Performance Analysis of Space Time Block Code for 4G Wireless Technology

Major Project Report

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology

In

Electronics and Communication Engineering

(Communication Engineering)

By

Nikunj K. Patel

(08MECC14)

Department of Electronics & Communication Engineering

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Communication Engineering at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Nikunj K. Patel

Certificate

This is to certify that the Major Project entitled **"Performance Analysis of Space Time Block Code for 4G Wireless Technology"** submitted by **Nikunj Patel (08MECC14)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electronics & Communication (Communication) of Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of our knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

The thesis is based on STBC (Space Time Block Code) which provides space time diversity to combat against multipath fading in the field of wireless communications. At the transmitter end, the data is encoded using the Alamouti's matrix and after it the encoded data is split into streams which are simultaneously transmitted using n_T transmit antennas and n_R receiver antenna over a Rayleigh fading channel. Secondly, different types of the SUI (Stanford University Interim) channels which are defined for different terrain types are used to analyze BER.

At the receiver end, the source information is recovered using the Maximum Likelihood Decoding Algorithm with the help of Alamouti's two branches transmit diversity scheme. Then the BER (Bit Error Rates) of different types of SUI channels along with different modulation techniques are calculated. The MatLab version 2009 (a) is used to carry out the simulations.

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Chapter 1

Introduction

1.1 Motivation

The field of wireless communication systems and networks has experienced explosive growth and wireless communications has become an important part of everyday live. Further, the rapidly increasing number of wireless communication subscribers, the growth of the internet and the quickly increasing use of wireless devices suggest that wireless internet multimedia access will rise rapidly over the next few years. Thus, the market for mobile devices has dramatically increased and continued growth is predicted. In today's scenario, there is big demand of more application, improved performance, and increased data rates in wireless communication. Everyone wants to communicate on their own terms; to get connected and stay connected in order to send and receive information in any form, let it be voice, text, image, or video. As an example, customers are using mobile telephone applications like Multimedia Message Services (MMS), an extension of text messaging (SMS), which adds pictures and sound elements. People want to stay connected in any condition from any device anywhere and anytime.

Wireless channels are random in nature and therefore results in uncontrolled reflection, scattering, shadowing and attenuation of the transmitted signal. Due to the constructive and destructive superposition of different signals at receiver, the detection of the transmitted signals becomes challenging. These effects can be statistically modeled as a multiplicative random variable and are referred to as fading.

The spectrum or bandwidth available to the service provider is often limited and expensive. Furthermore, the power requirements are such that devices should use as little power as possible to conserve battery life and keep the products small and cheap. This should also apply to next generation handset models of which many have built-in cameras. Furthermore, most models will be multi-band and multi-mode, allowing users to switch seamlessly between different services in various mobile technologies like UMTS (Universal Mobile Telecommunications System), GPRS (General Packet Radio Service), and GSM (Global System for Mobile Communications) in different frequency bands. Designers of wireless systems therefore face a two part challenge of increasing data rates and improving performance while incurring little or no increase in bandwidth or power and costs.

The dissertation work aims to provide analysis of the transmission schemes referred to as space time codes in order to guarantee reliable transmission and improved performance in mobile communication systems for the next generation standards. It fulfills some of the important aspects such as high data rate, low power, low cost, less bandwidth utilization, ubiquitous network by using MIMO (Multiple Input Multiple Output) concept. Space time diversity is one of the diversity schemes that fulfill all the above mentioned factors.

1.2 Introduction

Fading in wireless channels causes loss in performance of efficiency of channel, capacity of channel and data rate. Diversity is one of the most effective technique to overcome such adverse effects. In general, diversity means using different dimensions of the channel, e.g. space, time and frequency to improve the equivalent channel utilizations. A space-time code (STC) is designed for a multiple transmitter wireless system that attempts to achieve antenna (space) diversity. The very first design of space-time code was in the form of trellis-coded modulation [1], and suffered from exponential decoding complexity as the number of transmit antennas increased [2]. Alamouti had proposed a simple transmitter diversity scheme, which benefited from both full diversity of a two-transmit antenna channel as well as simple Maximum-Likelihood (ML) decoding. The properties of the code had inspired Tarokh to inspect the existence of similar designs for more numbers of transmit antennas [3]. In the case of complex codes, i.e. modulation schemes using complex constellation members, Alamouti had proposed a structured modulation scheme, called Orthogonal Space-time Block Code that could send on average one symbol in every two-time slot, and achieved full diversity as well as simple ML decoding.

1.3 Introduction of MIMO

MIMO [4] wireless systems have become an active research area, compared with the single input single output (SISO) systems. Three major advantages are provided by the MIMO wireless systems which are as follows:-

1. Diversity gain

2. Spectral efficiency

3. Multiplexing gain

By employing multiple antennas, multiple independent replicas of the information signal are received at the receiver, which means that more reliable reception can be achieved by applying an appropriate coding/decoding scheme. Recently, transmit diversity has been studied extensively because of the feasibility of having multiple antennas at the base station.

The idea of spatial multiplexing is that MIMO systems in a rich scattering environment provide multiple data pipes within the same frequency band yielding a linear increase in capacity channel. It is shown in that for a system with n_T transmit antennas and n_R receive antennas, the capacity is about min (n_T, n_R) times larger than that of a system with a single transmit and a single receive antenna. Most of the existing work in this area assumes that the antenna elements at the transmitter and the receiver of the MIMO system are placed far enough (spatially) such that the effect of the channel at a particular antenna element is different from the effect at all other antenna elements. This implies independent or spatially uncorrelated fading. This holds true only if spacing between transmit antennas or receive antennas is of the order of several wavelengths. MIMO antenna system together with space-time coding significantly improve the performance of wireless communication system by exploring the spatial and temporal diversities of the system.

1.4 Problem Definition

The aim of the project is to carry out an analysis of STBC (Space Time Block Code) code in general and comprehensive pertaining to 4G (4th Generation) [5] wireless technology which provides very high data rate, ubiquitous network. The following constrain are assumed to analyze the wireless system:-

1. The channel is completely known to a receiver, i.e. channel state-information.
2. Realistic channel (Rayleigh and SUI channels) conditions have been taken.
3. The individual antennas are correlated due to insufficient antenna spacing.
4. Different types of SUI (Stanford University Interim) channels are used to give multipath fading.

5. Maximum likelihood decoding is applied to recover the information signal back at the receiver end.

Following parametric goals have been set,

1. Investigate the effects of coded signal which are encoded by Alamouti's matrix and compare the performance of un-coded signal space-time block code.

2. Compare the bit error probability under SISO (Single Input Single Output) and MIMO condition for STBC as a function of Eb/N0 using different modulation schemes

3. Compare the performance of SISO, MISO (Multiple Input Single Output) and MIMO using different modulation techniques and different SUI channels.

1.5 Outline of the dissertation work

The work is organized as follows;

Chapter 2 introduces all diversity techniques. Need of Space Time Coding and STBC is discussed in this chapter. It gives also a brief explanation on Alamouti's scheme and ML decoding method.

Chapter 3 deals with different SUI channels and it performance with STBC code. All parameters of SUI channels are discussed in this chapter.

Chapter 4 provides algorithm to simulate STBC code with different modulation techniques using different SUI channels and their performances are evaluated by simulations.

Chapter 5 is devoted to result analysis of STBC code in different channel condition. Results are taken by comparing different modulation technique in different channel condition and different antenna types like SISO, MISO and MIMO.

Chapter 2

Space-Time Codes

2.1 Introduction to Diversity

In telecommunication, a diversity scheme refers to a method for improving the reliability of a message signal by utilizing two or more communication channels with different characteristics. Diversity plays an important role in combating fading and co-channel interference and avoiding error bursts. Multiple versions of the same signal may be transmitted and/or received and combined in the receiver. Alternatively, a redundant forward error correction code may be added and different parts of the message transmitted over different channels. Diversity techniques may exploit the multipath propagation, resulting in a diversity gain, often measured in decibels. Diversity can be achieved by using space time codes. The following classes of diversity schemes can be identified:

2.1.1 Time diversity

Multiple versions of the same signal are transmitted at different time instants. A redundant forward error correction code is added and the message is spread in time by means of bit-interleaving before it is transmitted.

2.1.2 Frequency diversity

The signal is transferred using several frequency channels or spread over a wide spectrum that is affected by frequency-selective fading.

2.1.3 Space diversity

Space diversity is also called antenna diversity. It is typically implemented using multiple antennas or antenna arrays arranged together in space for transmission and/or reception. The multiple antennas are separated physically by a proper distance so that the individual signals are uncorrelated. The separation requirements vary with antenna height, propagation environment and frequency. Typically a separation of a few wavelengths is enough to obtain uncorrelated signals. In space diversity, the replicas of the transmitted signals are provided to the receiver in the form of redundancy in the space domain. Space diversity does not induce any loss in bandwidth efficiency.

Receive and Transmit diversity

Depending on whether multiple antennas are used for transmission or reception, we can classify space diversity into two categories: receive diversity and transmit diversity [6]. In receive diversity, multiple antennas are used at the receiver site to pick up independent copies of the transmit signals. The replicas of the transmitted signals are properly combined to increase the overall received SNR (Signal to Noise Ratio) and mitigate multipath fading. In transmit diversity; multiple antennas are deployed at the transmitter site. Messages are processed at the transmitter and then spread across multiple antennas. In practical communication systems, in order to meet the system performance requirements, two or more conventional diversity schemes are usually combined to provide multidimensional diversity. For example, in GSM cellular systems multiple receive antennas at base stations are used in conjunction with interleaving and error control coding to simultaneously exploit both space and time diversity.

2.2 Introduction to Space Time Code

Space-time code (STC) is a method employed to improve the reliability of data transmission in wireless communication systems using multiple transmit antennas. STCs rely on transmitting multiple, redundant copies of a data stream to the receiver with the aim that at least some of them may survive the physical path between transmission and reception in a state so as to allow reliable decoding.
Different types of Space Time Codes are,

1. Space Time Block Code
2. Space-Time Trellis Codes
3. Space-Time Turbo Trellis Codes
4. Layered Space-Time Codes
5. Differential Space-Time Block Codes

2.3 Need of Space Time Code

An effective and practical way to approaching the capacity of multiple-input multiple-output (MIMO) wireless channels is to employ space-time (ST) coding. Space-time coding is a coding technique which is designed with multiple transmit/receive antennas. Coding is performed in both spatial and temporal domains to introduce correlation between signals transmitted from various antennas at various time periods. For each input symbol, the space-time encoder chooses the constellation points to simultaneously transmit from each antenna so that coding and diversity gains are maximized. Fading problems can be easily minimized by using STC and can increase spectral efficiency without sacrificing with bandwidth. It improves the downlink performance without the need for multiple receive antennas at the terminals. Space-Time Codes have been implemented in cellular communications as well as in wireless local area networks.

Essentially, 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 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 in case of two transmit antennas. The key feature of this scheme is the orthogonality between the signals vectors transmitted over the two transmit antennas. 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 rate exist.

2.4 Algorithm for Space-Time Block Codes

2.4.1 Introduction

Performance of STBC is evaluated. And Alamouti system is designed, which is a simple two branch transmit diversity scheme. The key feature of the scheme is that it achieves a full diversity gain with a simple maximum-likelihood decoding algorithm. Space-time block codes are presented with a large number of transmit antennas based on orthogonal designs the decoding algorithms for space-time block codes.

The Alamouti scheme achieves the full diversity with simple maximum-likelihood Decoding algorithm. The key feature of the scheme is orthogonality between the sequences generated by the two transmit antennas. The scheme was generalized to an arbitrary number of transmit antennas by applying the theory of orthogonal designs. The generalized schemes are referred to as space-time block codes (STBCs). The space-time block codes can achieve the full transmit diversity specified by the number of the transmit antennas n_T, and maximum likelihood decoding is used and it is very simple method to implement.

2.4.2 Alamouti Space-Time Codes

The Alamouti scheme is historically the first space-time block code to provide full transmit diversity for systems with two transmit antennas. It is worthwhile to mention that delay diversity schemes can also achieve a full diversity, but they introduce interference between symbols and complex detectors are required at the receiver. Alamouti's transmit diversity technique has been presented, including encoding and decoding algorithms and its performance.

2.4.3 Alamouti Space-Time Encoding

Figure 2.1 shows the block diagram of the Alamouti space-time encoder [4]. An M-ary modulation scheme is used. In the Alamouti space-time encoder, each group of m information bits is first modulated, where $m = \log_2 M$. Then, the encoder takes a block of two modulated symbols x_1 and x_2 in each encoding operation and maps them to the transmit antennas according to a code matrix given by,

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \tag{2.1}$$

The encoder outputs are transmitted in two consecutive transmission periods from two transmit antennas. During the first transmission period, two signals x_1 and x_2 are transmitted simultaneously from antenna one and antenna two, respectively. In the second transmission period, signal $-x_2{}^*$ is transmitted from transmit antenna one and signal x_1^* from transmit antenna two, where x_1^* is the complex conjugate of x_1.

It is clear that the encoding is done in both the space and time domains. De-

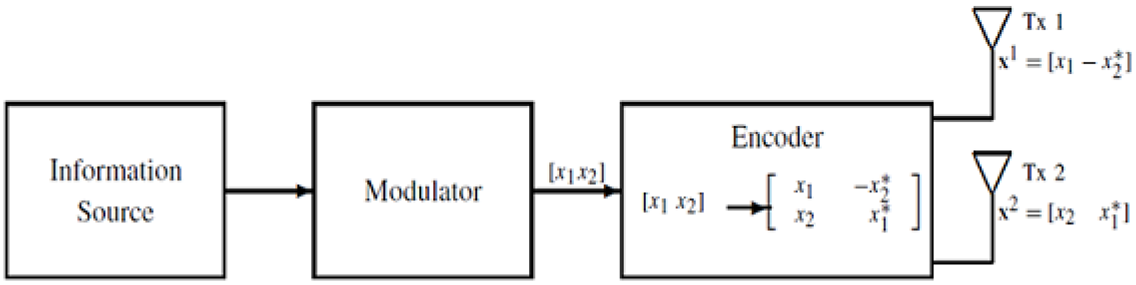

Figure 2.1: A block diagram of Alamouti Space Time Coder

note the transmit sequence from antennas one and two by X^1 and X^2 respectively.

$$X^1 = [x_1, \ -x_2^*] \tag{2.2}$$

$$X^2 = [x_2, x_1^*] \tag{2.3}$$

The key feature of the Alamouti scheme is that the transmit sequences from the two transmit antennas are orthogonal, since the inner product of the sequences X^1 and X^2 is zero, i.e.

$$X^1.X^2 = x_1 x_2^* - x_2^* x_1 = 0 \tag{2.4}$$

The code matrix has the following property,

$$X.X^H = \begin{bmatrix} |x_1|^2 + |x_2|^2 & 0 \\ 0 & |x_1|^2 + |x_2|^2 \end{bmatrix} \tag{2.5}$$

where I_2 is a 2×2 identity matrix.

One receive antenna is used at the receiver. The block diagram of the receiver for the Alamouti scheme is shown in Fig 2.2. The fading channel coefficients from the first and second transmit antennas to the receive antenna at time t are denoted by $h_1(t)$

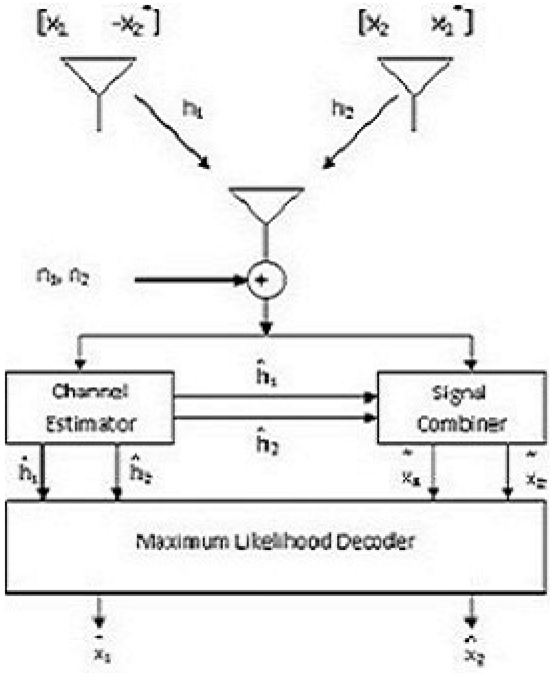

Figure 2.2: Recevier of Alamouti scheme

and $h_2(t)$, respectively. Assuming that the fading coefficients are constant across two consecutive symbol transmission periods, they can be expressed as follows

$$h_1(t) = h_1(t+T) = h_1 = |h_1| e^{j\theta_1} \tag{2.6}$$

$$h_2(t) = h_2(t+T) = h_2 = |h_2| e^{j\theta_2} \tag{2.7}$$

where, $|h_i|$ and θ_i,i=0,1,are the amplitude gain and phase shift for the path from transmit antenna i to the receive antenna, and T is the symbol duration.
At the receive antenna, the received signals over two consecutive symbol periods, denoted by r_1 and r_2 for time t and t+T, respectively.

$$r_1 = h_1 x_1 + h_2 x_2 + n_1 \tag{2.8}$$

$$r_2 = -h_1 x_2^* + h_2 x_1^* + n_2 \tag{2.9}$$

Here as shown in figure below n_1 and n_2 are independent complex variables with zero mean and power spectral density $N_0/2$ per dimension, representing additive white Gaussian noise samples at time t and $t+T$, respectively.

