

# Palestine Polytechnic University



**Collage of Engineering & Technology**

**Electrical & Computer Engineering Department**

**Graduation Project**

**Diversity in 4G**

**Project Team**

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**Project Supervisor**

Dr. Khaled Hijjeh

Hebron –Palestine

June, 2011

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جامعة بوليتكنك فلسطين

الخليل- فلسطين

كلية الهندسة والتكنولوجيا

دائرة الهندسة الكهربائية والحاسوب

اسم المشروع

## Diversity in 4G

أسماء الطلبة

أنوار أبو عفيفة أمينة مصري

ليندا مناصرة ولاء السيد احمد

بناء على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية والحاسوب وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة الاتصالات والالكترونيات \*

توقيع المشرف

.....

توقيع اللجنة الممتحنة

.....

توقيع رئيس الدائرة

.....

## **Dedication**

*To Those Whom We Love*

*To Those Who Support us in Our Dark Days*

*To Those Whose their Souls Dancing around us*

*To The Palestinian Martyrs*

*To The Palestinian Refugees*

*To The Palestinian Prisoners*

*To Our Families, Aunts & Uncles*

*To Our Great Parents*

*Brothers & Sisters*

*To Our Brilliant Supervisor Dr. Khaled Hijjeh*

*We dedicate Our Graduation Project*

## **Acknowledgment**

We like to express our thanks and gratitude to Allah, the most Beneficent, the most Merciful who granted us the ability and willing to start and complete this project. We pray to his greatness to inspire us the right path to his connect and enable us to continue the work started in this project to benefits of our country.

We wish to express our thanks to Dr. Khaled Hijjeh, for a valuable help, encouragement, supplying references, supervision and guidance in solving the problems that we faced from time to time during this project, we wish to express our deep and sincere thanks and gratitude to Palestine Polytechnic University, the Department of Electrical and Computer Engineering, College of Engineering and Technology.

Work Team

## Abstract

The main subject of this project is to deeply study the diversity characteristics of the MIMO antennas, which will be adopted in 4G systems. The project discusses the performance of Diversity in MIMO, and then it explains how diversity reception and transmission technique is used to mitigate the effects of fading over communication link.

The project handles Space-Time Block Coding (STBC) transmit diversity combined with receive diversity scheme when the Channel is perfectly known to the receiver unknown to the transmitter in order to achieve diversity in MIMO.

The results of the simulation show that the Diversity performance of  $N \times M$  system using STBC improves when  $N$  or  $M$  or both increase. Orthogonality shows a great effect on the system performance, increasing orthogonality reduced BER. Moreover reducing the code rate has a bad impact on the system performance.

Anew Quasi-OSTBC for  $16 \times M$  was introduced in this project benefitting from known orthogonal design for STBC matrices.

Channel estimator is used to estimate channel information when the channel is unknown to the receiver using pilot signals.

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## Abbreviations

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CELL_FACH	UTRAN RRC transition state between Cell_PCH and Cell_DCH
CELL_PCH	UTRAN RRC state where UE has no dedicated resources are allocated
CK	Channel Known
CQI	Channel Quality Information
CSI	Channel State Information
CU	Channel Unknown
DSTTD	Double Space Time Transmit Diversity
EGC	Equal Gain Combining
FDFR	Full Diversity Full-Rank
FER	Forward Error correction
GSM	Global System for Mobile communications
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access (HSDPA + HSUPA)
HSPA+	High Speed Packet Access Plus (also known as HSPA Evolution or Evolved HSPA)
LHS	Left Hand Side Scatters
LOS	Light Of Sight3GPP

LTE	Long Term Evolution
3G	Third Generation
3GPP	Partnership Project
RHS	Right Hand Side Scatters
MC_CDMA	Multicarrier Code-Division Multiple-Access
MIMO	Multiple input Multiple Output
MIMO-MU	MIMO Multiuser
MISO	Multiple Input Single Output
ML	Maximum-Likelihood
MMSE	Multimedia Messaging Service Environment
MR	Maximal Ratio
MRC	Maximum Ratio Combining
MRP	Market Representation Partner
MU	Multiuser
POC	Push-to-Talk Over Cellular
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplexing Access
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio Frequency
SC-FDMA	Synchronization Channel-Frequency Division Multiple Access
SDMA	Space Division Multiple Access
SER	Symbol Error Rate
SIMO	Single Input Multiple Output

SISO	Single-Input Single-Output
SINR	Signal _Interference Noise Ratio
SNR	Signal _Noise Ratio
SM/ SMUX	Spatial Multiplexing
ST	Space Time
STBC	Space-Time Block Code
SVD	Singular Values Decomposition
TDMA	Time Division Multiple Access
UE	User Equipment
URA_PCH	UTRAN Registration Area Paging Channel
VOIP	Voice and Video over Internet Protocol
WI MAX	Worldwide Interoperability for Microwave Access based on IEEE 802.16 standard
WINNER	Wireless World Initiative New Radio
WCDMA	Wideband Code Division Multiple Access
ZMCSCG	Zero Mean Circularly Symmetric Complex Gaussian

## Symbols

$A, a$	scalar
$\mathbf{A}, \mathbf{a}$	vector
$\mathbf{A}^T$	transpose of $\mathbf{A}$
$\mathbf{A}^*$	elementwise conjugate of $\mathbf{A}$
$\mathbf{A}^H$	conjugate transpose of $\mathbf{A}$
$\varepsilon$	expectation operator
$\ \mathbf{A}\ _F^2$	Squared Frobenius norm of $\mathbf{A}$
$\mathbf{daig}\{\mathbf{a}_1, \mathbf{a}_2, \dots, \mathbf{a}_n\}$	$n \times n$ diagonal matrix with $[\mathbf{daig}\{\mathbf{a}_1, \mathbf{a}_2, \dots, \mathbf{a}_n\}]_{i,i} = a_i$
$\text{vec}(\mathbf{A})$	stacks $\mathbf{A}$ into vector columnwise
If $\mathbf{A} = [\mathbf{a}_1 \ \mathbf{a}_2 \ \dots \ \mathbf{a}_n]$ is $m \times n$ , then $\text{vec}(\mathbf{A}) = [a_1^T \ a_2^T \ \dots \ a_n^T]$ is $mn \times 1$ .	

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# CHAPTER ONE

## INTRODUCTION

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**1.2. Main Idea of the Project.**

**1.3. Project Objectives.**

**1.4. 4G system.**

**1.5. Limitations Facing Wireless Communication Systems.**

**1.6. Introduction to Diversity.**

**1.7. Project Plane.**

**1.8. Project Tools and Materials.**

**1.9. Time Plane.**

## **1.1. Introduction**

This chapter introduces the project idea of Applying Diversity in multiple input multiple output( MIMO) which will be used in the coming 4G. This will include objectives of this project, and the reason for choosing it and over viewing its importance. This appears by over viewing the four generations (1G, 2G, 3G, and 4G), the limitations and challenges of wireless communication, and the role of diversity in communication systems.

