iJST EXPLORE International Journal of Science and Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-7318

International Journal of Science and Technology Volume 2 No. 2, February, 2013

Performance Evaluation of Space-Time Block Coding on MIMO Communication System Using Spatial Diversity

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ABSTRACT

Wireless technology makes our life easy and comfortable. And also the demand on bandwidth and spectral availability are endless. However, the designers have got difficult task of limited availability of radio spectrum, fading, multi-path, interference, to meet the demand for high data rate [1]. The 2G and 3G standards are not good enough to satisfy the demand of high capacity. Therefore, the new standard 4G which is the successor of 2G and 3G and Broadband Wireless Access (BWA) such as WiMAX have emerged as a promising solution for providing fully broadband internet for mobile and stationary users and they use the new technology called MIMO (Multiple Input Multiple Output). In this paper analysis of 16QAM modulation scheme in AWGN and Rayleigh channels were performed using different number of transmit and receive antennas to provide spatial diversity. The single-input single-output(SISO) system was compared with the various MIMO systems using Signal-to Noise Ratio (SNR) vs Bit Error Rate (BER). Significant SNR improvement and diversity gains were achieved when the MIMO system employs the same number of antenna both at the transmitter and receiver and especially if this number is greater or equal to 2. Significant SNR improvement can also be achieved when more antennas are used at the receiver than at the transmitter to provide diversity gain, SNR improvement and higher data rate.

Keywords: *STBC, ISI, LOS, NLOS, MIMO, SNR, BER, Spatial Diversity*

1. INTRODUCTION

Multi-Input Multi-Output (MIMO) technology has also been renowned as an important technique for achieving an increase in the overall capacity of wireless communication systems. In this multiple antennas are employed at the transmitter side as well as the receiver side [5]. One can achieve spatial multiplexing gain in MIMO systems realized by transmitting independent information from the individual antennas, and interference reduction. The enormous values of the diversity gain, multiplexing gain and/or capacity gain achieved by MIMO Spatial diversity and Spatial multiplexing techniques had a major impact on the introduction of MIMO technology in wireless communication systems such as the Worldwide Interoperability for Microwave Access (WiMAX). WiMAX is an IEEE 802.16 standard based technology responsible for bringing the Broadband Wireless Access (BWA) to the world as an alternative to wired broadband. The IEEE 802.16e air interface standard [2] is basically based on technology namely, orthogonal frequency-division multiplexing (OFDM), that has been regarded as an efficient way to combat the inter-symbol interference (ISI) for its performance over frequency selective channels for the broadband wireless networks.

2. MULTI INPUT MULTI OUTPUT (MIMO) SYSTEMS

Single Input Single Output (SISO) is the traditional model in wireless system which uses one antenna at transmitter and one antenna at receiver. Its overall performance is largely dependent on channel behavior and environment. It is used in radio and TV broadcast and our personal wireless technologies such as Wi-Fi and Bluetooth. To improve the channel performance we can use either single input multiple output (SIMO) or multiple input single output (MISO) [12]. MIMO is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver) as shown in Figure 1. The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed. Multi-antenna systems can be classified into three main categories. Multiple antennas used at the transmitter side of MIMO systems are mainly used for beamforming purposes to avoid the signal going to undesired directions. Transmitter or the receiver side multiple antennas are used for realizing different (frequency, space) diversity schemes in order to get diversity or capacity gain. The third class includes systems with multiple transmitter and receiver antennas that help in realizing spatial multiplexing which is often referred as MIMO by itself. In radio communications, MIMO means employing multiple antennas at both the transmitter and receiver side of a specific radio link [5]. In case of spatial multiplexing technique, different data symbols are transmitted through different antennas with the same frequency within the same time interval. Multipath propagation phenomenon is assumed in order to ensure that there is correct operation of spatial multiplexing, since MIMO performs better in terms of channel capacity in a rich multipath scattering environment.