2.4.4 Combining and Maximum Likelihood Decoding

If the channel fading coefficients, h_1 and h_2, can be perfectly recovered at the receiver, the decoder will use them as the channel state information (CSI). Assuming that all the signals in the modulation constellation are equiprobable, a maximum likelihood decoder chooses a pair of signals $(\widehat{x_1}\ ,\ \widehat{x_2})$ from the signal modulation constellation to minimize the distance metric,

$$(\widehat{x_1}\ ,\ \widehat{x_2}) = \arg \min_{(\widehat{x_1}\ ,\ \widehat{x_2}) \in C} \left(|h_1|^2 + |h_2|^2 - 1\right) \left(|\widehat{x_1}|^2 + |\widehat{x_2}|^2\right) + d^2\left(\widetilde{x_1}\ ,\ \widehat{x_1}\right) + d^2\left(\widetilde{x_2},\ \widehat{x_2}\right) \tag{2.10}$$

where C is the set of all possible modulated symbol pairs $(\widehat{x_1}\ ,\ \widehat{x_2})$, $\widetilde{x_1}$ and $\widetilde{x_2}$ are two decision statistics constructed by combining the received signals with channel state information. The decision statistics are given by,

$$\widetilde{x_1} = h_1^* r_1 + r_2^* h_2 \tag{2.11}$$

$$\widetilde{x_2} = h_2^* r_1 - h_1 r_2^* \tag{2.12}$$

Substituting r_1 and r_2 from (2.8) and (2.9), respectively, into (2.11) and (2.12), the decision statistics can be written as,

$$\widetilde{x_1} = \left(|h_1|^2 + |h_2|^2 x_1\right) + h_1^* n_1 + n_2^* h_2 \tag{2.13}$$

$$\widetilde{x_2} = \left(|h_1|^2 + |h_2|^2 x_2\right) - n_2^* h_1 + h_2^* n_1 \tag{2.14}$$

For a given channel realization h_1 and h_2, the decision statistics $\widetilde{x_i}$, $i = 1, 2$, is only a function of x_i, $i = 1, 2$. Thus, the maximum likelihood decoding rule (2.10) can be separated into two independent decoding rules for x_1 and x_2, given by

$$\widehat{x_1} = \arg \min_{\widehat{x_1} \in S} \left(|h_1|^2 + |h_2|^2 - 1 \right) \ |\widehat{x_1}|^2 + d^2 \left(\widetilde{x_1} \ , \ \widehat{x_1} \right) \tag{2.15}$$

and

$$\widehat{x_2} = \arg \min_{\widehat{x_2} \in S} \left(|h_1|^2 + |h_2|^2 \right) \ |\widehat{x_2}|^2 + d^2 \left(\widetilde{x_2} \ , \ \widehat{x_2} \right) \tag{2.16}$$

Maximum Likelihood (ML) Receiver ML achieves the best system performance (maximum diversity and lowest bit error ratio (BER) can be obtained). The ML receiver calculates all possible noiseless receive signals by transforming all possible transmit signals by the known MIMO channel transfer matrix. Then it searches for that signal calculated in advance, which minimizes the Euclidean distance to the actually received signal. The undisturbed transmit signal that leads to this minimum distance is considered as the most likely transmit signal. Note that the above described detection process is optimum in sense of BER for white Gaussian noise. Using higher signal modulation, this receiver option is extremely complex. There exist approximate receive strategies, which achieve almost ML performance and need only a fraction of the ML complexity.

2.4.5 The Alamouti Scheme with Multiple Receive Antennas

The Alamouti scheme can be applied for a system with two transmit and n_R receive antennas. The encoding and transmission for this configuration is identical to the case of a single receive antenna. Let us denote by r_1^j and r_2^j the received signals at the jth receive antenna at time t and t + T , respectively.

$$r_1^j = \ h_{j,1} x_1 + \ h_{j,2} x_2 + \ n_1^j \tag{2.17}$$

$$r_2^j = \ -h_{j,1} x_2^* + \ h_{j,2} x_1^* + \ n_2^j \tag{2.18}$$

Where hj,i, i = 1, 2, j = 1, 2, . . . , , is the fading coefficient for the path from transmit antenna I to receive antenna j,and n_1^j and n_2^j are the noise signals for receive antenna j at time t and t + T , respectively. The receiver constructs two decision statistics based on the linear combination of the received signals. The decision statistics, denoted by $\widetilde{x_1}$ and $\widetilde{x_2}$, are given by,

$$r_1^j = \; h_{j,1}x_1 + \; h_{j,2}x_2 + \; n_1^j \tag{2.19}$$

$$r_2^j = \; -h_{j,1}x_2^* + \; h_{j,2}x_1^* + \; n_2^j \tag{2.20}$$

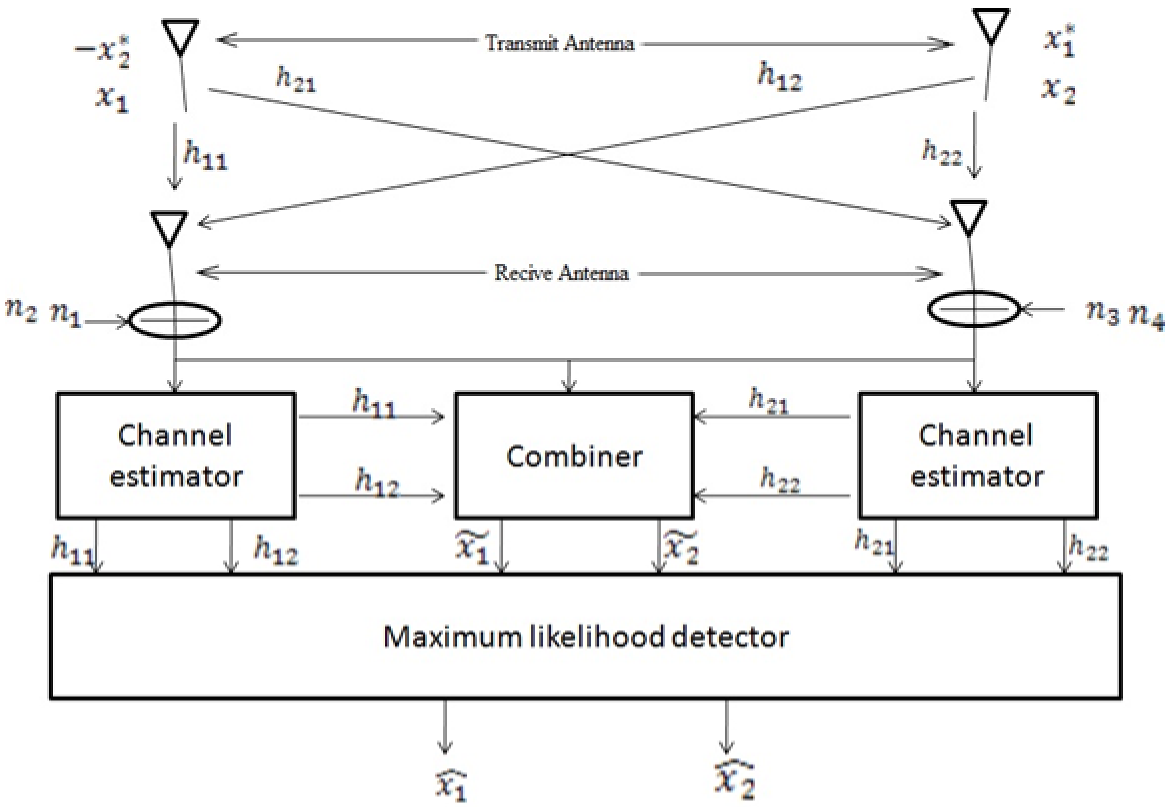

Figure 2.3: Alamouti scheme for 2Tx, 2Rx

$$\widetilde{x_1} \;=\; \sum_{j=1}^{n_R} h_{j,1}^* r_1^j + \; h_{j,2}\big(r_2^j\big)^* \;=\; \sum_{i=1}^{2} \;\; \sum_{j=1}^{n_R} |h_{j,1}|^2 x_1 + \; \sum_{j=1}^{n_R} h_{j,1}^* n_1^j + \; h_{j,2}\big(n_2^j\big)^* \quad (2.21)$$

$$\widetilde{x_2} \;=\; \sum_{j=1}^{n_R} h_{j,2}^* r_1^j - \; h_{j,1}\big(r_2^j\big)^* \;=\; \sum_{i=1}^{2} \;\; \sum_{j=1}^{n_R} |h_{j,1}|^2 x_2 + \; \sum_{j=1}^{n_R} h_{j,2}^* n_1^j - \; h_{j,2}\big(n_2^j\big)^* \quad (2.22)$$

The maximum likelihood decoding rules for the two independent signals x_1 and x_2 are given by

$$\widehat{x_1} = \arg\min_{\widehat{x_1}\ \in s} \left[\left(\sum_{j=1}^{n_R} (|h_{j,1}|^2 + \; |h_{j,2}|^2) - 1 \right) \; |\widehat{x_1}|^2 + \; d^2(\widetilde{x_1}\ ,\ \widehat{x_1}) \right] \qquad (2.23)$$

$$\widehat{x_2} = \arg\min_{\widehat{x_2}\ \in s} \left[\left(\sum_{j=1}^{n_R} (|h_{j,1}|^2 + \; |h_{j,2}|^2) - 1 \right) \; |\widehat{x_2}|^2 + \; d^2(\widetilde{x_2}\ ,\ \widehat{x_2}) \right] \qquad (2.24)$$

For M-PSK modulation, all the signals in the constellation have equal energy. The maximum likelihood decoding rules are equivalent to the case of a single receive antennas, as shown in equation (2.15) and (2.16).

Chapter 3

MIMO Channel Models

3.1 Introduction

The term channel refers to the medium between the transmitting antenna and the receiving antenna.The characteristics of wireless signal changes as it travels from the transmitter antenna to the receiver antenna. These characteristics depend upon the distance between the two antennas, the path taken by the signal, and the environment (buildings and other objects) around the path. The wireless channel is characterized by:

1) Path Loss

2) Shadowing (like log-normal shadowing)

3) Multipath Delay Spread

4) Fading Characteristics

5) Doppler Spread

6) Co-channel and adjacent channel interference

Terrain Type	SUI Channels
A	SUI-5, SUI-6
B	SUI-3, SUI-4
C	SUI-1, SUI-2

Table 3.1: Different terrain types

3.2 Stanford University Interim Channel Models

Each of the SUI-Channels [7] corresponds to particular terrain category A, B, and C. Type A terrain category include SUI-5, 6 (hilly/heavy tree density), Type B include SUI-3, 4 (moderate tree density) and Type C include SUI-1, 2 (flat/light tree density). A set of six typical channels were selected for the different terrain types that are describe in table 3.1. These models can be used for simulations, design, development and testing of technologies suitable for fixed broadband wireless applications. The parameters were selected based upon statistical models.

3.3 The generic structure of SUI channel models

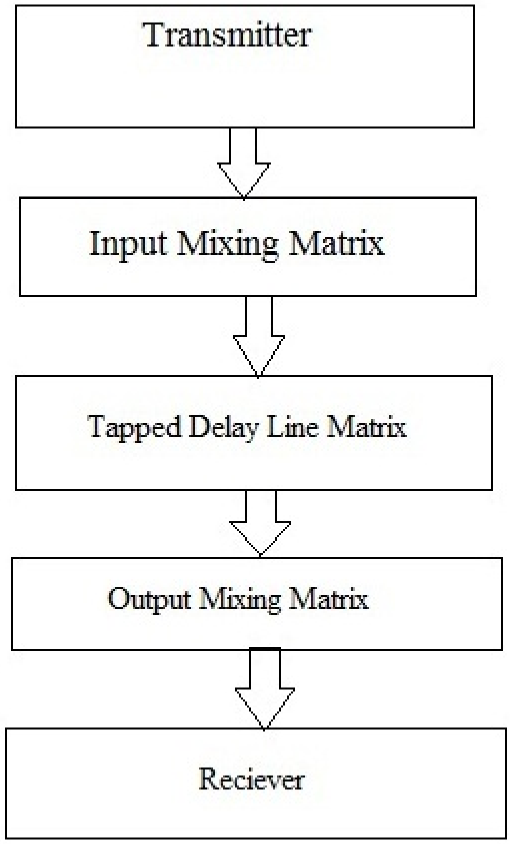

Figure 3.1: The generic structure of SUI channel models

The above structure is general for Multiple Input Multiple Output (MIMO) channels and includes other configurations like Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) as subsets. The SUI channel structure is the same for the primary and interfering signals.

Input mixing matrix that correlation between the input signals if multiple transmitting antennas are used.Tapped Delay Line Matrix is the multipath fading part of the channel. The multipath fading is modeled as a tapped-delay line with 3 taps with non-uniform delays. The gain associated with each tap is characterized by a distribution (Ricean with a K-factor >0, or Rayleigh with K-factor = 0) and the maximum Doppler frequency.Output Mixing Matrix correlates the output signals if multiple receiving antennas are used.Using the above general structure of the SUI Channel and assuming the following scenario, six SUI channels are constructed which are representative of the real channels.

3.4 Physical scenario for SUI channels

1. A cell size of 4 miles (6.4 km)
2. BTS (Base Transreceiver Station) Antenna height: 50ft
3. MS (Mobile Station) antenna height: 10ft
4. BTS Antenna Beamwidth: 120 deg
5. MS Antenna Beamwidth: 50 deg
6. Vertical Polarization only

For the above scenario, using the channel model, the following are the six specific SUI channels.

SUI	P(dB)	K	Tau	Doppler(Hz)	Ant-Corr.	Fnorm(dB)
1	[0 -15 -20]	[4 0 0]	[0 0.4 0.9]	[0.4 0.5 0.3]	0.7	-0.1771
2	[0 -12 -15]	[2 0 0]	[0 0.4 1.1]	[0.2 0.15 0.25]	0.5	-0.3930
3	[0 -5 -10]	[1 0 0]	[0 0.4 0.9]	[0.4 0.3 0.5]	0.4	-1.5113
4	[0 -4 -8]	[0 0 0]	[0 1.5 4]	[0.2 0.15 0.25]	0.3	-1.9218
5	[0 -5 -10]	[0 0 0]	[0 4 10]	[2.0 1.5 2.5]	0.3	-1.5113
6	[0 -10 -14]	[0 0 0]	[0 14 20]	[0.4 0.3 0.5]	0.3	-0.5683

Table 3.2: SUI channel parameter values for 3 tap channel

Table 3.2 shows the parameter of SUI channels [8] for different terrains. Three taps are taken in to consideration.

P - Power in each tap in dB,

K- Rayleigh K-factor in linear scale,

Tau - tap delay, Doppler - Doppler maximal frequency parameter in Hz,

Ant-corr - antenna correlation (envelope correlation coefficient),

Fnorm-gain normalization factor in dB.

Chapter 4

STBC Encoding and Decoding Algorithm

4.1 Introduction

This section illustrates the performance of STBC through simulation. MatLab is been used as a tool to carry out the simulations. Following simulation set-up has been developed in MatLab (R2009a) environment.

4.2 Simulation set up

The simulation set up is composed of four distinct parts, namely the bit generator, the STBC-encoder, the channel and the ML decoder.

4.2.1 Information Bit Generator

Information Bit Generator generates the sequence of bits composed of 0 and 1 using uniformly distributed random numbers. The mean value and variance value of input bits are 0.5 and 0.25 respectively.

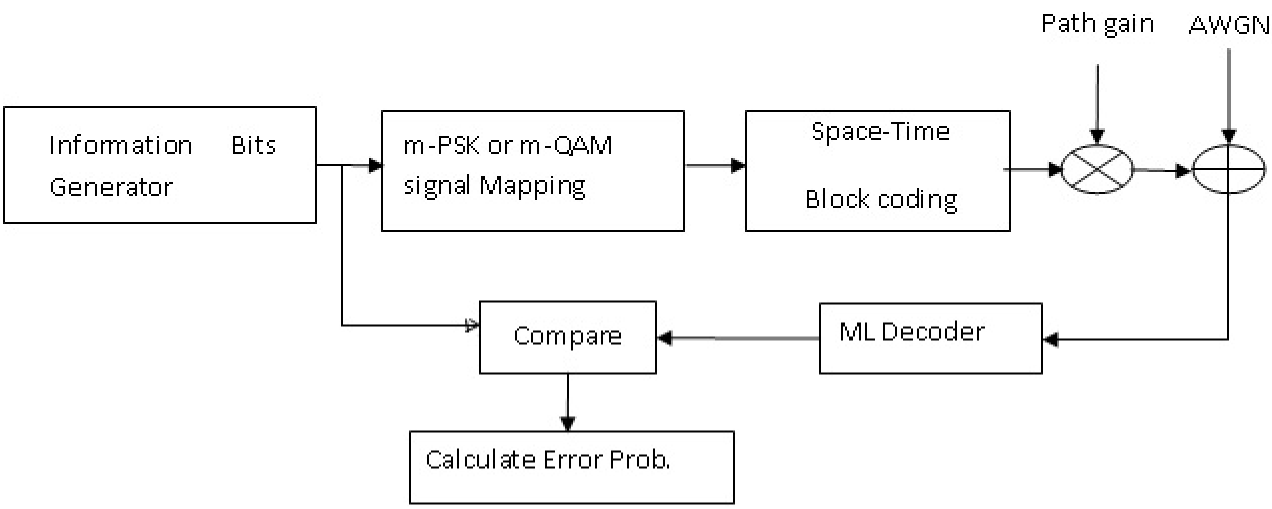

Figure 4.1: Block diagram of simulation

4.2.2 M-PSK Mapping

M-PSK Mapping BPSK, 4-PSK, 8-PSK, 16-PSK modulations have been used. The bit sequence is divided into symbols which are composed of several bits, e.g., 2 bits represents one symbol for Q-PSK, and then each symbol is been mapped to the constellation points using Gray-Coded ordering. The gray coded symbol is changed to the complex output form.