## **1.2. Main Idea of the Project**

Wireless channel faces many challenges , such as fading , path loss and capacity. Diversity came to overcome fading and improve the quality of wireless communication system.

In this project diversity will be applied in MIMO using space time block coding ( STBC) for different systems such as (2- 4, 6-8, 10, 12, 14 and 16)  $\times$ M MIMO systems. Then full simulation of these systems will be implemented using MATLAB program. The performance of the systems will be shown by noting the relation between the signal to noise ratio (SNR) versus bit error rate (BER).

## **1.3. Project Objectives**

1. To study the concept of diversity in MIMO (Multiple Input Multiple Output).
2. To build a new Matlab simulation for more advanced diversity techniques that are used in 4G systems.
3. The use of STBC on (2- 4, 6-8, 10, 12, 14 and 16)  $\times$ M MIMO systems.

## **1.5. 4G system**

The four generations are the first generation, second generation, third generation, and fourth generation. In the first generation (1G) almost all of the systems which used this generation were analog systems, and voice was considered to be the main traffic. After that the second generation (2G) came which was built mainly for telephone calls and slow data transmission such as Global System for Mobile Communication (GSM). Then, the third generation (3G) appears to provide the ability to transfer simultaneously both voice data (a telephone call) and non voice data. 3G technologies enable network operators to offer users a wider range of more advanced services, while achieving greater network capacity through improving spectral efficiency [11].

The coming future will show the Fourth generation (4G) which will be a fully internet protocol (IP)-based integrated system of systems and network of networks. This is achieved after the convergence of wired and wireless networks as well as computer, consumer electronics, communication technology, and several other convergences that will be capable of providing 100 Mbps and 1Gbps, respectively, in outdoor and indoor environments with end-to-end Quality of services (QoS) and high security, offering any kind of services anytime, anywhere, at affordable cost and one billing [11].

### **Motivation for 4G Research**

1. 3G performance may not be sufficient to meet needs of future high-performance applications like multimedia, full-motion video, wireless teleconferencing. We need a network technology that extends 3G capacity by an order of magnitude [11].
2. We need all digital packet networks that utilize IP in its fullest form with converged voice and data capability [11].

3. Researchers have come up with spectrally more efficient modulation schemes that cannot be retrofitted into 3G infrastructure [11].

## **1.5. Limitations Facing Wireless Communication Systems**

### **1.5.1. Fading**

Fading describes the received signal's fluctuations. There are two types of fading:

1. Macroscopic fading: it's the long term fading which results from shadowing effects of buildings and natural features. It is described by log-normal distribution [1].
2. Microscopic fading: it's the short term fading which describes the rapid fluctuations of the received signals in space, time and frequency [1].

Signal scattering off the objects between transmitter and receiver is considered as the main reason for microscopic fading occurrence [1].

### **1.5.2. Path loss**

Path loss is a measure of attenuation based only on the distance to the transmitter.

Path loss equals the ratio between the transmitted power and the received power :

$PL = P_t/P_r$ . The path loss exponent is different in different environment [12].

### **1.5.3. Capacity**

In his mathematical theory of communication, Claude Shannon showed that even a noisy communication channel has a channel capacity measured in bits per second. If a communication channel of bandwidth  $B$  Hz is considered and the power received over the channel with a signal power  $S$  and a noise power  $N$  from noise somehow

added during transmission and amplification. The channel capacity  $C$  in bits per second is:  $C = B \log_2 (1 + S / N)$  [1]. (1.1)

The equation shows the advantage of using a broad bandwidth to transmit messages. Channel capacity is defined as: the maximum error free data rate that channel supports [1].

## **1.6. Introduction to Diversity**

Diversity is a scheme that is used to improve the received signal quality; as it fights fading; reducing its depth and duration. Diversity is applied at both transmitter and receiver to improve the quality of communication link in the presence of same air interference with same transmitter power and same bandwidth.

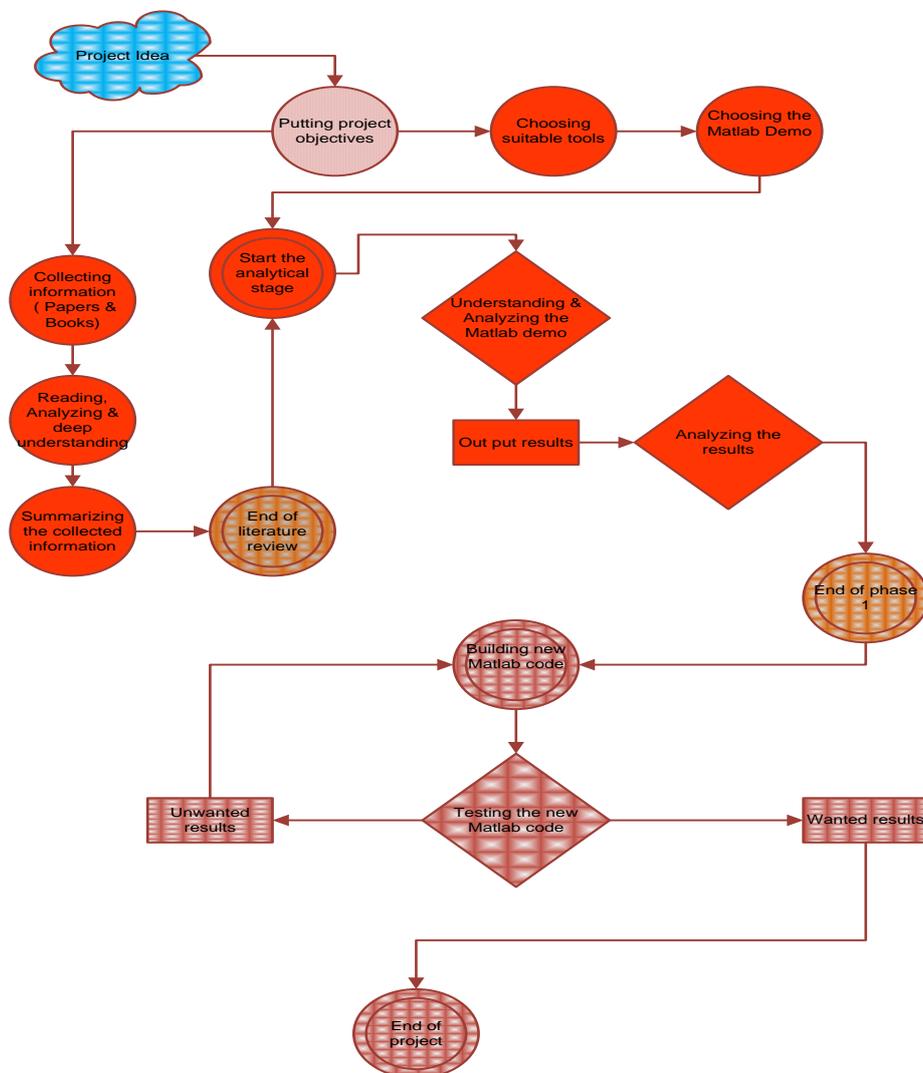
There are several techniques used for applying diversity. First, frequency diversity which is used to provide signal replicas at different frequency. Second, time diversity that provides signal replicas at different time. Finally Antenna Diversity which provides signal replicas using multiple antennas at transmitter or receiver or both. Spatial diversity is considered as most common technique where multiple antennas are spaced and connected to the receiver. Also, there is another diversity scheme which selects the strongest channel to downlink from the base station when channel dependent scheduling is used; this is called multi-user diversity [12].