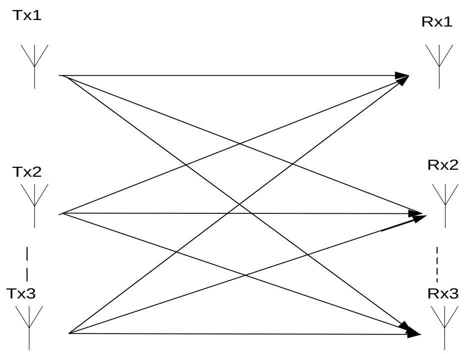

Fig.1. Block Diagram of MIMO system with M Transmitters and N Receivers

3. MIMO TECHNIQUES

3.1 Spatial Diversity

Diversity is one of the ways to combat the phenomenon of multipath fading. The main idea behind the diversity technique is to provide multiple replicas of the transmitted signal to the receiver. If these multiple replicas fade independently with each other, there is less probability for having all copies of the transmitted signal in deep fade simultaneously [6]. MIMO system takes advantage of the spatial diversity technique by placing independent separate antennas in a dense multipath scattering environment. In spatial diversity, same information is being sent on the independent individual antennas at the transmitter side. These systems can be implemented in a number of ways to obtain a diversity gain to combat with signal fading or a capacity improvement can also be done. Thus, the receiver can easily decode the transmitted signal using these received signals. This technique involves Space Time Block Coding (STBC) and Space Time Trellis Coding (STTC). Diversity techniques can be implemented into different ways in order to improve the bit error rate of the system [7].

3.2 Spatial Multiplexing

This form of MIMO is used to provide additional data capacity by utilizing the different paths to carry additional traffic, i.e. increasing the data throughput capability. The spatial multiplexing mitigates the multipath propagation phenomenon problem that is experienced by most of the microwave transmissions. MIMO techniques permit multiple streams that help in improving the signal-to-noise ratio and also the reliability that significantly improves over other versions of the standard. Spatial multiplexing includes transmitting different information onto different independent individual antennas at the transmitter side of the MIMO system and thus helps in attaining the capacity gain. This technique includes V-BLAST technology that is used to improve the spectral efficiency of the system [8]. MIMO systems utilize spatial multiplexing under rich scattering environment; independent data streams are simultaneously transmitted over different antennas to increase the effective data rate. MIMO spatial multiplexing [9] requires at least 2 transmitters and 2 receivers, and the receivers must be in the same place that means they should be in the same device. Because the transmitting antennas are not required to be in the same device and also two mobiles can be used together in the uplink.

3.3 Beamforming

Beamforming enables performance gains with multiple antennas at the BS and even a single antenna at the MS so as to direct the beam in a particular direction such that the signal going in the desired direction is increased and the signal going to the other directions is decreased. Such performance gains are derived from the array gain obtained from the phased array antennas used in the beamforming plus the diversity gain, which can be as much as 10 dB for a system having four antennas at the base station and a single antenna at the mobile station. Beamforming is a signal processing technique used to control the directionality of the transmission and reception of radio signals. The most effective and efficient type of beamforming is dynamic digital beamforming [10]. This uses an advanced, on-chip digital signal processing (DSP) algorithm in order to gain complete control over all the Wi-Fi signals.

4. MIMO SIMULATION MODEL

The main aim of combining an existing wireless communication system with either the Spatial diversity or Spatial multiplexing MIMO technique is to achieve higher data rates by lowering the BER and improving the SNR of the whole system. The block diagram of the MIMO system is as shown in Figure 2.

4.1 Input Data

It is the message signal intended for transmission. The message may either be in analog form such as audio signal or digital form like bit stream from computer. The message signal from source is usually in the form of baseband signal.

4.2 Transmitter

It operates in some way on message signal and produces a signal suitable for transmission to the receiving point over the specific channel. A transmitter consists of a modulator to perform the function of mapping of digital information into analog form in order to transmit the data over the channel which can be done by changing the amplitude, frequency or phase. Various digital modulation techniques can be used are M-PSK and M-QAM [7].