4.2.3 Space -Time Block Coding

Space -Time Block Coding generates Alamouti's encoder matrix (2×1, 2×2, 2×3, 2×4) and transmit to the channel. Generation of Alamouti's matrix is explained briefly in section 2.4.

4.2.4 Channel

Channel is considered as Rayleigh flat fading channel. The dominant factor is the path gain from each transmit antenna to each receive antenna. The path gain is the independent complex Gaussian random variables with variance 0.7 per real and imaginary parts. Additionally, the usual additive white Gaussian noise corrupts the signal. The AWGN and the Rayleigh fading channel are generated using

$$n_j = randn(1, N) + j * randn(1, N))$$

$$h_j = 0.7 * ((randn(1, N) + j * randn(1, N))$$

And SUI channels are developed as per their parameter. All parameters and their physical scenario are briefly discussed in chapter 3 and in table 3.1.

4.2.5 Maximum Likelihood (ML) Decoding

ML Decoding algorithm is been used to decode the received complex signal. Decoding algorithm and equations are given in section 2.5.4.

4.2.6 Bit Error Rate

Bit Error Rate of the system is been computed as the ratio of incorrect data bits divided by the total number of data bits transmitted and the probability of bit error rate can be calculated as following equation:

$$P_B = Q\left(\sqrt{2\frac{E_b}{N_0}}\right) \tag{4.1}$$

Where P_B = probability of bit error rate for BPSK modulation

$$P_E = Q\left(\sqrt{2\frac{E_s}{N_0}}\sin\frac{\pi}{M}\right) \tag{4.2}$$

Where P_E = probability of symbol error rate for MPSK modulation

$$P_B = \frac{P_E}{\log_2 M} \tag{4.3}$$

The above equation shows relation between probability of bit error rate and symbol error rate.

4.2.7 Simulation Flowchart of Transmitter

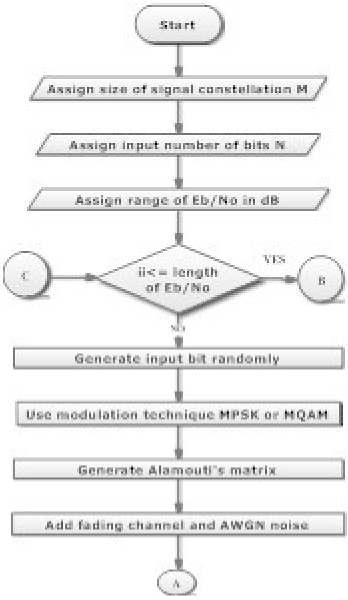

Figure 4.2: Flow chart of Transmitter

Above figure 4.1 shows the simulation setup of transmitter which is described in section 4.2

4.2.8 Simulation Flowchart of Receiver

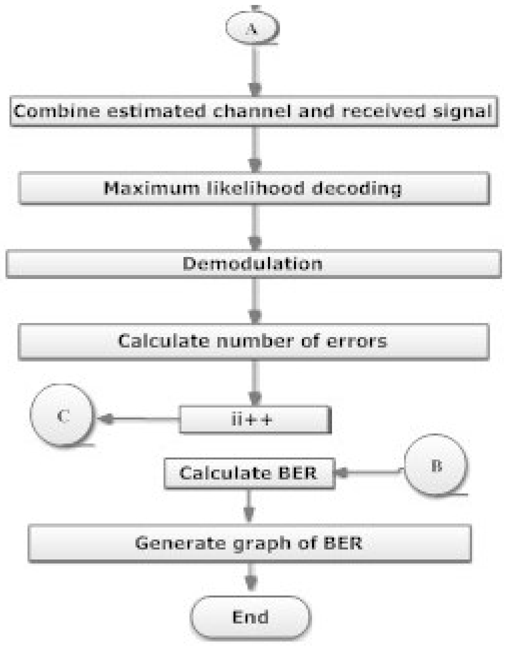

Figure 4.3: Flow chart of Receiver

Figure 4.3 shows the simulation set up of the receiver.

Chapter 5

Simulation Results and Analysis

5.1 Introduction

The following simulation results provide the performance of space-time block codes. Various modulation techniques have been tested for a comparative analysis. The results are based on bit error rate (BER) performance over a range of E_b/N_0.

5.2 Result analysis for MISO with all possible modulation schemes

Figure 5.1 shows BER for transmission of 1bit/sec/Hz for the following cases: Uncoded case which uses one transmit antenna and one receive antenna, coded case which uses two transmit antennas and one receive antenna. MPSK and MQAM constellations are used. Where the bit error rate improvement over the uncoded case in percentage is computed as below:

$$\left| \frac{BER_{uncoded} - BER_{(nTx,nRx)}}{BER_{uncoded}} \right| X100\% \tag{5.1}$$

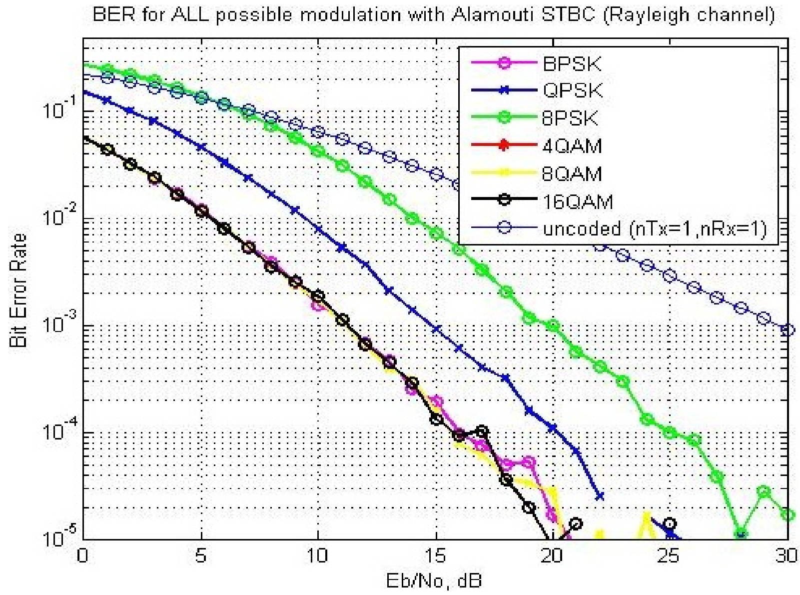

Figure 5.1: Bit error rate vs. E_b/N_0 for MISO with all possible modulation schemes

Sr. No.	Modulation Scheme	Uncoded BER	2Tx, 1Rx BER	Improvement BER over un-coded
1	BPSK	0.0097	0.0002	97.67%
2	QPSK	0.0097	0.0015	84.74%
3	8PSK	0.0158	0.0106	33.28%
4	4QAM	0.0097	0.0003	96.87%
5	8QAM	0.0163	0.00031	98.06%
6	16QAM	0.0185	0.00027	98.51%

Table 5.1: Result analysis of M-PSK and M-QAM for MISO STBC(15db)

Table 5.1 shows summary and performance of BER over uncoded signal for all possible modulation techniques. This is shown in above table. As per simulation results 16QAM provides higher BER improvement over uncoded signal as well as over other modulation schemes. All BER performance is calculated at 15 dB of E_b/N_0.

5.3 Simulation result analysis for MISO with all SUI channels using BPSK modulation

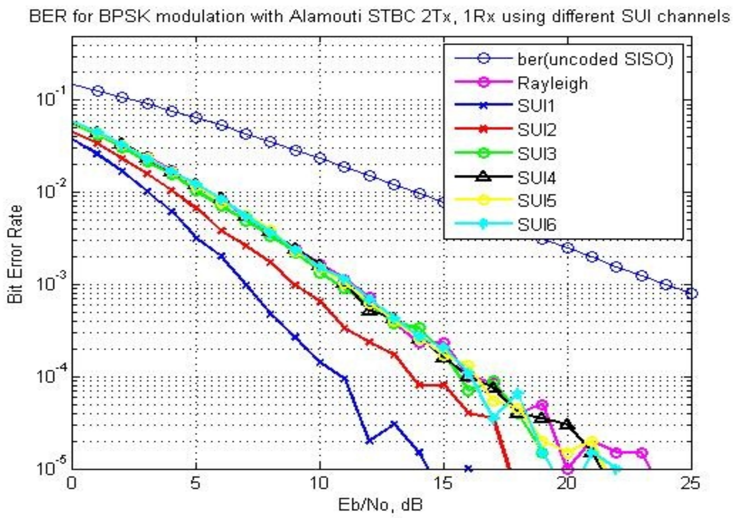

Figure 5.2: BER for MISO with all SUI channel using BPSK modulation scheme

Channel Type	SUI-6	SUI-5	SUI-4	SUI-3	SUI-2	SUI-1	Rayleigh
BER	0.0014	0.0014	0.0013	0.0013	5.55e-4	1.55e-4	0.0013
Imp. over SUI-6	-	0.0%	7.14%	7.14%	60.36%	85.71%	7.14%
Imp. over SUI-5	-	-	7.14%	7.14%	60.36%	85.71%	7.14%
Imp. over SUI-4	-	-	-	0.0%	57.31%	84.62%	0.0%
Imp. over SUI-3	-	-	-	-	57.31%	84.62%	0.0%
Imp. over SUI-2	-	-	-	-	-	72.07%	-
Imp. over Ray leigh	-	-	7.14%	7.14%	60.36%	85.71%	-

Table 5.2: Simulation result analysis for MISO with all SUI channels using BPSK modulation (10db)

5.4 Simulation result analysis for MISO with all SUI channels using QPSK modulation

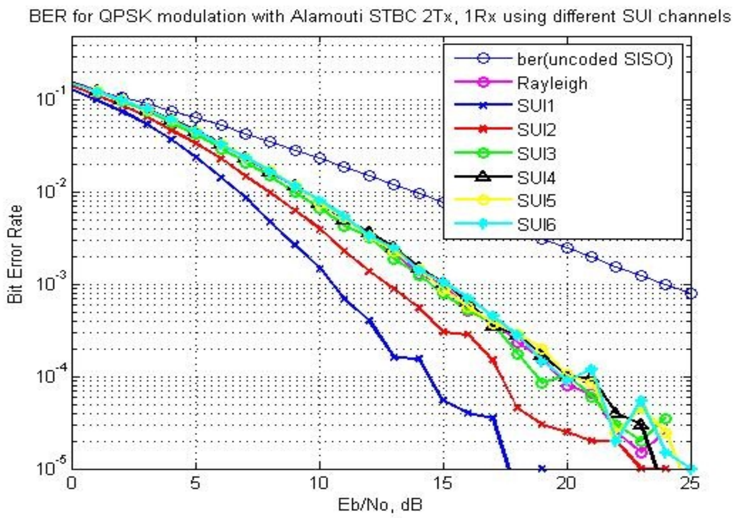

Figure 5.3: BER for MISO with all SUI channel using QPSK modulation scheme

Channel Type	SUI-6	SUI-5	SUI-4	SUI-3	SUI-2	SUI-1	Rayleigh
BER	0.0014	0.0014	0.0013	0.0013	5.55e-4	1.55e-4	0.0013
Imp. over SUI-6	-	0.0%	7.14%	7.14%	60.36%	85.71%	7.14%
Imp. over SUI-5	-	-	7.14%	7.14%	60.36%	85.71%	7.14%
Imp. over SUI-4	-	-	-	0.0%	57.31%	84.62%	0.0%
Imp. over SUI-3	-	-	-	-	57.31%	84.62%	0.0%
Imp. over SUI-2	-	-	-	-	-	72.07%	-
Imp. over Ray leigh	-	-	7.14%	7.14%	60.36%	85.71%	-

Table 5.3: Simulation result analysis for MISO with all SUI channels using QPSK modulation (15db)

5.5 Simulation result analysis for MISO with all SUI channels using 8PSK modulation

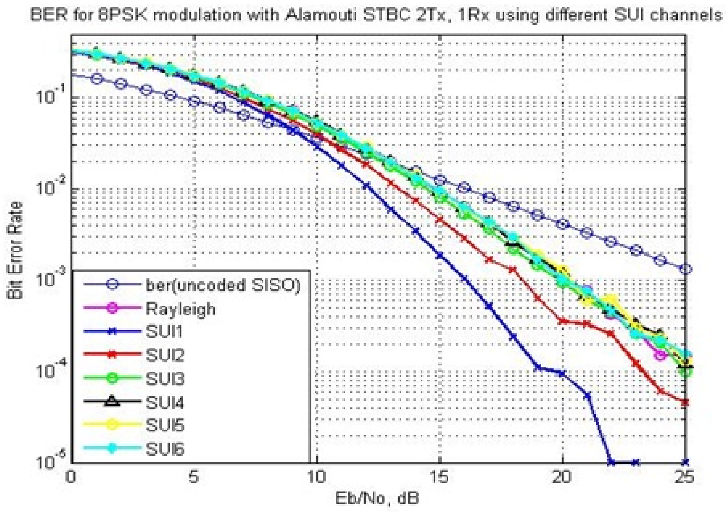

Figure 5.4: BER for MISO with all SUI channel using 8PSK modulation scheme

Channel Type	SUI-6	SUI-5	SUI-4	SUI-3	SUI-2	SUI-1	Rayleigh
BER	0.0019	0.0019	0.0018	0.0014	6.45e-4	1.45e-4	0.0019
Imp. over SUI-6	-	0.0%	5.26%	26.32%	68.42%	94.74%	0.0%
Imp. over SUI-5	-	-	5.26%	26.32%	68.42%	94.74%	0.0%
Imp. over SUI-4	-	-	-	22.22%	66.67%	94.44%	-
Imp. over SUI-3	-	-	-	-	53.93%	92.86%	-
Imp. over SUI-2	-	-	-	-	-	77.52%	-
Imp. over Ray leigh	-	-	5.26%	26.32%	68.42%	94.74%	-

Table 5.4: Simulation result analysis for MISO with all SUI channels using 8PSK modulation 20db)

5.6 Simulation result analysis for MISO with all SUI channels using 16PSK modulation

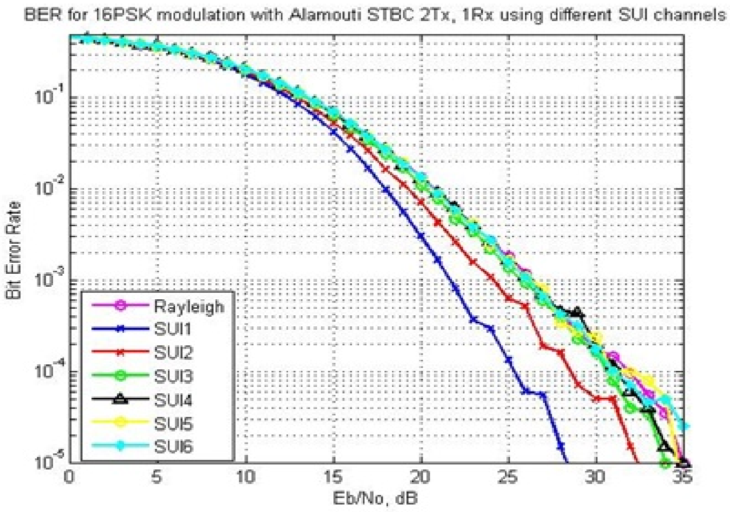

Figure 5.5: BER for MISO with all SUI channel using 16PSK modulation scheme

Channel Type	**SUI-6**	**SUI-5**	**SUI-4**	**SUI-3**	**SUI-2**	**SUI-1**	**Rayleigh**
BER	0.0023	0.0023	0.0021	0.0021	9.9e-4	1.95e-4	0.0026
Imp. over SUI-6	-	0.0%	8.70%	8.70%	56.52%	91.30%	-
Imp. over SUI-5	-	-	8.70%	8.70%	56.52%	91.30%	-
Imp. over SUI-4	-	-	-	0.0%	52.38%	90.48%	-
Imp. over SUI-3	-	-	-	-	52.38%	90.48%	-
Imp. over SUI-2	-	-	-	-	-	80.30%	-
Imp. over Ray leigh	11.54%	11.54%	19.23%	19.23%	61.54%	92.31%	-

Table 5.5: Simulation result analysis for MISO with all SUI channels using 16PSK modulation 25db)