Diversity uses different techniques to select and combine the signal replicas. In diversity selection, the strongest received signal is chosen for demodulation and detection. But in equal gain combining, the receiver uses all received components for demodulation and detection after estimating channel parameters and correcting all replicas offsets. Finally, maximal ratio combiner (MRC); same as equal gain combiner in addition to that it gives a weight to each received replica which is directly proportional to the replica strength [12].

## 1.7. The Project Plane

This project introduces the idea of applying diversity in MIMO. First a Matlab demo about Transmit vs. receive diversity will be analyzed .Second , information from scientific papers and books will be collected in order to support the project with strong background. Third, a new Matlab code will be built to simulate the performance of diversity in different MIMO systems. Fourth ,the new code will be tested ensure that it given the wanted results. Finally, the new code will be corrected if it has any mistake.

The following figure shows the plane of the project.



**Figure 1.1:** The Project Plane.

## 1.8. Project Tools and Materials

The project needs a good number of specialized books, scientific papers & other references, other references mainly from IEEE, 3rd Generation Partnership Project (3GPP), and the International Telecommunication Union ITU websites. Also Matlab program version 7.10.0.499 (R2010a) was used for programming and simulation of the several MIMO systems that are used in this project.

Matlab stand for "Matrix Laboratory" and is a numerical computing environment and fourth generation programming language, developed by The Math Work, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, and FORTRAN.

MATLAB supports structure data types. Since all variable in MATLAB are arrays, a more adequate name is "structure arrays".

We have chosen Matlab for this proje due to several important features such as:

1. Matlab performs signal processing, analysis, and algorithm development.
2. Matlab designs and simulates signal processing systems which provide algorithms and tools for the design and simulation of signal processing systems.
3. It Designs and analyzes algorithms for the physical layer of communication systems where computing environment with fun//ction , plots, and a graphical user interface (GUI) for exploring, designing, analyzing, and simulating algorithms for the physical layer of communication systems.
4. Communications Toolbox in Matlab provides specialized plots for communication engineering, such as eye diagrams, constellation plots, and bit error rate versus signal-to-noise ratio plots. With the BER Tool GUI, you can combine data from several simulation runs and compare the results with theoretical benchmarks in one combined plot window.

## 1.9. Time Plane

**Table1.1: Project Outline**

<b>First Semester</b>		
<b>Activity</b>	<b>Time</b>	<b>Explanation</b>
Chapter One	2 weeks	<ol style="list-style-type: none"> <li>1. Project objectives written as clear specific points.</li> <li>2. Explanation of what we did in the project.</li> <li>3. Timeframe: what &amp; when the activities needed for the project was done.</li> <li>4. Explanation of what we used in full details (tools, software, references, the needed programming ..... )</li> <li>5. Giving brief idea about the results of the project</li> </ol>
Chapter Two	4 weeks	Discussion & explanation the literature review
Chapter Three	4 weeks	Analysis the Matlab Demo in details
Chapter Four	1 week	Explain what was done in the project.
<b>Second semester</b>		
<b>Activity</b>	<b>Time</b>	<b>Explanation</b>
Software implementation and Testing	14 weeks	<ol style="list-style-type: none"> <li>1.Designing the Matlab codes.</li> <li>2. Testing and Implementation of the Matlab codes.</li> <li>3. Analyzing the resulted figures.</li> </ol>
Documentation	3 weeks	<ol style="list-style-type: none"> <li>1. Summarizing the results and writing the conclusion.</li> <li>2. Preparing the final project and printing it.</li> </ol>

## **CHAPTER TWO**

### **LITERATURE REVIEW**

- 2.1. Introduction.**
- 2.2. Principles of spatial processing.**
- 2.3. ST coding.**
- 2.4. Multiantenna Methods.**
- 2.5. Diversity order and channel variability.**
- 2.6. Diversity performance in extended channels.**
- 2.7. Combined space and path diversity.**
- 2.8. Diversity- Multiplexing trade off.**
- 2.9. Indirect transmit diversity.**
- 2.10. Combining methods.**
- 2.11. Wireless data trends and forecasts.**

## **2.1.Introduction**

This chapter presents Diversity utilization in multiantenna technique. First, it offers an overview about mlti-antenna methods and techniques. Then, it views the diversity gain, and how diversity is applied in Single Input Multiple Output(SIMO), Multiple Input Single Output (MISO), and Multiple Input Multiple Output (MIMO) either in the presence or absence of channel knowledge. Finally, it represents diversity application, its rule and how does it combined with other systems and a comparison between diversity gain and multiplexing gain.

### **2.1.1. Antenna array topology**

Antenna topology influences Space Time (ST) channel as there is a significant difference between the base station and terminal. Antenna topology choices at the terminal are limited due to size constraints. However, the presence of rich scattering near the terminal allows spacing as small to capture diversity [2].

### **2.1.2. Reciprocity and its implication**

Reciprocity means that the channel from transmitter to receiver is the same as that from receiver to transmitter. implication means the Doppler spectrum and delay spectrum are the same for transmitter and receiver, but the angle spectrum is the same if only the paths that reach the terminal are counted [2].

## **2.2. Principles of spatial processing**

Different multi-antenna methods benefit from different properties of the radio channel to achieve performance improvements. It's can be accomplished by spatial processing component of the multi-antenna method that uses one or more of the following gains:

- Array gain.

- Diversity gain.
- Spatial multiplexing gain.
- Interference suppression gain.

A trade off exists between these gains. In order to leverage these gains specific processing is required at transmitter and receiver or both. Radio channel properties and the amount of its knowledge available at the receiver and transmitter affect the link gain. Two types of the measurements describe channel knowledge; channel state information (CSI) and channel quality information (CQI). A CSI represents the knowledge of (complex valued) radio channel for both the link of interest and the other interfering links. Whereas CQI represents the (real valued) measure of the channel's quality, for instance Signal \_Interference Noise Ratio (SINR) after processing which is used in code rate, modulation order, and spreading adaptation at transmitter[4].