4.3 Communication Channel

It is a media used to transmit the signal from transmitting to receiving point. During transmission, noise and different kind of interfering signals added to transmitted signal by the channel. Communication channel is a medium of communication between transmitter and receiver. There are three main types of channels usually identified in wireless communication systems: Additive White Guassian Noise(AWGN) channel, Ricean and Rayleigh fading channels. The AWGN channel is considered the most benign of them all. The Ricean and Rayleigh channels may be divided into fast and slow fading channels. A channel is known as fast fading if the impulse response of the channel changes approximately at the symbol rate of the communication system, whereas in slow fading channel, impulse response stays unchanged for several symbols. Both AWGN and Rayleigh channels are used for the analysis purpose in this paper. Constructive and destructive nature of multipath components in flat fading channels can be approximated by Rayleigh distribution if there is no line of sight which means when there is no direct path between transmitter and receiver [4]. The received signal can be simplified to:

$$r(t) = s(t) * h(t) + n(t) \quad (1)$$

where h(t) is the random channel matrix having Rayleigh distribution and n(t) is the Additive White Gaussian noise. The Rayleigh distribution is regarded as the magnitude of the sum of two equal independent orthogonal Gaussian random variables and is useful in LOS condition only.

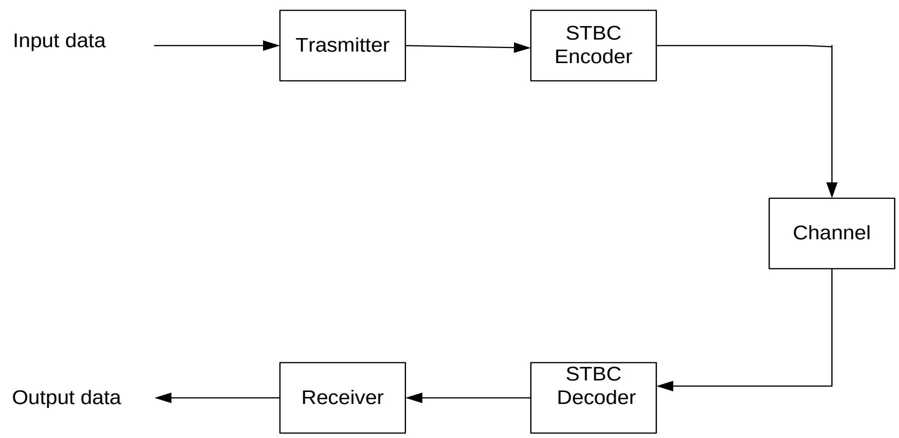

Fig. 2: MIMO System

4.4 Receiver

It operates on receive signal and tries to reproduce original signal from it since the received signal is a corrupted version of transmitted signal. In order word, it performs an inverse process at the receiver, called demodulation.

4.5 Output Data

It is the replica of the input data.

4.6 STBC Encoder/ Decoder

The use of any wireless technology with the MIMO technology provides an attractive solution for future broadband wireless systems that require reliable, efficient and high-rate data transmission. Spatial multiplexing technique of MIMO systems provides spatial multiplexing gain that has a major impact on the introduction of MIMO technology in wireless systems thus improving the capacity of the system. Combining of both the existing wireless systems involves employing STBC encoder and decoder at the transmitter and receiver side of that system respectively.

5. RESULTS AND SIMULATIONS

This paper analyzes the behavior of MIMO systems under 16-QAM modulation scheme for AWGN and Rayleigh channel. Results are shown in the form of SNR vs BER plot for different antenna combinations. The simulations are done for spatial diversity so as to attain more efficient performance of the MIMO systems as compared to simple SISO system. The performance in the form of BER vs SNR plots for different modulations over AWGN and Rayleigh channels for MIMO systems have been presented in Figure 3(a)–(d). Each graph shows an improvement generally in SNR using spatial diversity technique of MIMO system compared to the SISO system. Table 1 shows the approximate value of SNR required to achieve the BER of 10^{-4} for both the AWGN and Rayleigh channels for each of the systems investigated.