5.7 Simulation result analysis for MISO with all SUI channels using 4QAM modulation

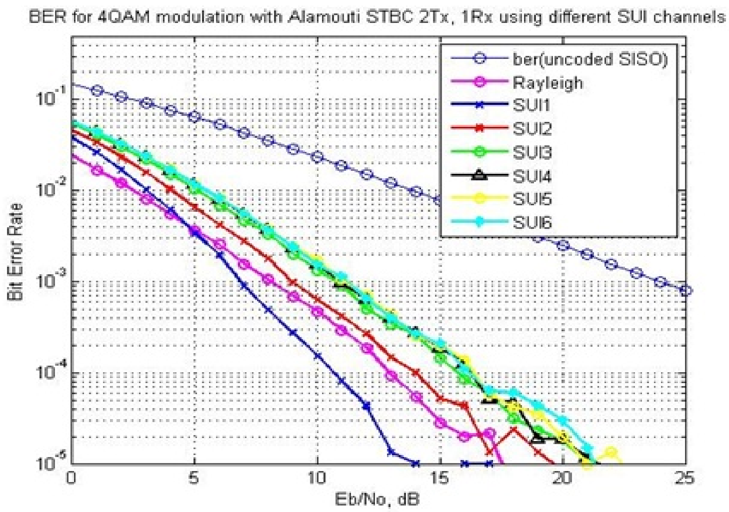

Figure 5.6: BER for MISO with all SUI channel using 4QAM modulation scheme

Channel Type	SUI-6	SUI-5	SUI-4	SUI-3	SUI-2	SUI-1	Rayleigh
BER	0.0024	0.0024	0.0024	0.0020	9.766e-4	2.766e-4	6.916e-4
Imp. over SUI-6	-	0.0%	0.0%	16.67%	59.31%	88.47%	71.18%
Imp. over SUI-5	-	-	0.0%	16.67%	59.31%	88.47%	71.18%
Imp. over SUI-4	-	-	-	16.67%	59.31%	88.47%	71.18%
Imp. over SUI-3	-	-	-	-	51.17%	86.17%	65.42%
Imp. over SUI-2	-	-	-	-	-	71.67%	29.18%
Imp. over Ray leigh	-	-	-	-	-	60%	-

Table 5.6: Simulation result analysis for MISO with all SUI channels using 4QAM modulation 10db)

5.8 Simulation result analysis for MISO with all SUI channels using 16QAM modulation

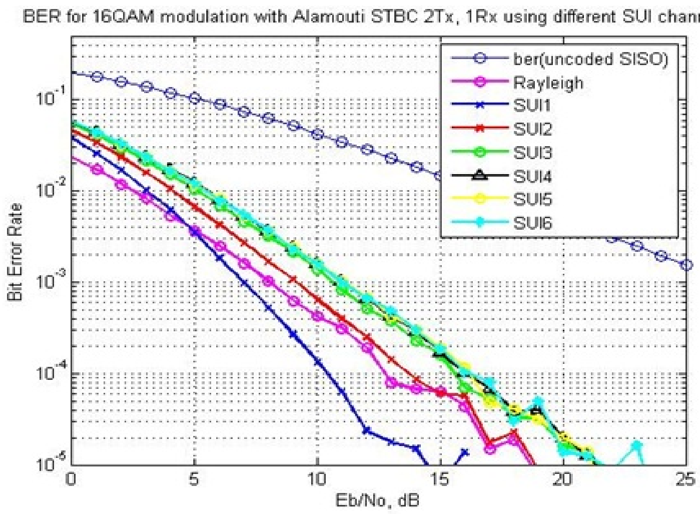

Figure 5.7: BER for MISO with all SUI channel using 16QAM modulation scheme

Channel Type	**SUI-6**	**SUI-5**	**SUI-4**	**SUI-3**	**SUI-2**	**SUI-1**	**Rayleigh**
BER	0.0024	0.0024	0.0024	0.0020	0.0011	2.93e-4	6.91e-4
Imp. over SUI-6	-	0.0%	0.0%	16.67%	54.17%	87.78%	71.18%
Imp. over SUI-5	-	-	0.0%	16.67%	54.17%	87.78%	71.18%
Imp. over SUI-4	-	-	-	16.67%	54.17%	87.78%	71.18%
Imp. over SUI-3	-	-	-	-	51.17%	85.33%	65.42%
Imp. over SUI-2	-	-	-	-	-	73.33%	37.12%
Imp. over Ray leigh	-	-	-	-	-	57.59%	-

Table 5.7: Simulation result analysis for MISO with all SUI channels using 16QAM modulation 10db)

5.9 Simulation result analysis for 2Tx, 2Rx (MIM0) with all SUI channels using BPSK modulation

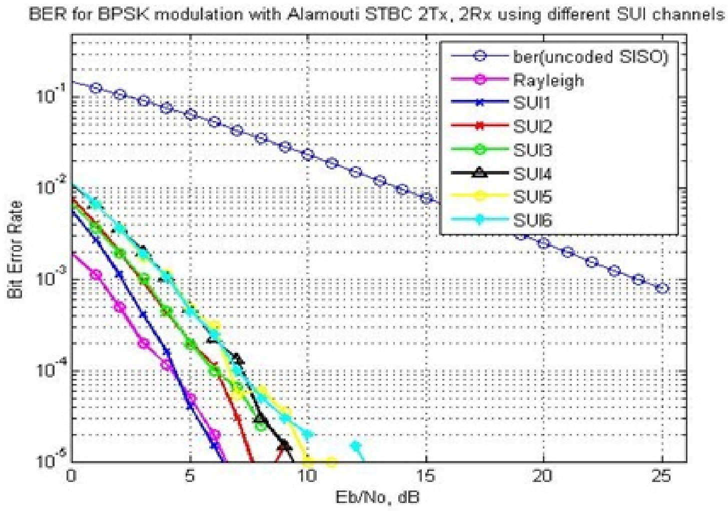

Figure 5.8: BER for MIMO (2Tx, 2Rx) with all SUI channel using BPSK modulation

Channel Type	SUI-6	SUI-5	SUI-4	SUI-3	SUI-2	SUI-1	Rayleigh
BER	0.0011	0.0011	0.0011	4.5e-4	4.25e-4	1.6e-4	1.15e-4
Imp. over SUI-6	-	0.0%	0.0%	59.09%	61.36%	85.45%	89.55%
Imp. over SUI-5	-	-	0.0%	59.09%	61.36%	85.45%	89.55%
Imp. over SUI-4	-	-	-	59.09%	61.36%	85.45%	89.55%
Imp. over SUI-3	-	-	-	-	5.56%	64.44%	74.44%
Imp. over SUI-2	-	-	-	-	-	62.35%	72.94%
Imp. over SUI-1	-	-	-	-	-	-	28.13%

Table 5.8: Simulation result analysis for MIMO (2Tx, 2Rx) with all SUI channels using BPSK modulation (5db)

5.10 Simulation result analysis for 2Tx, 2Rx (MIM0) with all SUI channels using QPSK modulation

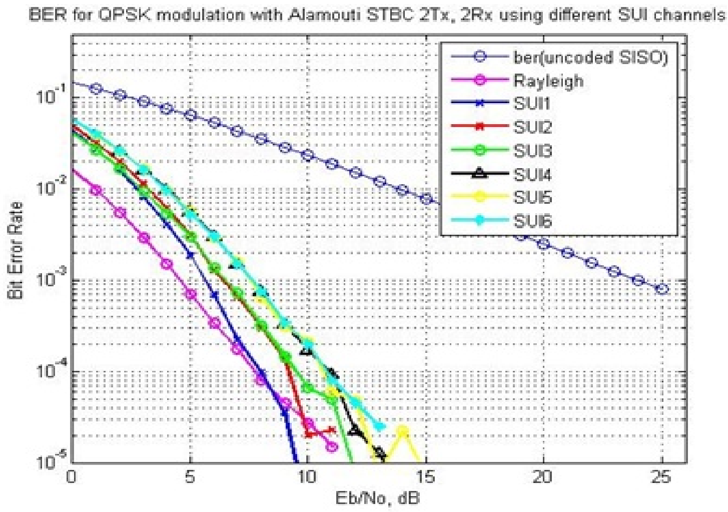

Figure 5.9: BER for MIMO (2Tx, 2Rx) with all SUI channel using QPSK modulation

Channel Type	**SUI-6**	**SUI-5**	**SUI-4**	**SUI-3**	**SUI-2**	**SUI-1**	**Rayleigh**
BER	0.0097	0.0096	0.0090	0.0080	0.0061	0.0040	0.0015
Imp. over SUI-6	-	1.03%	7.22%	17.53%	37.11%	58.76%	84.54%
Imp. over SUI-5	-	-	6.25%	16.67%	36.46%	58.33%	84.38%
Imp. over SUI-4	-	-	-	11.11%	32.22%	55.56%	83.33%
Imp. over SUI-3	-	-	-	-	23.75%	50.00%	81.25%
Imp. over SUI-2	-	-	-	-	-	34.43%	75.41%
Imp. over SUI-1	-	-	-	-	-	-	62.50%

Table 5.9: Simulation result analysis for MIMO (2Tx, 2Rx) with all SUI channels using QPSK modulation (5db)

5.11 Simulation result analysis for 2Tx, 2Rx (MIM0) with all SUI channels using 8PSK modulation

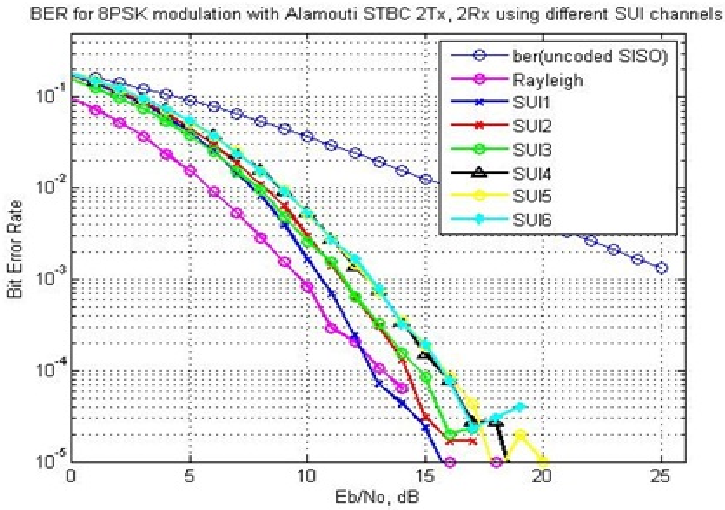

Figure 5.10: BER for MIMO (2Tx, 2Rx) with all SUI channel using 8PSK modulation

Channel Type	**SUI-6**	**SUI-5**	**SUI-4**	**SUI-3**	**SUI-2**	**SUI-1**	**Rayleigh**
BER	0.0097	0.0096	0.0090	0.0080	0.0061	0.0040	0.0015
Imp. over SUI-6	-	1.03%	7.22%	17.53%	37.11%	58.76%	84.54%
Imp. over SUI-5	-	-	6.25%	16.67%	36.46%	58.33%	84.38%
Imp. over SUI-4	-	-	-	11.11%	32.22%	55.56%	83.33%
Imp. over SUI-3	-	-	-	-	23.75%	50.00%	81.25%
Imp. over SUI-2	-	-	-	-	-	34.43%	75.41%
Imp. over SUI-1	-	-	-	-	-	-	62.50%

Table 5.10: Simulation result analysis for MIMO (2Tx, 2Rx) with all SUI channels using 8PSK modulation (10db)

5.12 Simulation result analysis for 2Tx, 2Rx with all SUI channels using 16PSK modulation

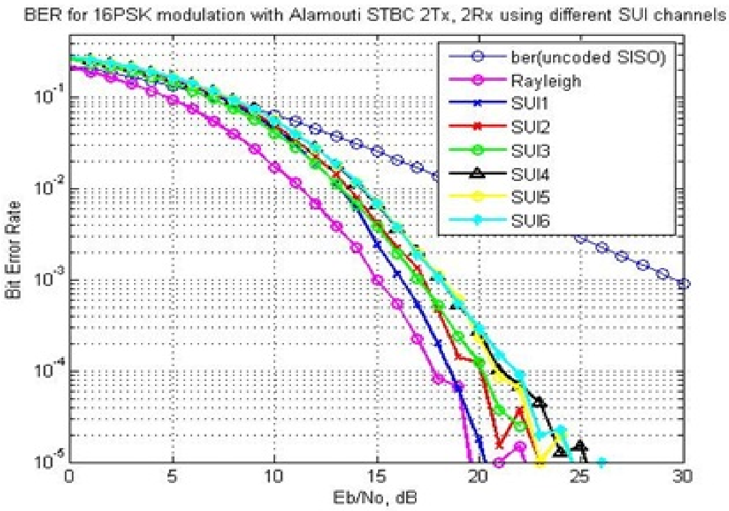

Figure 5.11: BER for 2Tx, 2Rx with all SUI channel using 16PSK modulation

Channel Type	**SUI-6**	**SUI-5**	**SUI-4**	**SUI-3**	**SUI-2**	**SUI-1**	**Rayleigh**
BER	0.0119	0.0119	0.0115	0.0067	0.0065	0.0061	0.0022
Imp. over SUI-6	-	0.0%	3.36%	43.70%	45.38%	48.74%	81.51%
Imp. over SUI-5	-	-	3.36%	43.70%	45.38%	48.74%	81.51%
Imp. over SUI-4	-	-	-	41.74%	43.48%	46.96%	80.87%
Imp. over SUI-3	-	-	-	-	2.99%	8.96%	67.16%
Imp. over SUI-2	-	-	-	-	-	6.15%	66.15%
Imp. over SUI-1	-	-	-	-	-	-	63.93%

Table 5.11: Simulation result analysis for MIMO (2Tx, 2Rx) with all SUI channels using 16PSK modulation (15db)

5.13 Simulation result analysis for 2Tx, 2Rx with all SUI channels using 16QAM modulation

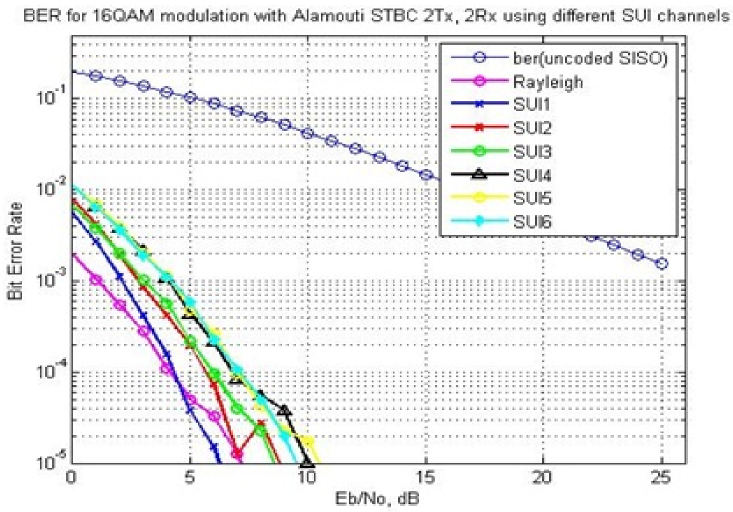

Figure 5.12: BER for 2Tx, 2Rx with all SUI channel using 16QAM modulation

Channel Type	**SUI-6**	**SUI-5**	**SUI-4**	**SUI-3**	**SUI-2**	**SUI-1**	**Rayleigh**
BER	0.001	0.0010	0.001	4.77e-4	4.17e-4	1.27e-4	9.5e-5
Imp. over SUI-6	-	0.0%	0.0%	52.25%	58.25%	87.25%	90.50%
Imp. over SUI-5	-	-	0.0%	52.25%	58.25%	87.25%	90.50%
Imp. over SUI-4	-	-	-	52.25%	58.25%	87.25%	90.50%
Imp. over SUI-3	-	-	-	-	2.99%	73.30%	80.10%
Imp. over SUI-2	-	-	-	-	-	69.46%	77.25%
Imp. over SUI-1	-	-	-	-	-	-	25.49%

Table 5.12: Simulation result analysis for MIMO (2Tx, 2Rx) with all SUI channels using 16QAM modulation (5db)

5.14 Simulation result analysis for 2Tx, 3Rx (MIM0) with all SUI channels using BPSK modulation

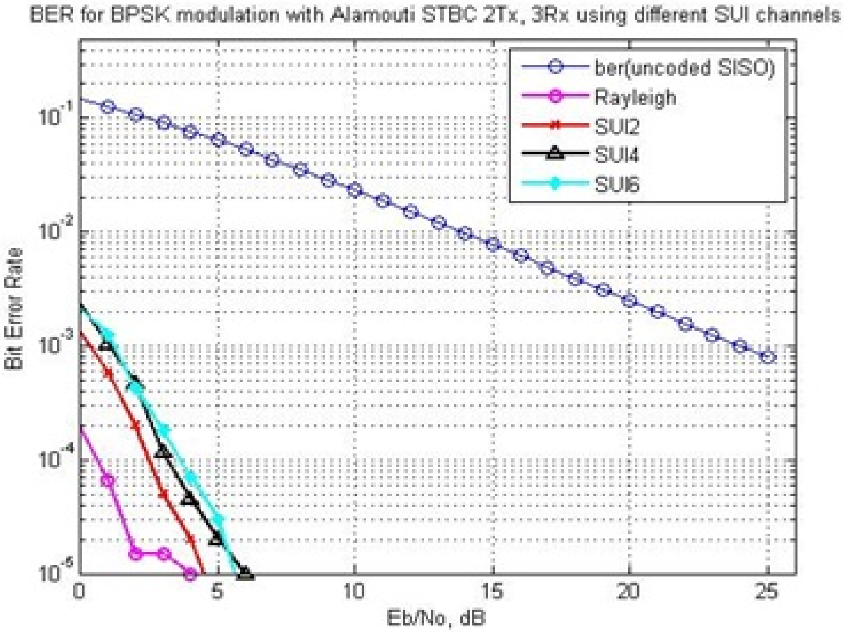

Figure 5.13: BER for 2Tx, 3Rx with all SUI channel using BPSK modulation

Channel Type	**SUI-6**	**SUI-4**	**SUI-2**	**Rayleigh**
BER	4.25e-4	3.25e-4	1.5e-4	2.5e-5
Imp. over SUI-6	-	23.53%	64.71%	94.12%
Imp. over SUI-4	-	-	53.85%	92.31%
Imp. over SUI-2	-	-	-	83.33%