### **2.2.1. Array gain**

Array gain represents the average of increase in the SNR at the receiver which results from combining multiple antennas coherently at the transmitter [2,4]. The signal power increases proportionally to the number of receive antennas. When multiple antennas exist at transmitter, channel knowledge must be considered in order to facilitate array gain knowledge [2]. CSI is needed for accurate array gain extraction [4].

### **2.2.2. Diversity gain**

Diversity is a mean to mitigate fading which results from signal fluctuations through the wireless channel [2,4]. It describes the difference in SNR at the out put of the diversity combiner compared to that of single branch diversity at certain probability level [5]. It represents the degree at which the multiple data replicas are faded independently [4]. In SIMO channel, the receive antenna diversity is used by combining all the independently received copies of the transmitted signal and this

results in considerable decrease in the amplitude fluctuations. While MISO channel applies transmit antenna diversity with or without channel knowledge at the transmitter, ST diversity coding is a powerful technique which is used to extract transmit antenna diversity. Diversity order is the number of independently faded branches, which equals the number of receive antenna in SIMO channel and the number of transmit antenna in MISO. The combination of both transmit and receive diversity results in diversity in MIMO channel, where the diversity order equals the multiplication of the number of transmit and receive antennas[2].

If the transmitted symbols, drawn from a scalar constellation having a unit average energy, and there are  $M$  identical independent Rayleigh fading links between transmitter and receiver. These could be multiple coherence bandwidths in frequency diversity case or multiple coherent time intervals in time diversity. To apply diversity, the same symbols must be transmitted by the transmitter across all links. The receiver sees multiple independent faded versions of the transmitted signal  $s$ , when frequency flat fading across all diversity branches is existed [2].

$$y_i = \sqrt{\frac{E_s}{M}} h_i + n_i, i = 1, \dots, M \quad (2.1)$$

Where  $\frac{E_s}{M}$  is the symbol energy available for each of the  $M$  diversity branches at transmitter,  $y_i$  is the received signal corresponding to the  $i$ th diversity branch, and  $n_i$  is additive Zero Mean Circularly Symmetric Complex Gaussian (ZMCSCG) noise with variance  $N_0$ . Also, it is assumed that  $\varepsilon\{n_i n_j\} = 0$ , that to ensure that additive noise in diversity branches is uncorrelated [2].

### 2.2.2.1. Coding vs. diversity gain

Diversity gain increases the slope magnitude of the SER curve while coding gain shifts the curve of error rate to the left [2].

### **2.2.3. Spatial multiplexing**

Spatial multiplexing offers a linear (in the number of transmit – receive antenna pairs) increase in the transmission rate for same bandwidth with no additional power [2,4].

Spatial multiplexing can be used in multiuser format (MIMO-MU) also known as Space Division Multiple Accesses or SDMA. SM is only possible in MIMO[2].

In a multi-antenna system, spectral efficiency is increased by spatial diversity that can be viewed as parallel spatial; which transmit independent data stream. In case of CSI and favorable channel condition, the receiver distinguishes and extracts the data streams correctly. The disadvantage of spatial multiplexing is that it reduces the reliability as diversity gain is reduced. But full diversity could be accomplished if mapping from bit stream to antenna changes periodically [4].

### **2.2.4. Interference suppression**

Co-channel results from frequency reuse in wireless channel. When using multi-antenna, it's important to distinguish between the desired and the co-channel signal. Spatial interference suppression (avoidance) is a scheme that benefits from channel knowledge about interference to reduce it [2,4]; by shaping effective antenna beam and transmit and/ or receive in different directions [4]. Interference reduction (or avoidance) can be implemented at the transmitter to minimize the interference energy sent toward the co-channel users, in the same time delivering the signal to the desired user. This allows aggressive reuse factor and improvement in network capacity [2].

Exploiting all leverages simultaneously may not be possible due to conflicting demands on the spatial degree of freedom (or number of antennas). It's a matter of Signaling schemes and receiver design to which degree these conflicts are resolved [2].

### **2.3. Space-Time (ST) coding.**

Wireless systems face many challenges, mainly: limited availability of radio frequency (RF) and the complex time-varying environments (such as fading and multipath). Moreover the demand for higher data rates, better quality of service (QoS), reduces the number of dropped calls, higher network capacity, and user coverage calls for innovation techniques that cause improvement in spectral efficiency and link reliability. To solve all the previous challenges, multiple antennas are used at transmitter and /or receiver which are known as multi- antenna communication, or smart antennas or ST wireless [2]. ST coding depends on the spread of the transmitted signal. This dispersion is done linearly by orthogonal block structure which facilitates the decoding. Dispersion matrices can be considered as optimal criteria, their design is more flexible using matrix modulation, their flexibility avoids structural limitations that simpler ST codes face, and so high data rates are achieved without diversity scarification. This adds more complexity in receiver design. Dispersion can be achieved by Trellis codes and their detection, but it is hard to achieve as system grows [4]. Using antenna arrays at the transmitter and receiver in multiple-input multiple-output (MIMO) wireless channel causes high capacity and diversity benefit antenna arrays at the transmitter and at the receiver. Full diversity can be achieved by the attraction between Spatial multiplexing (SM) and space-time block coding (STBC) [6].

### **2.4. Multiantenna Methods:**

#### **2.4.1. Beamforming technique:**

Beamforming technique is a technique that leverages array and interference rejection gains by focusing beams in specific spatial direction [4].

## 2.4.2. Diversity Techniques:

### 2.4.2.1. Receive antenna diversity.

The simple way to achieve spatial diversity is to use multiple antennas at receiver which is known as receiver diversity. It is an efficient way which provides simple possibility to increase the link reliability [2,4]. However, its applicability becomes immediately limited if the size of the receiving terminal is very small. Cell phones for mobile radio communications have become smaller and smaller in recent years so that it is a difficult task to place several antennas on such small devices. Also the receive diversity in cell phones becomes costly to deploy. This is one of the main reasons why transmit diversity became popular. Since transmit diversity is easier to implement at the base station. Receiver that has multiple antennas receives multiple copies (replicas) of the same transmitted signal, for SIMO channel the transmission came from space path. If the signal path between each antenna pair fades independently, then when one the signal path between each antenna pair fades independently, then when one path is in a fade, the other paths are also don't fade. Therefore, the loss of signal power due to fade in one path is countered by the same signal but received through a different path (route) [7]. Maximum SINR is achieved by choosing optimal weights of signals to be summed from each receive antenna which relays on instantaneous fading state. When state is known to the receiver but it has statistical channel information, correlation matrix is used for that. For spatially white noise plus interference, Maximal Ratio Combining (MRC) is the optimal [4], and it improves the signal quality [7], and for spatially colored case, Minimum Mean-Square-Error (MMSE) is the best choice [4]. Receive antenna diversity is applied in a SIMO. It combines the signals coming from different receive antenna, and the resultant has less variation in amplitude than that of the single-receive antenna diversity [4]. If we consider flat fading condition, the channel vector  $\mathbf{h}$  for such a system is given by  $[h_1 \ h_2 \ \dots \ h_{M_R}]^T$  (2.2)

The  $M_R$  is the number of receive antenna, the other parameters is the symbol  $s$  to be transmitted is drawn from scalar constellation with unit average energy,

$$\mathbf{y} = \sqrt{E_s} \mathbf{h}s + \mathbf{n}, \quad (2.3)$$

This equation expressed the input-output relation of channel, where  $y$  is the  $M_R \times 1$  receive signal vector and  $n$  is noise with  $\varepsilon \{\mathbf{nn}^H\} = N_0 \mathbf{I}_{M_R}$  (2.4)

Receive diversity techniques are capable of extracting full diversity, full diversity gain, and array gain. The performance improvement is proportional to the number of received antenna used [2].