Table.1: SNR versus BER=10^{-4}

SISO/MIMO	AWGN (dB)	Rayleigh (dB)	Diff. (dB)
SISO	18.0	>>20 (BER≈10^{-2} at 20dB)	BER of 10^{-4} not attainable at 20dB
T2R1	17.2	>>20 (BER≈10^{-3} at 20dB)	BER of 10^{-4} not attainable at 20dB
T4R1	15.0	19.0	4.0
T1R2	14.0	≤22	≤8.0
T1R4	11.0	14.0	3.0
T2R2	14.5	18.5	4.0
T3R3	10.0	12.0	2.0
T4R4	9.0	10.0	1.0

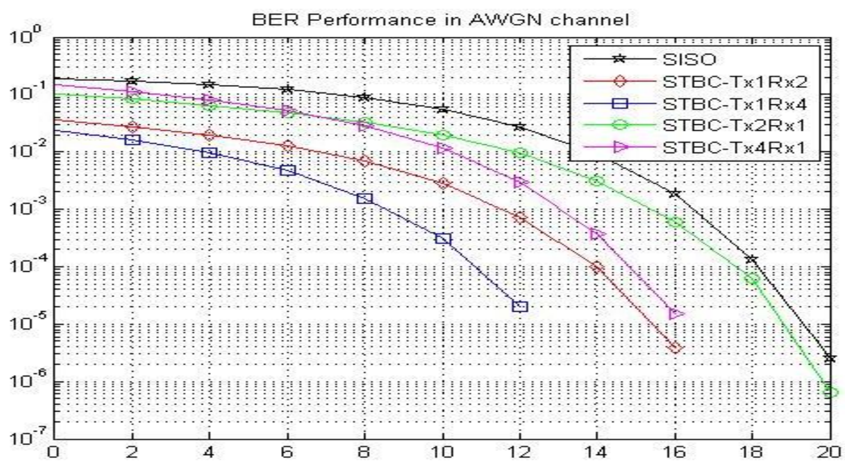

Fig 3(a): Different number of Transmit and Receive Antenna in AWGN channel

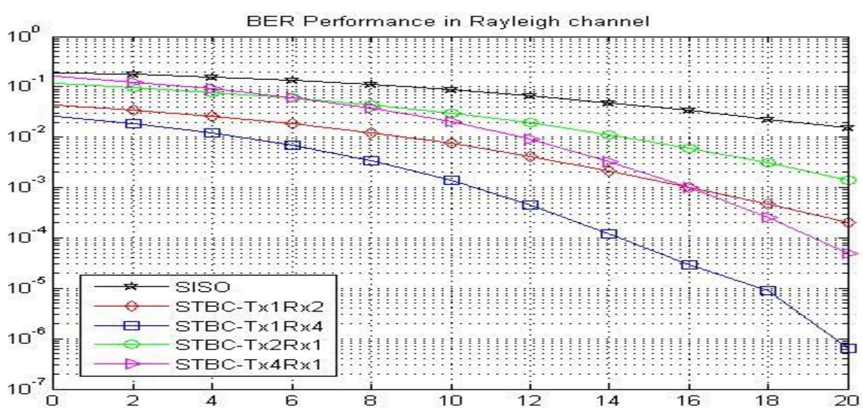

Fig 3(b): Different number of Transmit and Receive Antenna in Rayleigh channel

Fig.3 (c-d) shows the performances the MIMO system in AWGN and Rayleigh channels. It is observed that the STBC-Tx4Rx4 outperforms the other systems. In AWGN channel the STBCTx4Rx4, STBCTx3Rx3, STBCTx2Rx2 and SISO requires an SNR of about 9dB, 10dB, 14.5dB and 18.0dB respectively to attain a BER of 10^{-4}, whereas in the Rayleigh fading channel these systems requires an SNR of 10dB, 12dB, 18.5dB and >>20dB respectively to achieve the same BER of 10^{-4}. Comparing the BER performances of AWGN and Rayleigh channels, one notices only an SNR difference of 1dB, 2dB, 4.0dB respectively for the MIMO systems and too large SNR for the SISO(SISO can only attain a BER=10^{-2} at 20dB), thus indicating that MIMO systems provide higher diversity gains in Rayleigh fading.