Table 5.13: Simulation result analysis for MIMO (2Tx, 3Rx) with all SUI channels using BPSK modulation (3db)

5.15 Simulation result analysis for 2Tx, 3Rx (MIM0) with all SUI channels using QPSK modulation

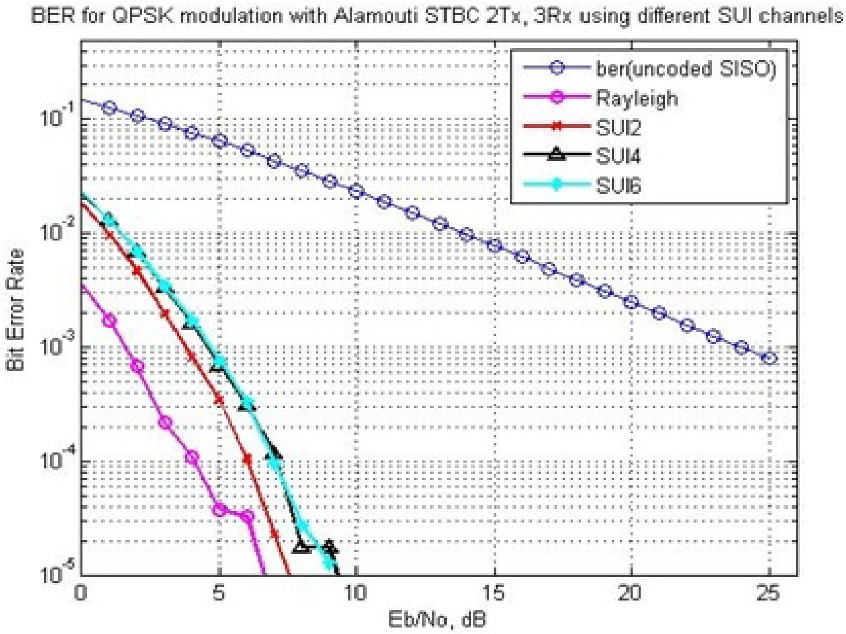

Figure 5.14: BER for 2Tx, 3Rx with all SUI channel using QPSK modulation

Channel Type	**SUI-6**	**SUI-4**	**SUI-2**	**Rayleigh**
BER	0.0015	0.001	7.77e-4	9.5e-5
Imp. over SUI-6	-	33.33%	48.17%	93.67%
Imp. over SUI-4	-	-	22.25%	90.50%
Imp. over SUI-2	-	-	-	87.78%

Table 5.14: Simulation result analysis for MIMO (2Tx, 3Rx) with all SUI channels using QPSK modulation (5db)

5.16 Simulation result analysis for 2Tx, 3Rx (MIM0) with all SUI channels using 8PSK modulation

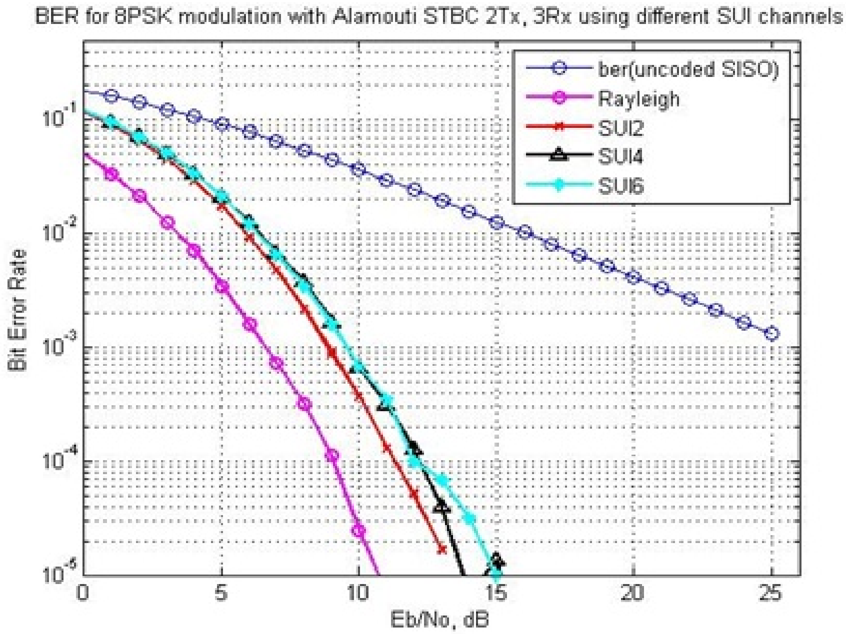

Figure 5.15: BER for 2Tx, 3Rx with all SUI channel using 8PSK modulation scheme

Channel Type	**SUI-6**	**SUI-4**	**SUI-2**	**Rayleigh**
BER	0.0016	0.001	8.83e-4	1.08e-4
Imp. over SUI-6	-	37.50%	44.79%	93.23%
Imp. over SUI-4	-	-	11.67%	89.17%
Imp. over SUI-2	-	-	-	89.58%

Table 5.15: Simulation result analysis for MIMO (2Tx, 3Rx) with all SUI channels using 8PSK modulation (10db)

5.17 Simulation result analysis for 2Tx, 3Rx (MIM0) with all SUI channels using 16PSK modulation

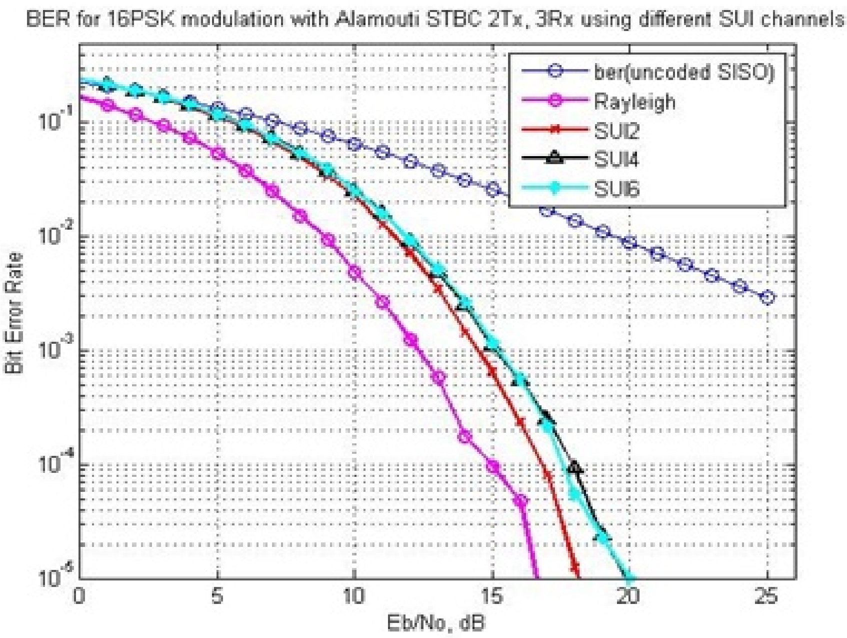

Figure 5.16: BER for 2Tx, 3Rx with all SUI channel using 16PSK modulation scheme

Channel Type	SUI-6	SUI-4	SUI-2	Rayleigh
BER	0.0026	0.0025	0.0014	1.75e-4
Imp. over SUI-6	-	3.85%	46.15%	93.27%
Imp. over SUI-4	-	-	44.00%	93.00%
Imp. over SUI-2	-	-	-	87.50%

Table 5.16: Simulation result analysis for MIMO (2Tx, 3Rx) with all SUI channels using 16PSK modulation (15db)

5.18 Simulation result analysis for 2Tx, 3Rx (MIM0) with all SUI channels using 16QAM modulation

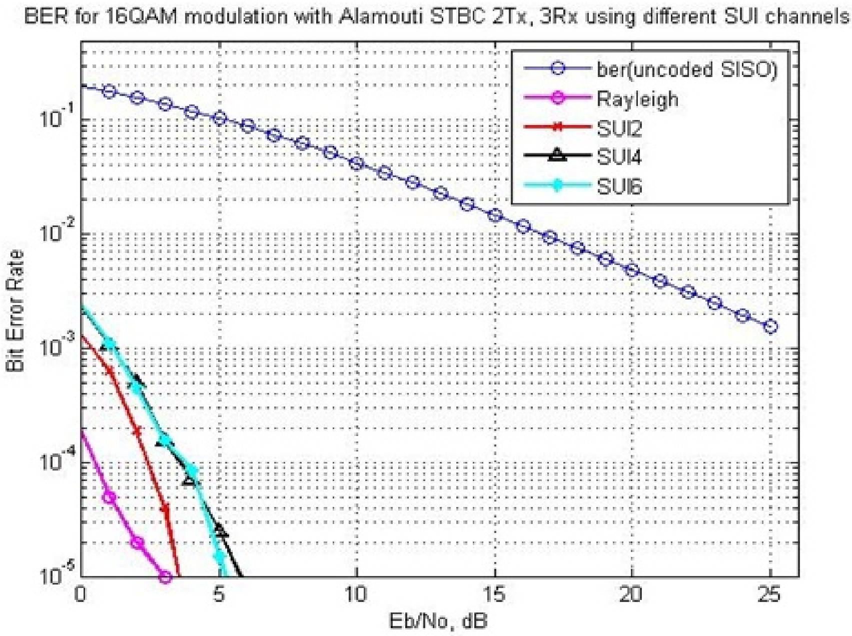

Figure 5.17: BER for 2Tx, 3Rx with all SUI channel using 16QAM modulation

Channel Type	**SUI-6**	**SUI-4**	**SUI-2**	**Rayleigh**
BER	5.10e-4	3.90e-4	1.60e-4	1.66e-5
Imp. over SUI-6	-	23.53%	68.63%	96.73%
Imp. over SUI-4	-	-	58.97%	95.73%
Imp. over SUI-2	-	-	-	89.58%

Table 5.17: Simulation result analysis for MIMO (2Tx, 3Rx) with all SUI channels using 16QAM modulation (3db)

5.19 Simulation result analysis for 2Tx, 4Rx (MIM0) with all SUI channels using QPSK modulation

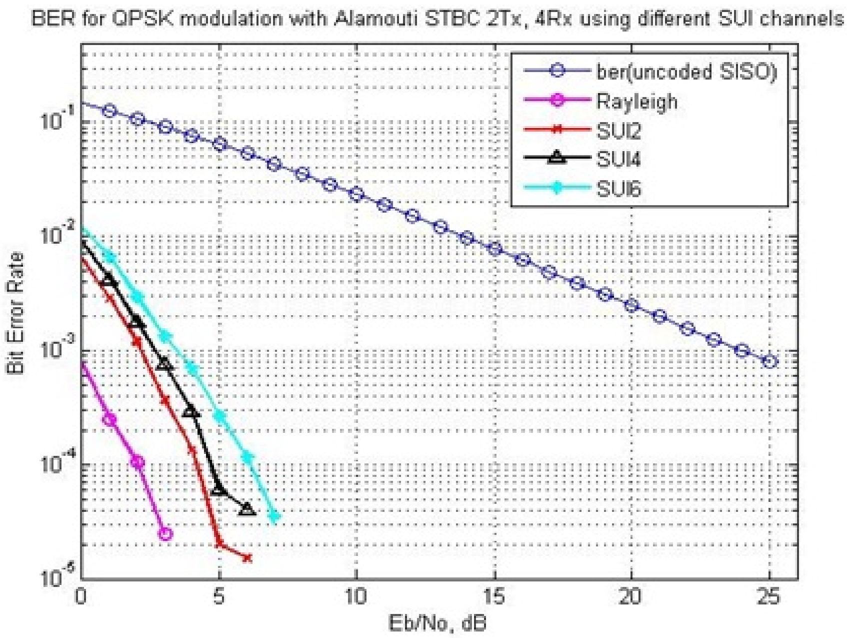

Figure 5.18: BER for 2Tx, 4Rx with all SUI channel using QPSK modulation

Channel Type	**SUI-6**	**SUI-4**	**SUI-2**	**Rayleigh**
BER	0.0031	0.0019	0.0010	1.30e-4
Imp. over SUI-6	-	38.71%	67.74%	95.81%
Imp. over SUI-4	-	-	47.37%	93.16%
Imp. over SUI-2	-	-	-	87.00%

Table 5.18: Simulation result analysis for MIMO (2Tx, 4Rx) with all SUI channels using QPSK modulation (3db)

5.20 Simulation result analysis for 2Tx, 4Rx (MIM0) with all SUI channels using 8PSK modulation

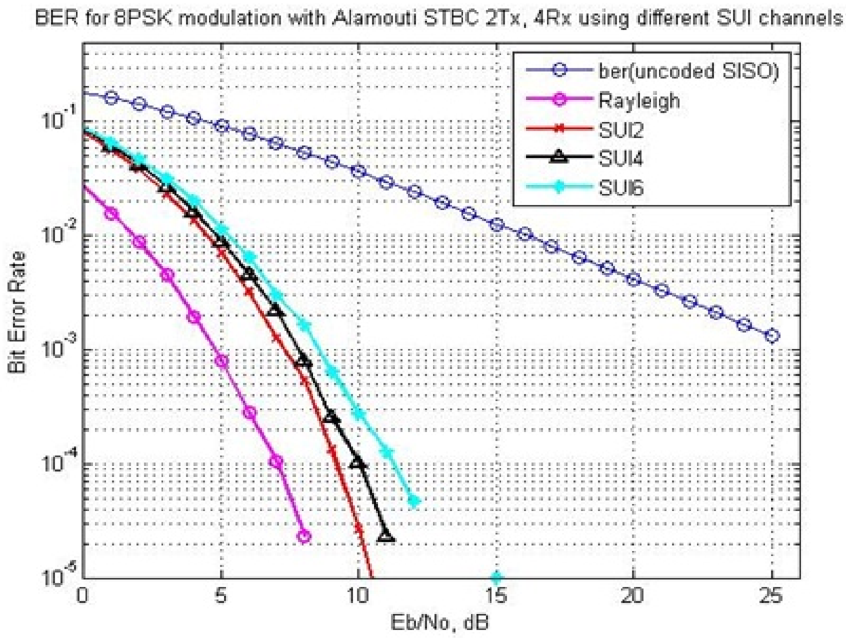

Figure 5.19: BER for 2Tx, 4Rx with all SUI channel using 8PSK modulation scheme

Channel Type	SUI-6	SUI-4	SUI-2	Rayleigh
BER	0.0065	0.0046	0.0032	2.83e-4
Imp. over SUI-6	-	29.23%	50.77%	95.64%
Imp. over SUI-4	-	-	30.43%	93.84%
Imp. over SUI-2	-	-	-	91.15%

Table 5.19: Simulation result analysis for MIMO (2Tx, 4Rx) with all SUI channels using 8PSK modulation (5db)

5.21 Simulation result analysis for 2Tx, 4Rx (MIM0) with all SUI channels using 16PSK modulation

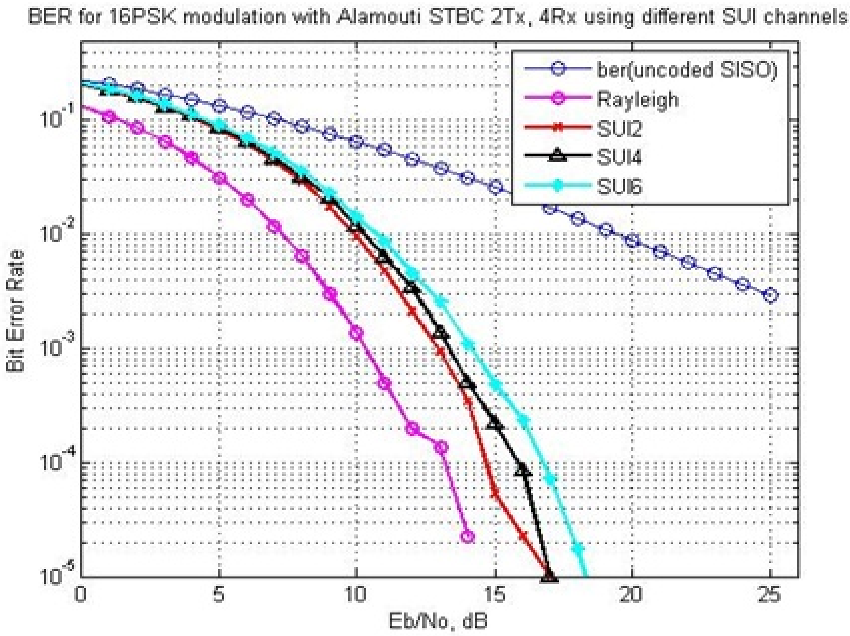

Figure 5.20: BER for 2Tx, 4Rx with all SUI channel using 16PSK modulation scheme

Channel Type	SUI-6	SUI-4	SUI-2	Rayleigh
BER	0.0086	0.0063	0.0048	5.0e-4
Imp. over SUI-6	-	26.74%	44.19%	94.19%
Imp. over SUI-4	-	-	23.81%	92.06%
Imp. over SUI-2	-	-	-	89.58%