#### **2.4.2.2. Transmit diversity:**

It is achieved by distributing the transmitted symbols over time and space (ST coding). Its design depends on the amount of channel knowledge at transmitter and receiver [4]. The transmit antenna diversity is present in MISO and MIMO channel, the signal to be transmitted needs to be pre-pressed or pre-coded [2]. Transmitter diversity is extracted in MISO systems, whether CSI present at the transmitter or not. In the last case, ST coding is useful technique to code data through transmitter [4].

The performance of wireless communication can be improved effectively by transmit diversity systems. For example, it [8] shows that the different transmit diversity schemes were investigated for multicarrier code-division multiple-access (MC-CDMA) systems. The performance of different transmit diversity methods was compared, including delay diversity, phase diversity, code diversity, scrambling code diversity and space-time block coding diversity for MC-CDMA. All the signal processing is done in the frequency domain. Correlated fading channels were used to show the impacts of the system load on the bit error rate performance. The performance of multiple transmit antennas and multiple receive antennas (MIMO) MC-CDMA is also considered. The space-time block coding method achieves the best performance based on the simulation results. In the heavily loaded system, the performance of all transmit diversity schemes is worse than no transmit diversity system. So it was proposed; a changing switched transmits diversity method according to the system load [8].

Suppose two transmitted antenna and single received antenna, so

$$y = \frac{\sqrt{E_s}}{\sqrt{2}} (h_1 + h_2) s + n, \quad (2.5)$$

Where:  $E_s$  is the average available at transmitter over a symbol period evenly divided between the transmitter antennas.

$n$ : is ZMCSCG noise at the receiver.

$h_1$  and  $h_2$  is assuming a flat fading environment, where the channel signature corresponding to transmitter antenna.

$Y$ : is the received signal.

The sum of two complex Gaussian random variable is considered complex Gaussian.

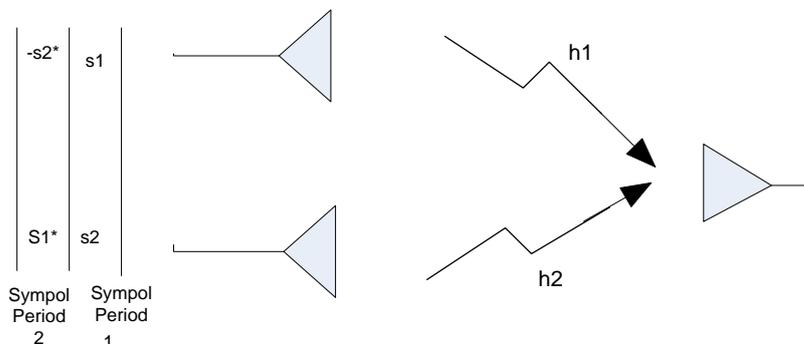
So,  $\frac{1}{\sqrt{2}}(h_1 + h_2)$  is ZMCSCG with unit variance ( $\epsilon(h^2) = 1$ ) so that

$$y = \sqrt{E_s} h s + n. \quad (2.6)$$

In [9] it was shown that using  $2 \times 1$  scheme and  $2 \times M$  need the same bandwidth, and the computation complexity is the same, but the second has diversity order better than the first.

In [10], the paper introduces the benefit of  $2 \times 1$  and the benefit of  $1 \times 2$  scheme, by combining them to producing GSM-like system and compare it with delay diversity scheme.

#### 2.4.2.2.1. Channel unknown to the transmitter: MISO.



**Figure 2.1:** A schematic of the transmission strategy in the Alamouti scheme. The transmission strategy orthogonalizes the channel irrespective of the channel realization [1].

In this technique two different symbols  $s_1$  and  $s_2$  are transmitted simultaneously from antenna 1 and 2 during the first symbol period and  $s_1^*$  and  $s_2^*$  is transmitted in the next symbol period as shown in the figure 2.1, so

$\mathbf{h} = [h_1 \quad h_2]$  and  $y_1$  and  $y_2$  received over the two symbol periods given by:

$$y_1 = \frac{\sqrt{E_s}}{\sqrt{2}} h_1 s_1 + \frac{\sqrt{E_s}}{\sqrt{2}} h_2 s_2 + n_1, \quad (2.7)$$

$$y_2 = \frac{-\sqrt{E_s}}{\sqrt{2}} h_1 s_2^* + \frac{\sqrt{E_s}}{\sqrt{2}} h_2 s_1^* + n_2, \quad (2.8)$$

$$\mathbf{Y} = \begin{bmatrix} Y_1 \\ Y_2^* \end{bmatrix} \quad (2.9)$$

Where  $n_1$  and  $n_2$  are ZMCSCG noise with  $\varepsilon(n_1^2) = \varepsilon(n_2^2) = N_0$ . (2.10)

And  $\frac{E_s}{2}$  is the transmitter energy per symbol period per antenna [2].

The absence of the channel knowledge at the transmitter may be designed to extract special diversity in systems with more than two transmit antennas however it does not allow array gain [2].

#### 2.4.2.2.2 Channel known to the transmitter: MISO

Consider a MISO system with  $M_T$  transmit antennas and frequency flat fading channel.

So, the vector channel  $\mathbf{h} = [h_1 \quad h_2 \quad \dots \quad h_{M_T}]$ . (2.11)

Where  $\mathbf{h}$  is the vector channel.

So,  $y = \frac{\sqrt{E_s}}{\sqrt{M_T}} \mathbf{h} \mathbf{w} s + n$ . (2.12)

Where  $y$ : is the received signal.

$\mathbf{w}$ : is weight vector of dimension  $M_T \times 1$ .