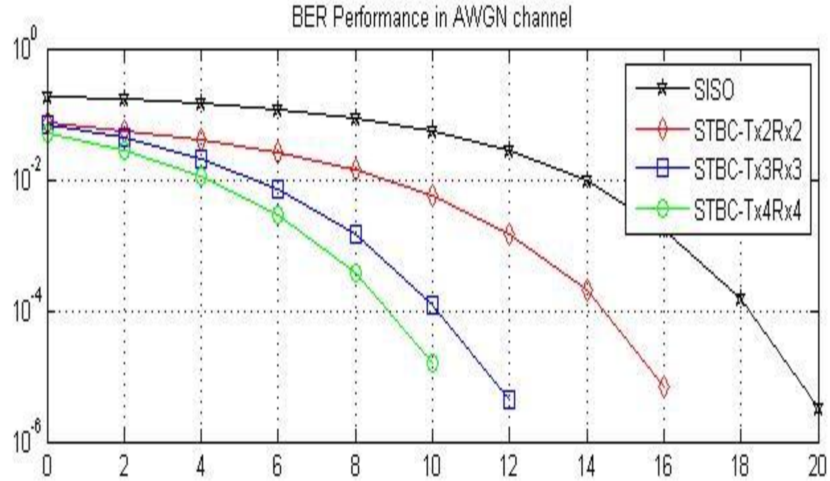

Fig 3(c): Same number of Transmit and Receive Antenna in Rayleigh channel

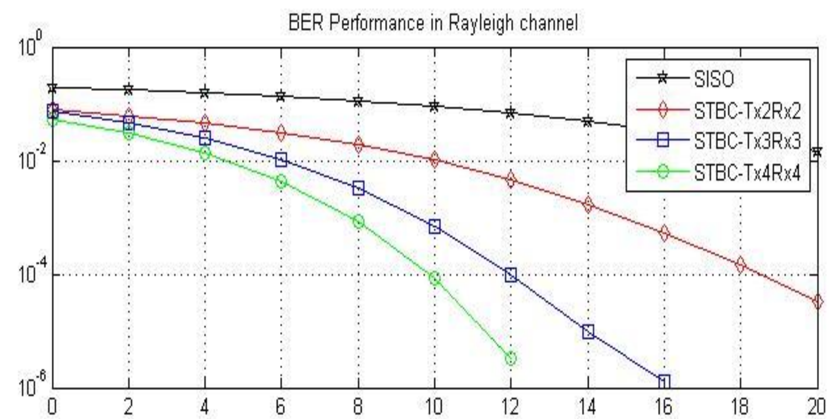

Fig 3(d): Same number of Transmit and Receive Antennas in Rayleigh channel

6. CONCLUSIONS

In this paper effect of employing spatial diversity technique of MIMO system in wireless communication has been simulated through Matlab2009a. This technique of MIMO systems provides spatial diversity gain that has a major impact on the introduction of MIMO technology in wireless systems. Both AWGN and Rayleigh channels have been taken into account for the analysis purpose. Simulations are based upon using different number of antennas at either the transmitter or receiver and show that there is improvement in the SNR value as well as capacity improvement by employing spatial diversity technique of MIMO system. Results are presented in the form of BER vs SNR value and show that BER reduces when we employ MIMO system in wireless systems in comparison to simple SISO communication. The higher value of SNR improvement was noticed with systems using same number of receiver antenna and transmit antenna especially when the number is greater than 2. It can also be concluded that the higher the number of receive antenna, compared to number of transmit antenna, the higher diversity gains and thus reduction in BER. This shows that employing MIMO system in wireless communications such as WiMAX improves the overall performance of the system and provides significant diversity gain and higher data rates for the transmission purpose such that originality of the input signal is retained.

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