Table 5.20: Simulation result analysis for MIMO (2Tx, 4Rx) with all SUI channels using 16PSK modulation (12db)

5.22 Simulation result analysis for 2Tx, 4Rx (MIM0) with all SUI channels using 16QAM modulation

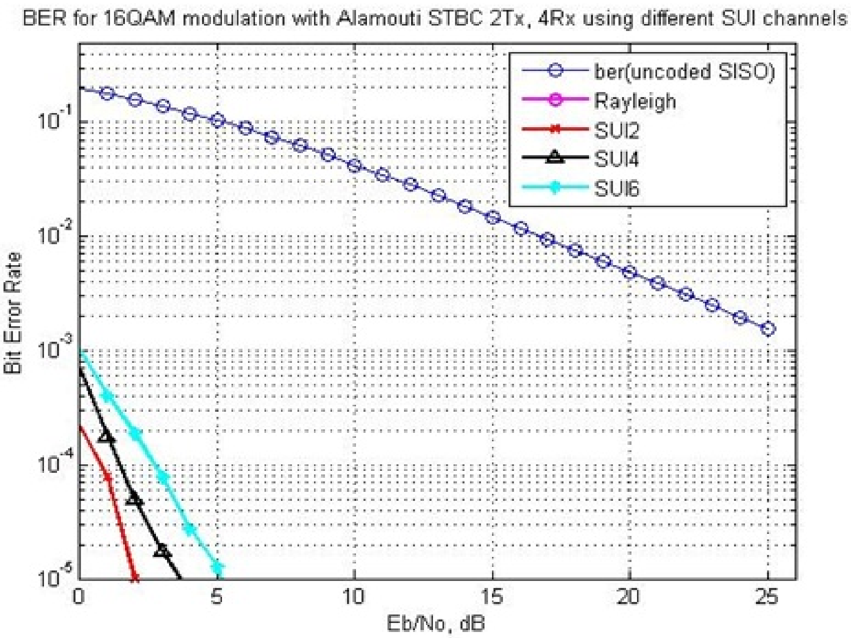

Figure 5.21: BER for 2Tx, 4Rx with all SUI channel using 16QAM modulation scheme

Channel Type	**SUI-6**	**SUI-4**	**SUI-2**
BER	1.87e-4	5.0e-5	1.0e-5
Imp. over SUI-6	-	73.33%	94.67%
Imp. over SUI-4	-	-	80.00%

Table 5.21: Simulation result analysis for MIMO (2Tx, 4Rx) with all SUI channels using 16QAM modulation (3db)

5.23 Simulation result for SISO, MISO and MIMO with SUI-1 channel using BPSK modulation

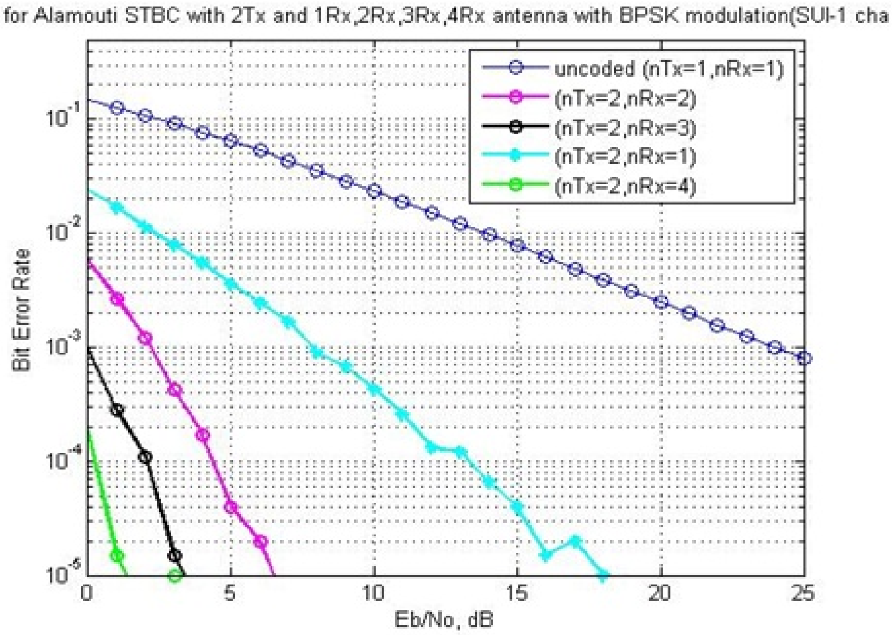

Figure 5.22: BER for SISO, MISO and MIMO with SUI-1 channel using BPSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1085	0.0113	0.0012	1.1e-4	5.e-6
Imp. over SISO	-	89.59%	98.89%	99.90%	99.99%
Imp. over (2Tx,1Rx)	-	-	89.38%	99.03%	99.96%
Imp. over (2Tx,2Rx)	-	-	-	90.38%	99.58%
Imp. over (2Tx,3Rx)	-	-	-	-	95.45%

Table 5.22: Simulation result analysis for SISO, MISO, MIMO with SUI-1 channel using BPSK modulation (3db)

5.24 Simulation result for SISO, MISO and MIMO with SUI-1 channels using QPSK modulation

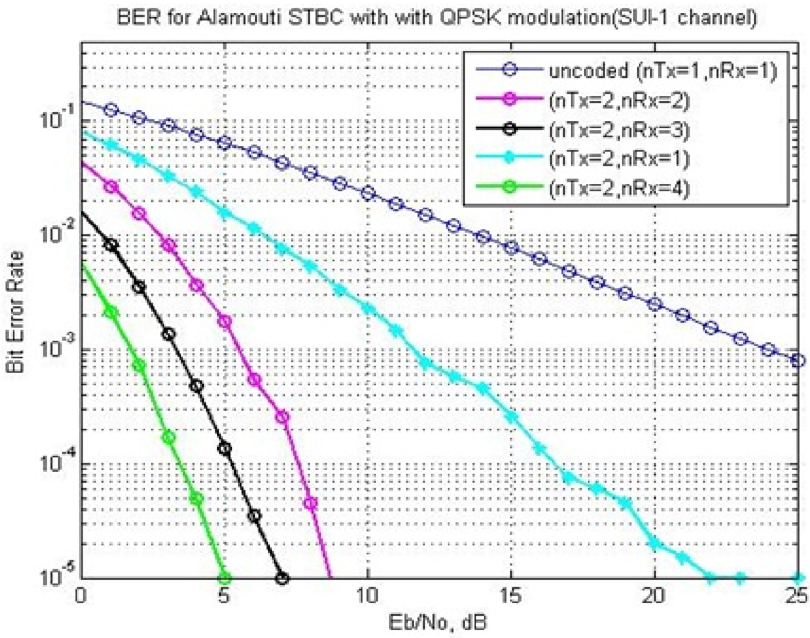

Figure 5.23: BER for SISO, MISO and MIMO with SUI-1 channel using QPSK

Diversity Type	SISO	2Tx,1Rx	2Tx,2Rx	2Tx,3Rx	2Tx,4Rx
BER	0.0771	0.0240	0.0036	4.75e-4	5.0e-5
Imp. over SISO	-	68.87%	95.33%	99.38%	99.94%
Imp. over (2Tx,1Rx)	-	-	85.00%	98.02%	99.79%
Imp. over (2Tx,2Rx)	-	-	-	86.81%	98.61%
Imp. over (2Tx,3Rx)	-	-	-	-	89.47%

Table 5.23: Simulation result analysis for SISO, MISO, MIMO with SUI-1 channel using QPSK modulation (5db)

5.25 Simulation result for SISO, MISO and MIMO with SUI-1 channels using 8PSK modulation

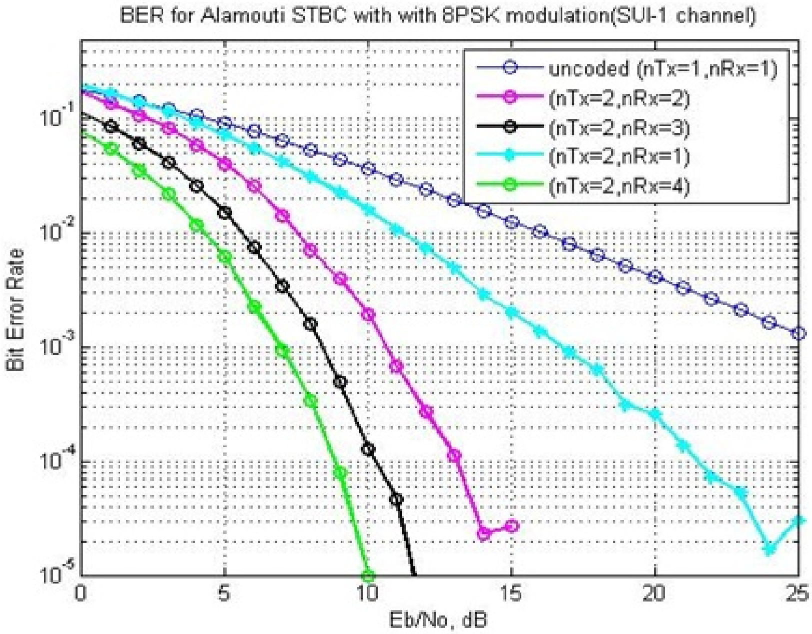

Figure 5.24: BER for SISO, MISO and MIMO with SUI-1 channel using 8PSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.0447	0.0227	0.0040	4.96e-4	8.0e-5
Imp. over SISO	-	49.22%	91.05%	98.89%	99.82%
Imp. over (2Tx,1Rx)	-	-	82.38%	97.81%	99.65%
Imp. over (2Tx,2Rx)	-	-	-	87.58%	98.00%
Imp. over (2Tx,3Rx)	-	-	-	-	83.89%

Table 5.24: Simulation result analysis for SISO, MISO, MIMO with SUI-1 channel using 8PSK modulation (10db)

5.26 Simulation result for SISO, MISO and MIMO with SUI-1 channels using 16PSK modulation

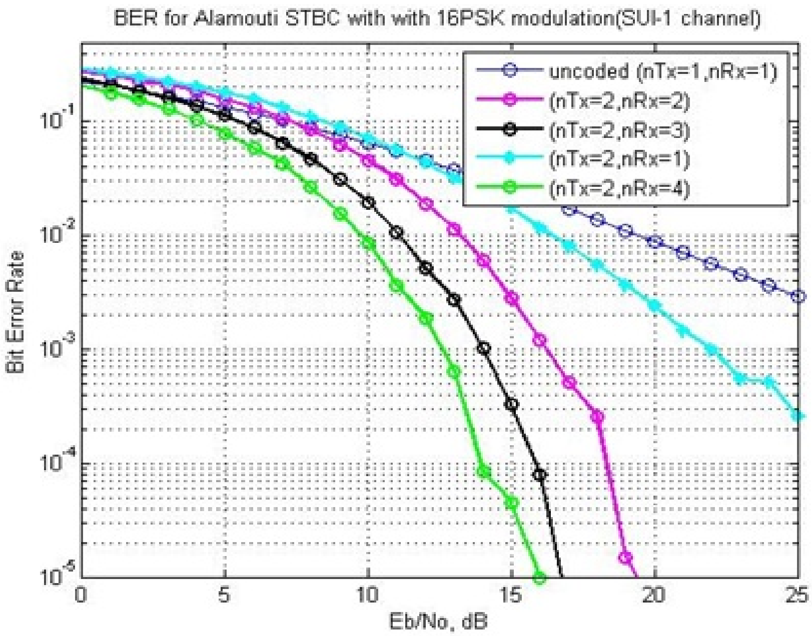

Figure 5.25: BER for SISO, MISO and MIMO with SUI-1 channel using 16PSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.0315	0.0233	0.0061	0.001	8.5e-5
Imp. over SISO	-	26.03%	80.63%	96.83%	99.73%
Imp. over (2Tx,1Rx)	-	-	73.82%	95.71%	99.64%
Imp. over (2Tx,2Rx)	-	-	-	83.61%	98.61%
Imp. over (2Tx,3Rx)	-	-	-	-	91.50%

Table 5.25: Simulation result analysis for SISO, MISO, MIMO with SUI-1 channel using 16PSK modulation (15db)

5.27 Simulation result for SISO, MISO and MIMO with SUI-1 channels using 4QAM modulation

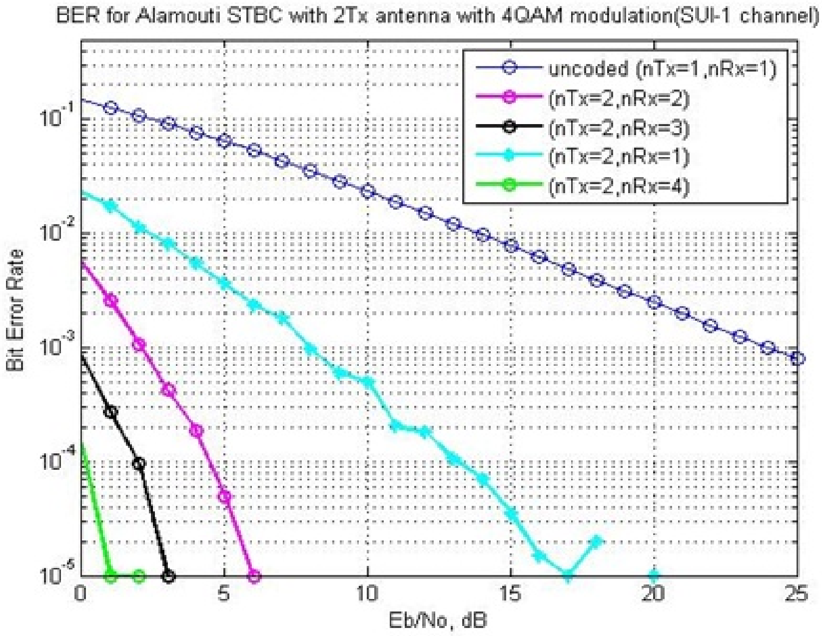

Figure 5.26: BER for SISO, MISO and MIMO with SUI-1 channel using 4QAM

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1085	0.0113	0.0011	9.5e-5	1.0e-5
Imp. over SISO	-	89.59%	98.99%	99.91%	99.99%
Imp. over (2Tx,1Rx)	-	-	90.27%	99.16%	99.91%
Imp. over (2Tx,2Rx)	-	-	-	91.36%	99.09%
Imp. over (2Tx,3Rx)	-	-	-	-	89.47%

Table 5.26: Simulation result analysis for SISO, MISO, MIMO with SUI-1 channel using 4QAM modulation (3db)

5.28 Simulation result for SISO, MISO and MIMO with SUI-1 channels using 16QAM modulation

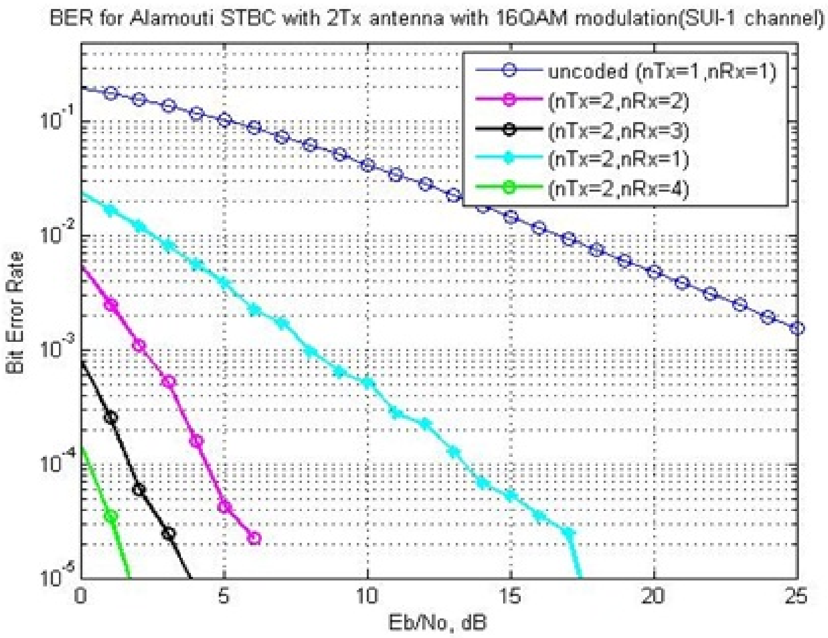

Figure 5.27: BER for SISO, MISO and MIMO with SUI-1 channel using 16QAM

Diversity Type	SISO	2Tx,1Rx	2Tx,2Rx	2Tx,3Rx	2Tx,4Rx
BER	0.1570	0.0121	0.0011	6.0e-5	5.0e-6
Imp. over SISO	-	92.29%	99.30%	99.96%	99.99%
Imp. over (2Tx,1Rx)	-	-	90.91%	99.50%	99.96%
Imp. over (2Tx,2Rx)	-	-	-	94.55%	99.55%
Imp. over (2Tx,3Rx)	-	-	-	-	91.67%

Table 5.27: Simulation result analysis for SISO, MISO, MIMO with SUI-1 channel using 16QAM modulation (3db)