$n$ : is ZMCSCG noise.

$$\mathbf{w} = \frac{\|\mathbf{w}\|_F^2 = M_T}{\|\mathbf{h}\|_F^2} \mathbf{h} \quad (2.13)$$

When  $\mathbf{w}$  is maximum, then the received SNR is given by:

$$\mathbf{w} = \frac{\sqrt{M_T} \mathbf{h}^H}{\sqrt{\|\mathbf{h}\|_F^2}}, \quad (2.14)$$

This scheme is known as transmit maximal ratio combining.

$$\eta = \|\mathbf{h}\|_F^2 \rho. \quad (2.15)$$

If  $\mathbf{h} = \mathbf{h}_w$  then,

$$\bar{P}_e \leq \bar{N}_e \left( \frac{\rho d_{\min}^2}{4} \right)^{-M_T} \quad (2.16)$$

Where  $\bar{P}_e$  is the probability of symbol error [2].

In MISO the receiver has full channel state information, and transmitter has only long-term channel state information in terms of the channel covariance matrix. Paper [11] shows how the optimal number of transmitter antenna can be computed to achieve full special diversity; this is done by given the channel covariance matrix. So in perfect channel knowledge is available to the transmitter, transmit\_ MRC will deliver array gain and diversity gain [2].

#### 2.4.2.2.3. MIMO channel

In MIMO Systems, diversity is achieved by transmitting and receiving combination. Maximum diversity gain is obtained if flat fading channel; as the multiplication of the number of transmit and receive antennas. When correlation matrix of the victories channel has full rank, maximum diversity gain is accomplished. The disadvantage of transmit diversity is that it exploits limited channel capacity [4]. Increasing the system capacity and improving the transmission rate, can be achieved by MIMO system. To reduce the system complexity and cost in MIMO system design, the antenna selection can be used to achieve this aim. The antenna selection has two schemes in correlated Rayleigh channels i.e. the maximal ratio transmission and Orthogonal Space-Time Block Code technique. The simulation result illustrates that; to obtain high performance to optimum selection with low computational complexity new antenna selection should be used [12].

Also in [20], paper discusses the problem of designing optimum full-symbol-rate linear space-time block codes (STBC) for a multi-input multi-output (MIMO) communication system with M transmitter and it was applied for:  $N \geq M$  receiver antennas and a linear minimum mean square error (MMSE) receiver.

Paper [13] presents a framework to exploit MIMO technique in the Worldwide Interoperability for Microwave Access (WIMAX) physical layer. In this paper, the network is divided into layers and the above exploitation of MIMO is realized between these layers in a network-to-network communication scenario.

#### 2.4.2.2.3.1. Channel unknown to the transmitter: MIMO.

Let  $2 \times 2$  channel.

$$\mathbf{H} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}. \quad (2.17)$$

The received signals are:

$$\mathbf{Y}_1 = \sqrt{\frac{Es}{2}} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (2.18)$$

$$\mathbf{Y}_2 = \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \sqrt{\frac{Es}{2}} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -s_2^* \\ s_1^* \end{bmatrix} + \begin{bmatrix} n_3 \\ n_4 \end{bmatrix} \quad (2.19)$$

Where  $n_1, n_2, n_3, n_4$  are uncorrelated ZMCSCG noise with  $\varepsilon\{|n_i|^2\} = N_0$ , ( $i = 1, 2, 3, 4$ ).

$$\mathbf{Y} = \begin{bmatrix} Y_1 \\ Y_2^* \end{bmatrix} \quad (2.20)$$

Note that the energy at the transmitter is divided between the transmitter antennas.

$$\mathbf{Y} = \sqrt{\frac{Es}{2}} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \\ h_{1,2}^* & -h_{1,1}^* \\ h_{2,2}^* & -h_{2,1}^* \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3^* \\ n_4^* \end{bmatrix} \quad (2.21)$$

$$\mathbf{Y} = \sqrt{\frac{Es}{2}} \mathbf{H}_{eff} \mathbf{s} + \mathbf{n} \quad (2.22)$$

$$\text{Where } \mathbf{s} = [s_1 \ s_2]^T \text{ and } \mathbf{n} = [n_1 \ n_2 \ n_3^* \ n_4^*]^T \quad (2.23)$$

$$P_e \leq N_e \left( \frac{\rho d^2_{min}}{8} \right)^{-4}, \quad (2.24)$$

$$\text{The average SNR } \bar{\eta} = 2\rho. \quad (2.25)$$

In the absence of knowledge of channel to the transmitter (MIMO), Alamouti scheme can represent the receiver array gain [2].

Alamouti technique is used to extract diversity in MIMO system with two transmitters and many receivers, but in spatial diversity MIMO used to extract more than two transmitter antennas [2,7]. The reason behind the arising of MIMO industry is the deployment of technique like Alamouti technique [7].

It was discussed in [7] that, if the channel is unknown to the transmitter, then the vector  $\mathbf{s}$  is statistically independent (i.e.,  $R_{ss} = I_{M_T}$ ). It is assumed that the signals transmitted from each antenna have equal powers of  $E_s / M_T$ . The covariance matrix for this transmitted signal is given by:

$$R_{ss} = \frac{E_s}{M_T} I_{M_T} \quad (2.26)$$

where  $E_s$  is the power across the transmitter irrespective of the number of antennas  $M_T$  and  $I_{M_T}$  is an identity matrix [2].

The band-width of the transmit signal is narrow; the assumption is that the channel matrix is known to the receiver, not to the transmitter. And if there is no correlation between components of  $\mathbf{n}$ , the covariance matrix is obtained as:  $R_{nn} = N_0 I_{M_R}$ , Each of the  $M_R$  receive branches has identical noise power of  $N_0$  [14].

#### 2.4.2.2.3.2. Channel known to the transmitter: MIMO

Here the spatial diversity extract diversity through technique known as dominant eigen mode transmission, here the same signal is transmitted from all antenna in transmitter array with weight vector  $\omega$ , the received signal is:

$$\mathbf{Y} = \sqrt{\frac{E_s}{M_T}} \mathbf{H} \omega \mathbf{s} + \mathbf{n}, \quad (2.27)$$

$$\text{And SNR is given by: } \eta = \lambda_{\max} \rho, \quad (2.28)$$

Where  $\lambda_{\max}$  is max eigen value of  $\mathbf{H}\mathbf{H}^H$ .

Here the array gain in dominant eigen mode transmission is given by  $\{\lambda_{\max}\}$ .

Array gain when the channel is known to transmitter is greater than or equal to array gain when the channel is unknown [2].

$$\bar{P}_e \geq \bar{N}_e \left( \frac{\rho d_{\min}^2}{8} \right)^{-M_R M_T}, \quad (2.29)$$

It's possible in various means, that the capacity is increased by using (water filling principle) which means, that the strongest transmitter antenna has the strongest transmitter power [7].

**Table 2.1.** Array gain and diversity order for different antenna configurations (CU = channel unknown on the transmitter and CK channel known on the transmitter) [2].

