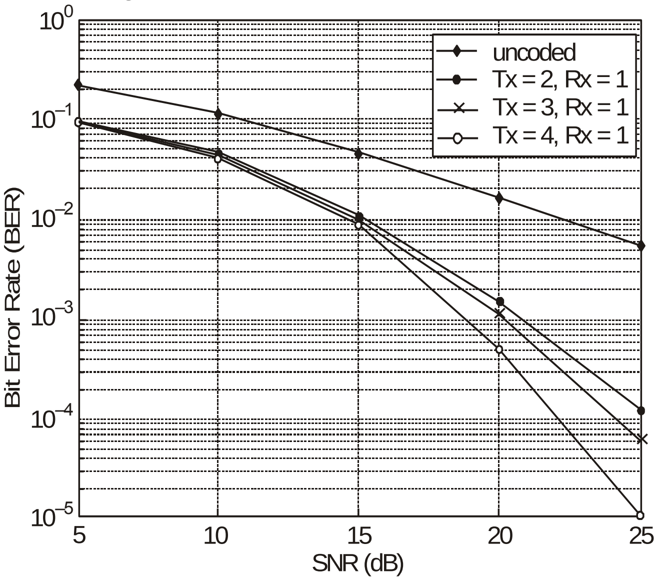

Fig. 2. BER performance for OSTBCs of 6 bits/channel using ($N_t \times 1$) configuration

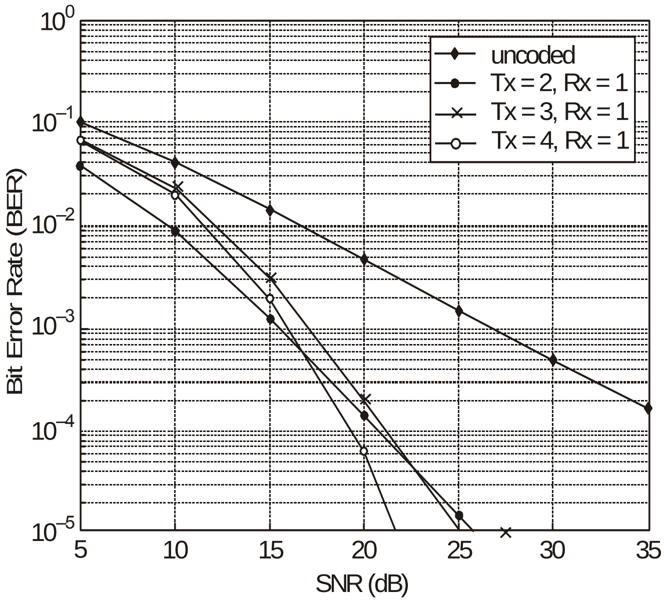

Fig. 3. BER performance for OSTBCs of 4 bits/channel using ($N_t \times 1$) configuration

VI. CONCLUSIONS

This paper presents the bit error rate performance evaluation of orthogonal space-time block codes with multiple transmit antennas in wireless mobile communication systems with the help of computer simulation. We plot the bit error rate (BER) versus SNR for the N_t x 1 configuration with Rayleigh channel coefficients using OSTBCs. From simulation results, it may be observed that increasing the number of transmit antennas yields reasonable performance gain. One of the most illustrative features of OSTBCs is that increasing the number of transmit antennas does not increase the decoding complexity significantly. This happens due to the fact that we need only linear processing for decoding. Simulation results show that full transmission rate is more important at very low SNR values and high BERs, whereas full diversity is the right choice for high SNR values and low BERs. This is due to the fact that the slope of the performance curve at high SNR is determined by the diversity order. Note that the receiver of the full diversity OSTBC can decode the symbols one by one. This means that the decoding complexity of the full diversity orthogonal codes is lower, although OSTBCs have a very low decoding complexity compared to the decoding of Space-Time Trellis Codes. The encoding complexity of the system is low for both types of OSTBCs. Thus, the research study shows that combined use of multiple transmit antennas and Orthogonal Space-Time Block Codes (OSTBCs) results in the significant overall system performance without ant extra signal processing.

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