5.29 Simulation result for SISO, MISO and MIMO with SUI-3 channels using BPSK modulation

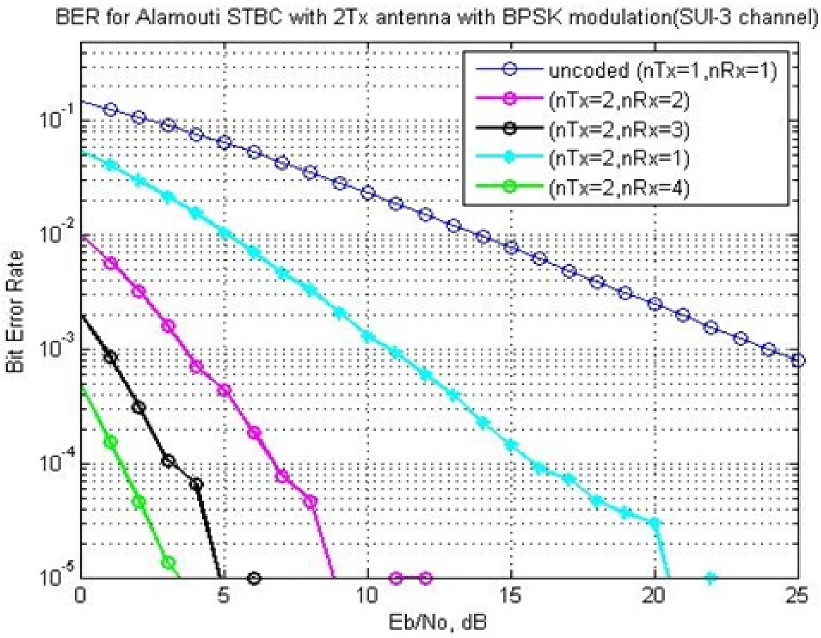

Figure 5.28: BER for SISO, MISO and MIMO with SUI-3 channel using BPSK

Diversity Type	SISO	2Tx,1Rx	2Tx,2Rx	2Tx,3Rx	2Tx,4Rx
BER	0.1085	0.0304	0.0032	3.5667e-4	6.0e-5
Imp. over SISO	-	71.98%	97.05%	99.67%	99.94%
Imp. over (2Tx,1Rx)	-	-	89.47%	98.83%	99.80%
Imp. over (2Tx,2Rx)	-	-	-	88.85%	98.12%
Imp. over (2Tx,3Rx)	-	-	-	-	83.18%

Table 5.28: Simulation result analysis for SISO, MISO, MIMO with SUI-3 channel using BPSK modulation (3db)

5.30 Simulation result for SISO, MISO and MIMO with SUI-3 channels using QPSK modulation

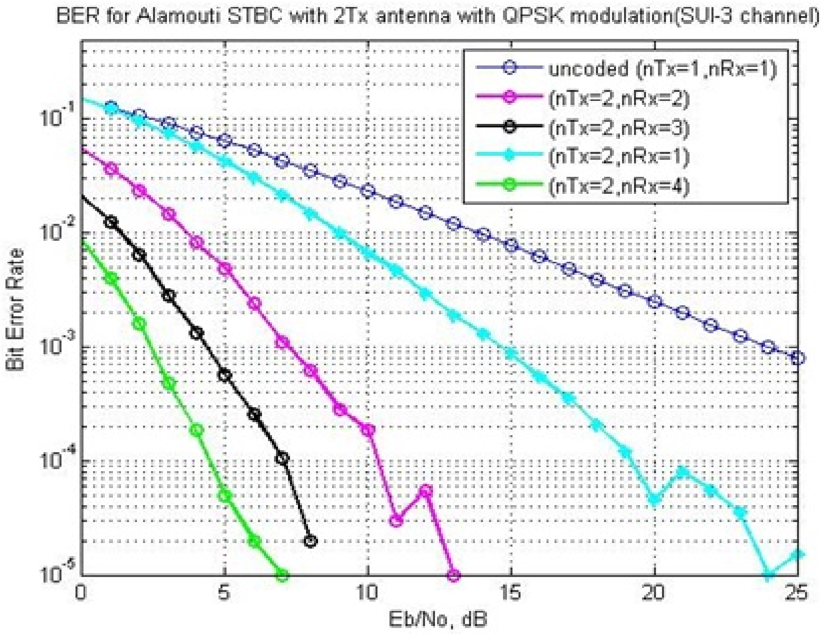

Figure 5.29: BER for SISO, MISO and MIMO with SUI-3 channel using QPSK

Diversity Type	SISO	2Tx,1Rx	2Tx,2Rx	2Tx,3Rx	2Tx,4Rx
BER	0.0771	0.0582	0.0085	0.0013	2.65e-4
Imp. over SISO	-	24.51%	88.98%	98.31%	99.66%
Imp. over (2Tx,1Rx)	-	-	85.40%	97.77%	99.54%
Imp. over (2Tx,2Rx)	-	-	-	84.71%	96.88%
Imp. over (2Tx,3Rx)	-	-	-	-	79.62%

Table 5.29: Simulation result analysis for SISO, MISO, MIMO with SUI-3 channel using QPSK modulation (5db)

5.31 Simulation result for SISO, MISO and MIMO with SUI-3 channels using 8PSK modulation

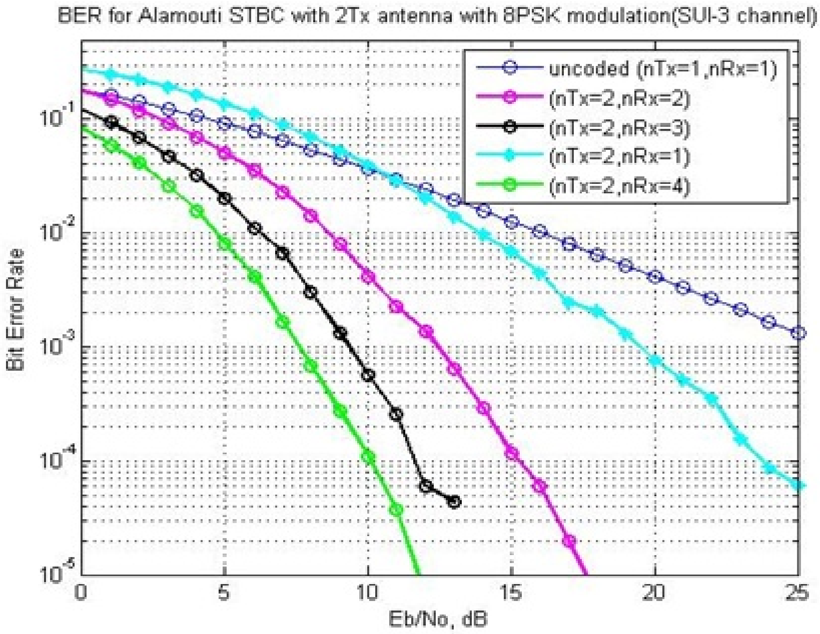

Figure 5.30: BER for SISO, MISO and MIMO with SUI-3 channel using 8PSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.0447	0.0400	0.0085	0.0013	2.33e-4
Imp. over SISO	-	10.51%	80.98%	97.09%	99.48%
Imp. over (2Tx,1Rx)	-	-	78.75%	96.75%	99.42%
Imp. over (2Tx,2Rx)	-	-	-	84.71%	97.25%
Imp. over (2Tx,3Rx)	-	-	-	-	82.05%

Table 5.30: Simulation result analysis for SISO, MISO, MIMO with SUI-3 channel using 8PSK modulation (10db)

5.32 Simulation result for SISO, MISO and MIMO with SUI-3 channels using 4QAM modulation

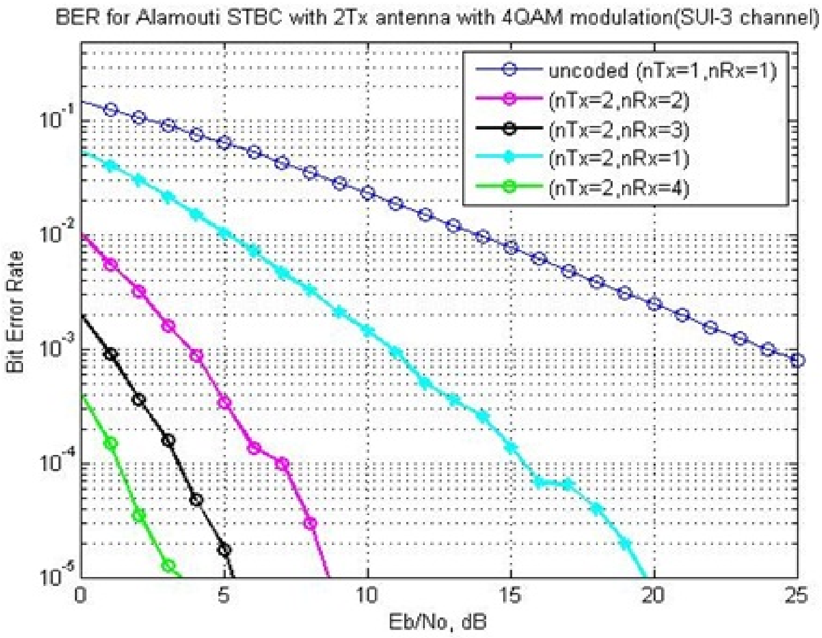

Figure 5.31: BER for SISO, MISO and MIMO with SUI-3 channel using 4QAM

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1085	0.0298	0.0032	3.70e-4	3.75e-5
Imp. over SISO	-	72.53%	97.05%	99.66%	99.97%
Imp. over (2Tx,1Rx)	-	-	89.26%	98.76%	99.87%
Imp. over (2Tx,2Rx)	-	-	-	88.44%	98.83%
Imp. over (2Tx,3Rx)	-	-	-	-	89.86%

Table 5.31: Simulation result analysis for SISO, MISO, MIMO with SUI-3 channel using 4QAM modulation (3db)

5.33 Simulation result for SISO, MISO and MIMO with SUI-3 channels using 16QAM modulation

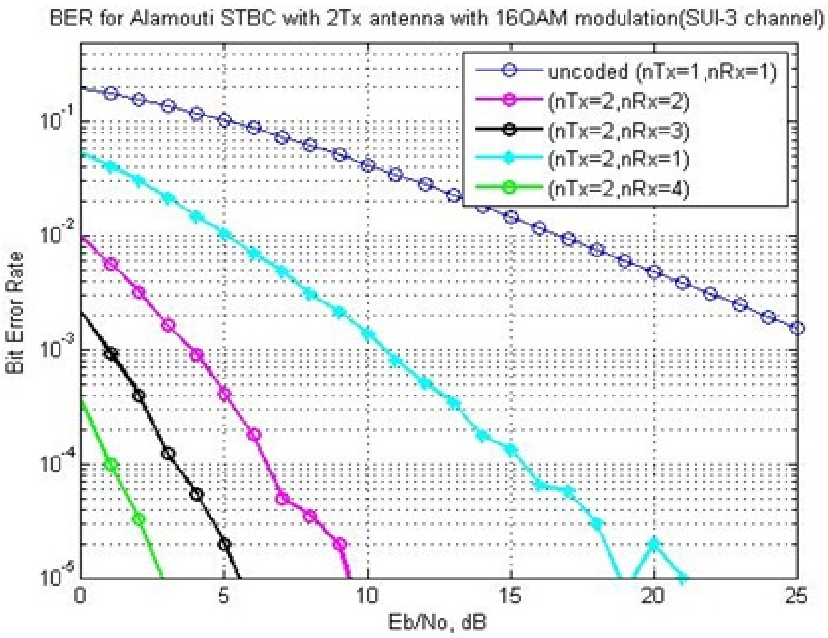

Figure 5.32: BER for SISO, MISO and MIMO with SUI-3 channel using 16QAM

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1570	0.0303	0.0032	3.67e-4	3.75e-5
Imp. over SISO	-	80.70%	97.96%	99.77%	99.98%
Imp. over (2Tx,1Rx)	-	-	89.44%	98.79%	99.88%
Imp. over (2Tx,2Rx)	-	-	-	88.52%	98.83%
Imp. over (2Tx,3Rx)	-	-	-	-	89.80%

Table 5.32: Simulation result analysis for SISO, MISO, MIMO with SUI-3 channel using 16QAM modulation (3db)

5.34 Simulation result for SISO, MISO and MIMO with SUI-5 channels using BPSK modulation

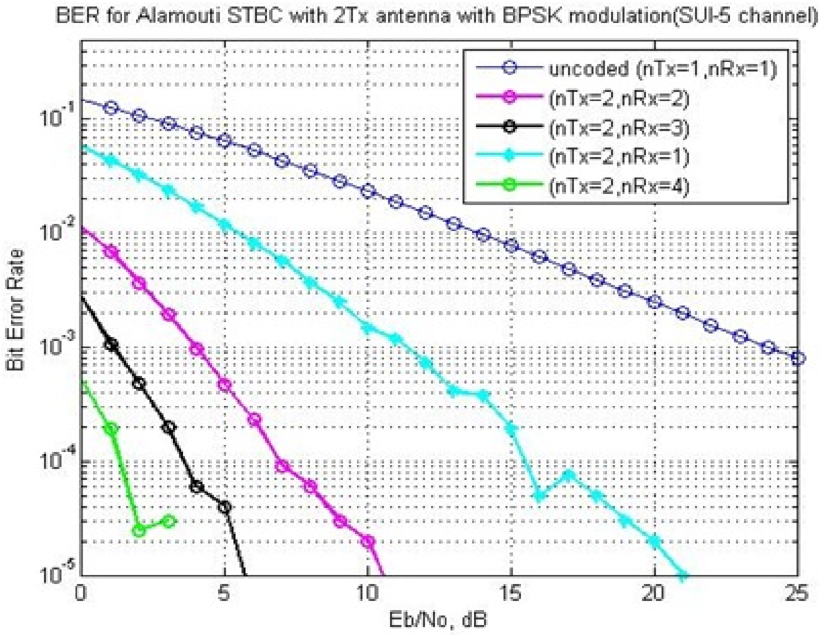

Figure 5.33: BER for SISO, MISO and MIMO with SUI-5 channel using BPSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1085	0.0330	0.0037	5.75e-4	6.5e-5
Imp. over SISO	-	69.59%	96.59%	99.47%	99.94%
Imp. over (2Tx,1Rx)	-	-	88.79%	98.26%	99.80%
Imp. over (2Tx,2Rx)	-	-	-	84.46%	98.24%
Imp. over (2Tx,3Rx)	-	-	-	-	88.70%

Table 5.33: Simulation result analysis for SISO, MISO, MIMO with SUI-5 channel using BPSK modulation (3db)

5.35 Simulation result for SISO, MISO and MIMO with SUI-5 channels using QPSK modulation

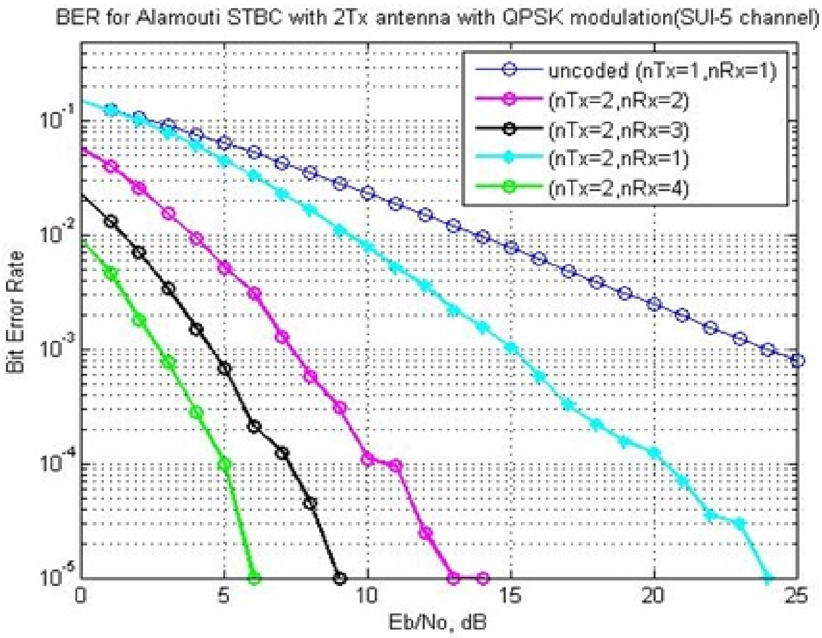

Figure 5.34: BER for SISO, MISO and MIMO with SUI-5 channel using QPSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.0771	0.0611	0.0093	0.0015	2.70e-4
Imp. over SISO	-	20.75%	87.94%	98.05%	99.65%
Imp. over (2Tx,1Rx)	-	-	84.78%	97.55%	99.56%
Imp. over (2Tx,2Rx)	-	-	-	83.87%	97.10%
Imp. over (2Tx,3Rx)	-	-	-	-	82.00%

Table 5.34: Simulation result analysis for SISO, MISO, MIMO with SUI-5 channel using QPSK modulation (5db)