Configuration	Expected array gain	Diversity order
<b>SIMO(CU)</b>	$M_R$	$M_R$
<b>SIMO(CK)</b>	$M_R$	$M_R$
<b>MISO(CU)</b>	1	$M_T$
<b>MISO(CK)</b>	$M_T$	$M_T$
<b>MIMO(CU)</b>	$M_R$	$M_R M_T$
<b>MIMO(CK)</b>	$\varepsilon\{\lambda_{\max}\}$	$M_R M_T$

In MIMO Systems, diversity is achieved by transmit and receive combination. Maximum diversity gain is obtained if flat fading channel; as the multiplication of the number of transmit and receive antennas. When correlation matrix of the victories channel has full rank, maximum diversity gain is accomplished. The disadvantages of transmit diversity is that it exploit limited channel capacity [4].

#### 2.4.2.3. Spatial diversity.

Spatial or antenna diversity is a method that uses multiple antennas at receiver and/ or transmitter to achieve diversity without suffering from bandwidth deficiency. Signals corresponding to different antennas fade independently, if the antennas are separated enough; more than half wavelength. Achieving spatial diversity may not be possible

in small handheld devices this is because of the need for a minimum physical separation between different antennas [15].

#### **2.4.2.4. Pattern (angle) and polarization diversity.**

Angular diversity is a scheme which achieves diversity by using directional antennas. From different angular directions different copies of the transmitted signal are collected. Unlike multiple antennas, it does not need separate physical locations; it is good for small devices [15].

Polarization diversity is a scheme that uses vertically and horizontally polarized antennas to achieve diversity. Because of the scattering, the arriving signal, which is not polarized, can be split into two orthogonal polarizations. If the signal goes through random reflections, its polarization state can be independent of the transmitted polarization. Unlike spatial diversity, polarization diversity does not require separate physical locations for the antennas. However, polarization diversity can only provide a diversity order of two and not more [15].

#### **2.5. Diversity order and channel variability.**

The signal suffers from deep fading when the spatial diversity ( $M_T = M_R = 1$ ) is absent, but if spatial diversity is increased, the depth of fading is reduced considerably and the effective channel tightens .

The degree of tightening of the channel can be defined as coefficient of variation which is given by:

$$\mu_{\text{var}} = \frac{1}{\sqrt{M_T M_R}}, \quad (2.30)$$

Where

$M_T$ : transmit antenna

$M_R$ : receive antenna

Coefficient of variation is inversely proportional to the square root of diversity order. This means that the channel becomes stable when the diversity order is infinite [2].

## **2.6. Diversity performance in extended channels.**

The influence of signal correlated and gain imbalance and influence of Ricean fading on performance of diversity techniques will be studied [2].

In an experiment done for line-of-sight microwave digital radio, in Mississippi to examine the performance of antenna pattern diversity and vertical space diversity. The measurements show that the vertical space diversity is better than antenna pattern diversity, since its improvement factor (at least one order of magnitude) greater compared to the other mentioned two types. This results when the fading margin related to thermal noise is not greater than that of dispersive [16].

### **2.6.1. The Influence of signal correlation and gain imbalance.**

Extracted diversity order depends on the diversity transmission in the presence of correlated fading or gain imbalance. It refers to the rank of covariance matrix  $\mathbf{R}$  [2].

$$\mathbf{R} = \varepsilon\{\text{vec}(\mathbf{H})\text{vec}(\mathbf{H})^H\}. \quad (2.31)$$

### **2.6.2. The Influence of Ricean fading.**

Mean Line- of- sight (LOS) component in the channel leads to Ricean of the distribution received field amplitude. Ricean K-factor is the ratio of power of the direct LOS component to the total power of the diffused non-line-of-sight components [2].

The paper [17] explains the tradeoff between Correlated Rayleigh and Rican MIMO Channels for Finite-SNR Diversity-Multiplexing. The finite-SNR diversity gain

provides an estimation of the additional power required to decrease the outage probability by a target amount. A finite-SNR spatial multiplexing gain dictates the sensitivity of the rate adaptation policy to SNR, Finite SNRs are important in analyzing the diversity–multiplexing tradeoff of MIMO systems in realistic environments, and For a general MIMO system, The diversity gain is estimated by using lower bounds on the outage probability for a fixed multiplexing gain.

When measuring antenna diversity, the noise making uncorrelated branches signal, this described by Ricean/Rayleigh fading process. This has a high importance in system design when estimating the diversity gain and the resulting link quality and cell layout. This paper analyses the total power cross correlation the 2<sup>nd</sup> function of SNR and Rican K-factor [18].

### 2.6.3. Degenerate MIMO channel.

Degenerate channels condition is a result of propagation condition in which a pin-hole effect forces all path to go through single pin hole. Pin hole have both left and right hand (LHS and RHS) scatterers [2].

In general, degenerate channel results of the effect of pin hole which forces all paths from the transmitter to receiver to go through a single pin- hole [2].

The signal emerging scatters around transmitter (left hand side scatters), and scatters around the fixed receiver (right-hand side scatters). Between transmitter and receiver scatters we put a shield with a pin-hole or (key hole). This leads, the signal emerging from the pin \_hole is appoint source for the RHS scatters [2].

Assume a pin-hole channel that is a time and frequency flat channel, with  $M_R$  receive antenna and  $M_T$  transmit antenna. Because the pin-hole effect as point source the MIMO channel becomes:

$$\mathbf{H}=\mathbf{h}_r\mathbf{h}_t^T \tag{2.32}$$

Where  $\mathbf{h}_r$  is the  $M_R \times 1$ , and  $\mathbf{h}_t^T$  is the  $1 \times M_T$  [2].

In degenerate channel, the diversity order equal to  $\min (M_T, M_R)$ , and it has zero correlation and no capacity [2].

## **2.7. Combined space and path diversity.**

Diversity can be extracted from multipath, so that achieving both space and path (frequency) diversity, in cases when significant delay spread exists in the channel.

The diversity order improves with delay spread and the diversity is  $M_R L$ , in the SIMO it is  $M_T L$  in the MISO case, but there is a loss in array gain if the transmitter does not know the channel. Likewise, in MIMO case,  $M_R M_T L$  is the diversity gain that could be achieved, and of course the transmit array gain is lost if channel is unknown to the transmitter [2].

In [19], it was shown that the maximum diversity could be achieved in frequency-selective MIMO fading channel; using space-time codes which achieves full diversity in quastatic codes flat fading environment.

The investigated performance of the combination between diversity structures and equalization technique which operate in frequency-selective fading mobile radio environment characterized by two Rayleigh-fading beams shows that, when received signals on various diversity branches are statically independent, they have unequal signal to noise ratios. In this analysis, Quadrature amplitude modulation, combining diversity and selective diversity structure are considered. In these optimal diversity structures, both linear and decision feedback equalization with finite and infinite types are used [20].