5.36 Simulation result for SISO, MISO and MIMO with SUI-5 channels using 8PSK modulation

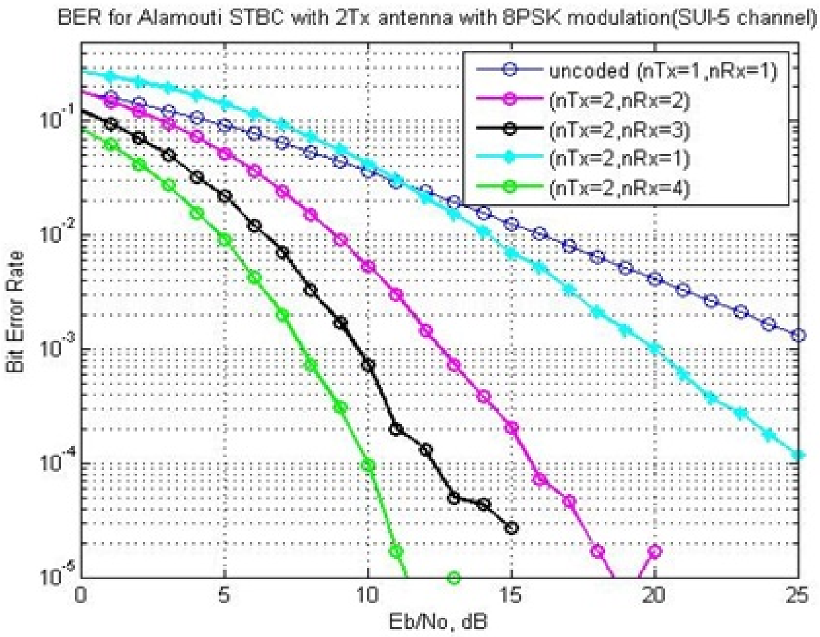

Figure 5.35: BER for SISO, MISO and MIMO with SUI-5 channel using 8PSK

Diversity Type	SISO	2Tx,1Rx	2Tx,2Rx	2Tx,3Rx	2Tx,4Rx
BER	0.0447	0.0400	0.0091	0.0018	3.13e-4
Imp. over SISO	-	10.15%	79.64%	95.97%	99.30%
Imp. over (2Tx,1Rx)	-	-	77.25%	95.50%	99.22%
Imp. over (2Tx,2Rx)	-	-	-	80.22%	96.56%
Imp. over (2Tx,3Rx)	-	-	-	-	82.59%

Table 5.35: Simulation result analysis for SISO, MISO, MIMO with SUI-5 channel using 8PSK modulation (10db)

5.37 Simulation result for SISO, MISO and MIMO with SUI-5 channels using 4QAM modulation

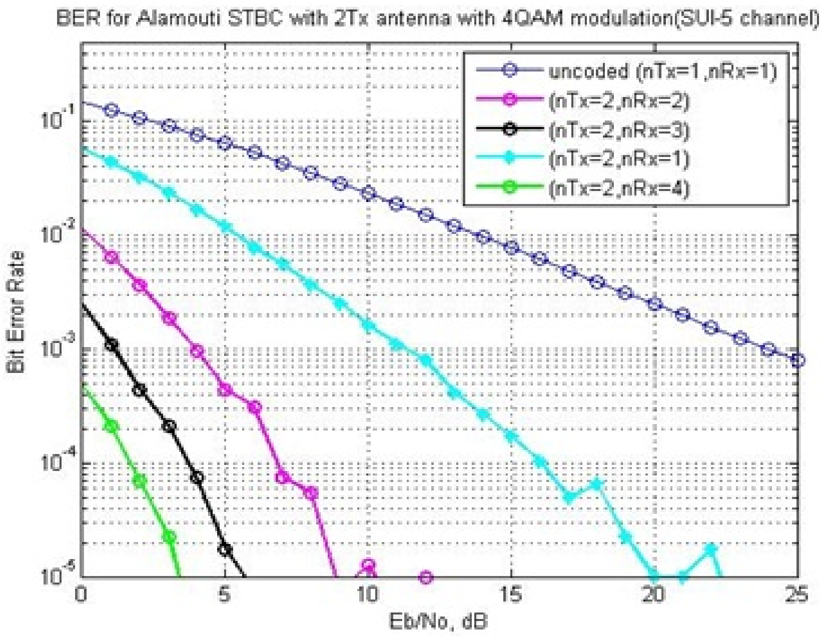

Figure 5.36: BER for SISO, MISO and MIMO with SUI-5 channel using 4QAM

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1085	0.0329	0.0037	4.95e-4	5.75e-5
Imp. over SISO	-	69.68%	96.59%	99.54%	99.95%
Imp. over (2Tx,1Rx)	-	-	88.75%	98.50%	99.83%
Imp. over (2Tx,2Rx)	-	-	-	86.62%	98.45%
Imp. over (2Tx,3Rx)	-	-	-	-	88.38%

Table 5.36: Simulation result analysis for SISO, MISO, MIMO with SUI-5 channel using 4QAM modulation (3db)

5.38 Simulation result for SISO, MISO and MIMO with SUI-5 channels using 16QAM modulation

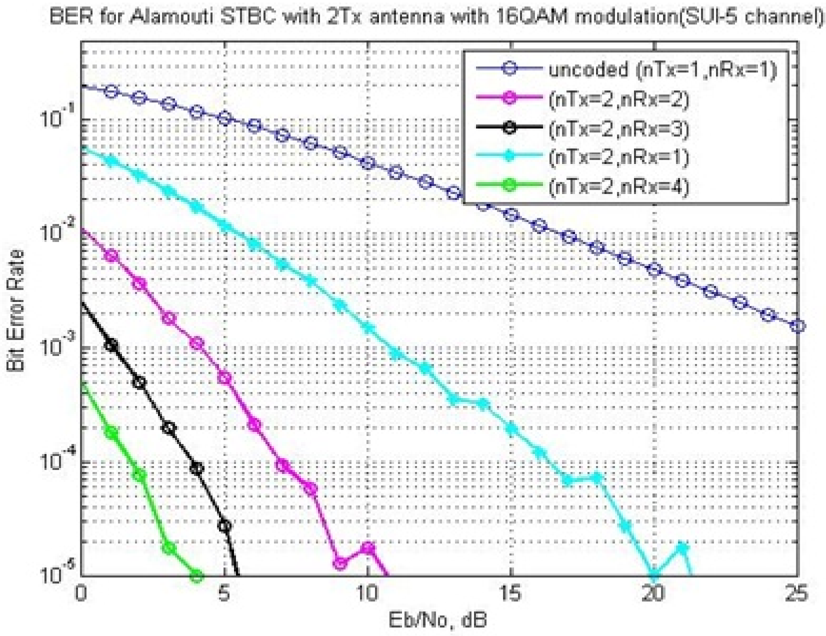

Figure 5.37: BER for SISO, MISO and MIMO with SUI-5 channel using 16QAM

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1570	0.0328	0.0036	4.0e-4	5.5e-5
Imp. over SISO	-	79.11%	97.71%	99.75%	99.96%
Imp. over (2Tx,1Rx)	-	-	89.02%	98.78%	99.83%
Imp. over (2Tx,2Rx)	-	-	-	88.89%	98.47%
Imp. over (2Tx,3Rx)	-	-	-	-	86.25%

Table 5.37: Simulation result analysis for SISO, MISO, MIMO with SUI-5 channel using 16QAM modulation (3db)

5.39 Simulation result for SISO, MISO and MIMO with Rayleigh channels using BPSK modulation

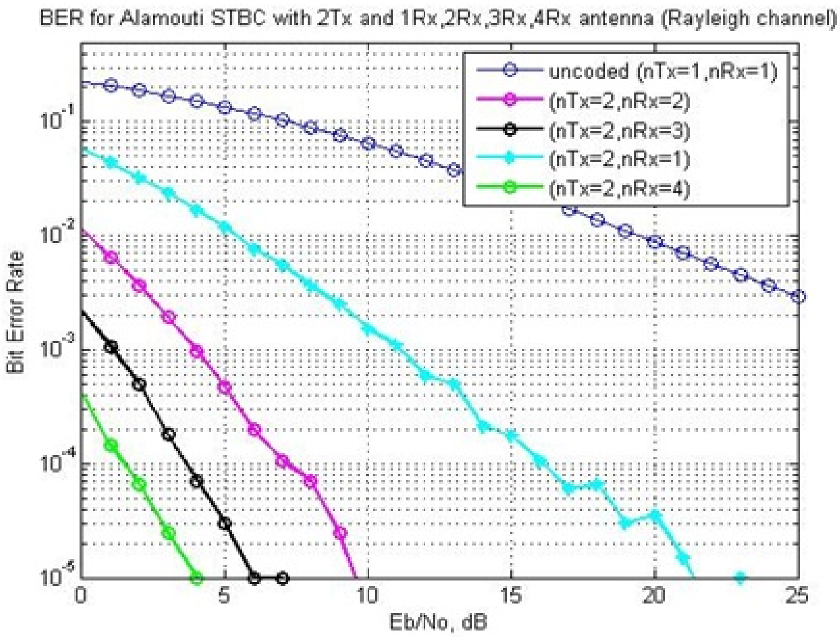

Figure 5.38: BER for SISO, MISO and MIMO with Rayleigh channel using BPSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1521	0.0172	0.0011	7.5*10ˆ-5	10ˆ-5
Imp. over SISO	-	88.68%	99.31%	99.95%	99.99%
Imp. over (2Tx,1Rx)	-	-	93.90%	99.56%	99.94%
Imp. over (2Tx,2Rx)	-	-	-	92.86%	99.05%
Imp. over (2Tx,3Rx)	-	-	-	-	86.67%

Table 5.38: Simulation result analysis for SISO, MISO, MIMO with Rayleigh channel using BPSK modulation (5db)

5.40 Simulation result for SISO, MISO and MIMO with Rayleigh channels using QPSK modulation

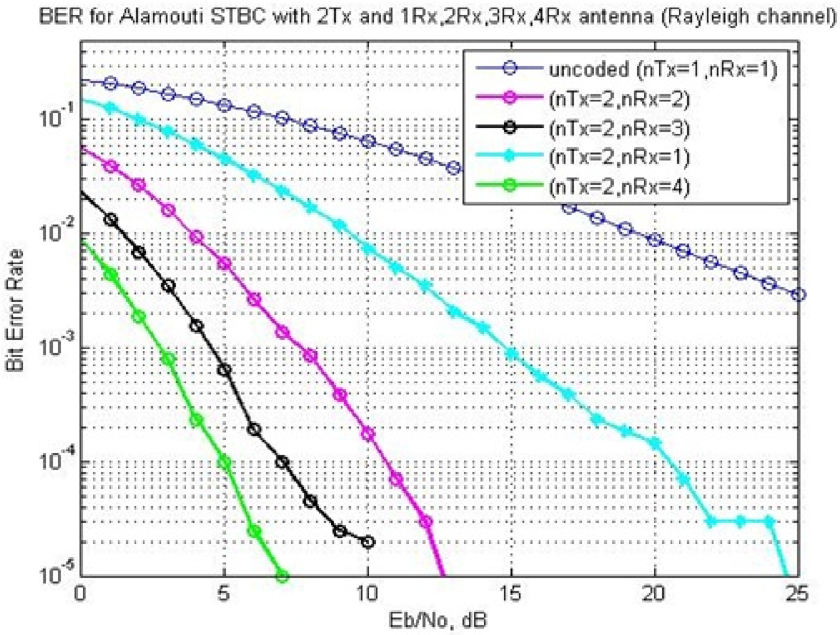

Figure 5.39: BER for SISO, MISO and MIMO with Rayleigh channel using QPSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.1521	0.0618	0.0100	0.0016	2.95e-4
Imp. over SISO	-	59.36%	93.46%	98.94%	99.22%
Imp. over (2Tx,1Rx)	-	-	83.81%	97.14%	99.52%
Imp. over (2Tx,2Rx)	-	-	-	84.00%	97.05%
Imp. over (2Tx,3Rx)	-	-	-	-	81.56%

Table 5.39: Simulation result analysis for SISO, MISO, MIMO with Rayleigh channel using QPSK modulation (5db)

5.41 Simulation result for SISO, MISO and MIMO with Rayleigh channels using 8PSK modulation

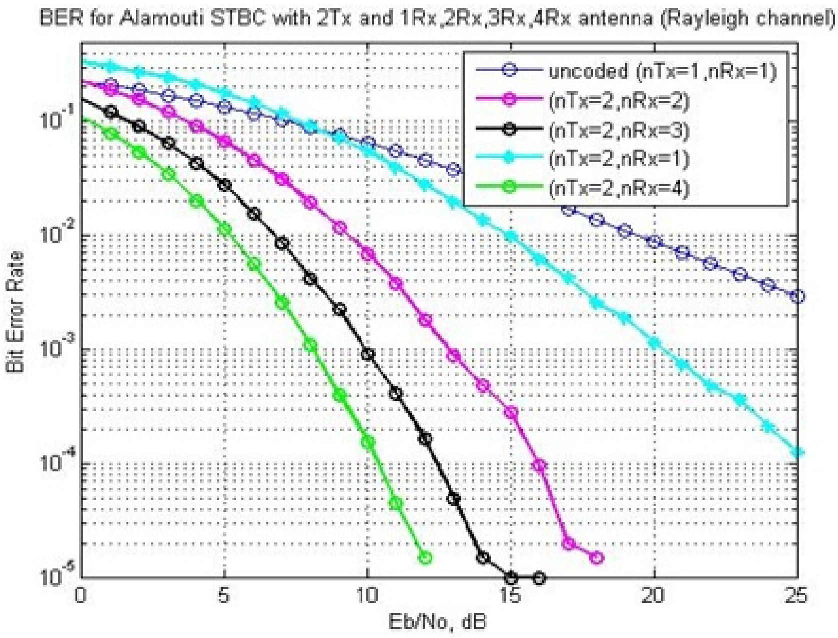

Figure 5.40: BER for SISO, MISO and MIMO with Rayleigh channel using 8PSK

Diversity Type	**SISO**	**2Tx,1Rx**	**2Tx,2Rx**	**2Tx,3Rx**	**2Tx,4Rx**
BER	0.0772	0.0718	0.0115	0.0023	3.7e-4
Imp. over SISO	-	6.9%	85.10%	97.02%	99.52%
Imp. over (2Tx,1Rx)	-	-	83.98%	96.79%	99.48%
Imp. over (2Tx,2Rx)	-	-	-	80.00%	96.78%
Imp. over (2Tx,3Rx)	-	-	-	-	83.91%

Table 5.40: Simulation result analysis for SISO, MISO, MIMO with Rayleigh channel using 8PSK modulation (10db)

5.42 Results Analysis

1. As shown in table 5.2 to 5.7 , SUI-1 channel gives high BER improvement than other SUI channels and Rayleigh channel for all possible modulation techniques using MISO diversity scheme. SUI-1 channel of terrain C type has less tree density and flat channel model.

2. As shown in table 5.8 to 5.20, Rayleigh channel gives high BER improvement over all types of SUI channels for different types of modulation techniques and diversity of 2Tx with 2Rx, 3Rx and 4Rx scheme.

3. As shown in table 5.22 to 5.40, diversity scheme of 2Tx with 4Rx provides highest BER improvement than all other diversity scheme which are shown in above simulations.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

1. Significant performances gains can be achieved by increasing the number of transmit/ receive antennas with considerable decoding complexity.

2. Performance plots for STBC indicate a relatively degradation of performance for low to higher constellation of MPSK modulation techniques.

3. 16QAM is providing better performance against SISO (uncoded), 4QAM and 8QAM modulation schemes.

4. 2Tx with 4Rx antenna pattern provides such a good improvement in BER than other 1Rx, 2Rx, and 3Rx diversity techniques.

5. BPSK modulation scheme with 2TX and 4Rx gives highest BER improvement than other modulation schemes.

6. SUI-1 gives a high BER improvement as compared to the other SUI channels.

7. BER improvement changes with the change in terrain types. Terrain C type which has less dense and flat channel model provides better BER performance than other terrain types B and A which are more dense than terrain C.

6.2 Future Scope

Based on the results, a number of interesting research directions have been pursued in the future. These are outlined below:

1. To implement STBC code for different diversity techniques.

2. To implement STBC code on a suitable DSP hardware.

Appendix A

List of Abbreviations

STBC	Space Time Block Code
SUI	Standford University Interim
BER	Bit Error Rate
AWGN	Additive White Gaussian Noise
UMTS	Universal Mobile Telecommunication System
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communication
STC	Space Time Coding
ML	Maximum Likelihood
SISO	Single Input Single Output
MISO	Multiple Input Single Output
MIMO	Multiple Input Multiple Output
4G	4th Generation
CSI	Channel State Information
SNR	Signal to Noise Ratio
STTC	Space Time Trellis Code
BTS	Base Transreceiver Station
MS	Mobile Station
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation

References

[1] S. M. Alamouti. A simple transmit diversity technique for wireless communications. *IEEE Journal Select. Areas Commun., vol. 16*, October 1998.

[2] N. Fisal N. Ngajikin, W. N. Ahmad and S. K. Yusof. Simulation on performance of space time block code.

[3] H. Jafarkhani V. Tarokh and A. R. Calderbank. Space-time block coding for wireless communications: performance results. *IEEE J. Select. Areas Commun., vol. 17*, March 1999.

[4] B.Vucetic and J.Yuan. *Space-Time Coding*. Jhon Wiley and Sons Ltd., October 2004.

[5] Toru Otsu Narumi Umeda and Tatsuro Masamura. Overview of the fourth-generation mobile communication system. *NTT Technical Review, vol.2, No.9*, september 2004.

[6] Manisha Upadhyay. Simulation and performance analysis of space time block code.

[7] Daniel S. Baum. Simulating the sui channel models. *IEEE 802.16 Broadband Wireless Access Working Group*, April 2001.

[8] Senthil Kumaran D Karthikeyan V, Malmurugan N. Performance evaluation of preamble detection under itu and sui channel models in mobile wimax.