In frequency selective fading, the unbalanced- diversity system still have effective operation although the mean power difference results in a degree of degradation that is proportional to it. The diversity gain is nearly lost for two path systems when unequal mean power exceeds 15 dB [20].

Paper [14] shows the effect of combining space and path diversity on TDMA for multimedia wireless communication system. It maximizes the average bit rate to 10Mb/sec with acceptable BER, and compensates the delay spread to 250 n sec of one symbol duration, in microcellular environment.

The study [21] evaluates the performance of wideband communication systems which combine antenna branch from multiple antennas and path from multiple paths for each selected antenna branch.

### **2.8. Diversity- Multiplexing trade off:**

The two competing MIMO gains achieved through diversity and SMUX can't be accomplished simultaneously. Link reliability is increased by transmit diversity which introduces redundancy in multiple dimensions (space, time, frequency,). So all available channels are used to send unique data (fewer streams). On the other hand, high spectral efficiency is achieved through SMUX technique, as it transmits symbol streams independently, and hence doesn't provide reliability directly. So there is a tradeoff between Diversity and SMUX gains [4]. Simple trade off technique is done by transmitting several simultaneous streams, where STBC is used to decode each stream benefiting from transmitting diversity. This technique is referred to as Open-Loop Hybrid schemes or Double Space-Time Transmit Diversity (DSTTD) [4].

The recent design of the wireless multi-antenna communications aims to achieve two main objectives through diversity and multiplexing techniques. Diversity usage in MIMO channels provides high-performance, while the capitalization of space-time multiplexing achieves high data rates by ensuring high capacity of MIMO fading channels. These two aims can be combined by designing full diversity full-rank (FDFR) giving any number of transmits and receives antennas. FDFR is applied for flat fading, frequency- selective and time fading MIMO channels [22].

In [23], it was shown that both diversity and multiplexing gains can be increased by multiple antenna utilization. Trade off between how much can coding schemes offer

of these two gains, although they can be obtained simultaneously in MIMO channel. This trade off is achieved by using STBC constructions.

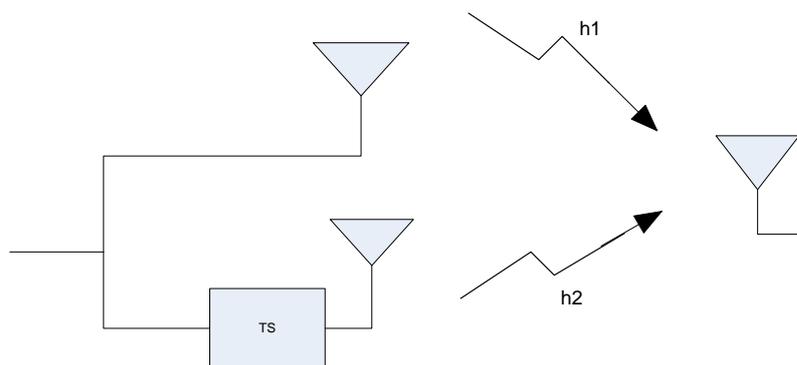
## 2.9. Indirect transmit diversity.

The spatial diversity may be converted to time/ frequency diversity which can be readily exploited using standard techniques (such that forward error correction FER). This part contains two parts: delay diversity, which converts space to frequency diversity, and phase- roll diversity, which converts space to time diversity [4].

### 2.9.1. Delay diversity

Delay diversity converts the available spatial diversity into frequency by the data signal from the first antenna and delayed replicas of the same from the second antenna [2].

It was shown that high rate generalized coded delays diversity scheme for any number of transmit and receive antennas, in which both the extreme points of optimal diversity-multiplexing trade off curve is met [23].

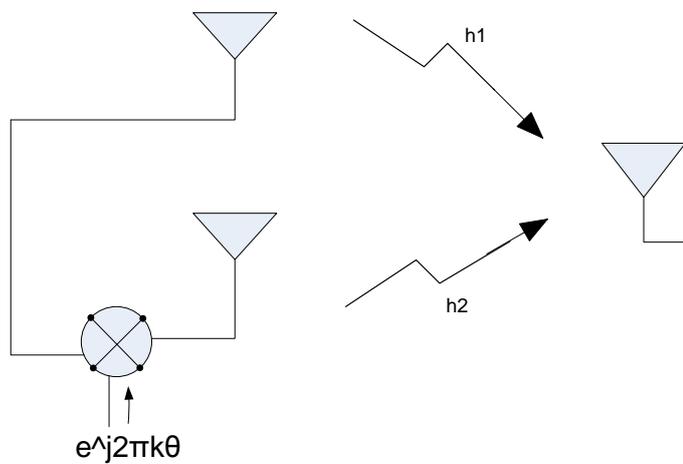


**Figure 2.2:** Schematic of delay diversity- a space selective channel at the transmitter is converted into a frequency selective channel at the receiver.

### 2.9.2. Phase – roll diversity

Phase-roll diversity converts space to time diversity, the effective channel in time is a SISO channel which is given by:

$$h[k] = h_1 + h_2 e^{j2k\pi\theta}, k=0,1,2,\dots \quad (2.33)$$



**Figure 2.3.** Schematic of phase roll-diversity – a space selective channel at the transmitter channel at the transmitter is converted into a time selective the receiver [2].

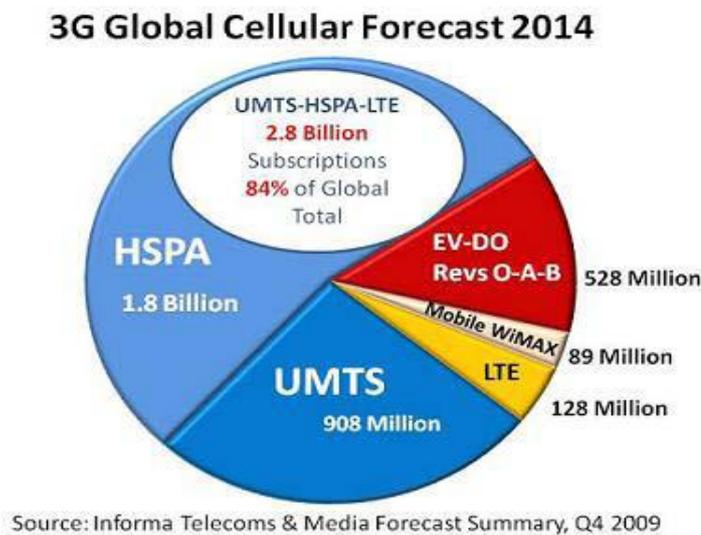
### 2.10. Combining methods

Combining the multiple versions of the signals created by different diversity schemes is needed for improving the performance. Maximal ratio combining technique uses a maximum-likelihood (ML) decoder to combine these M received signals to find the most likely transmitted signal. The sum of the received SNRs for M different paths is the effective receive SNR of a system with diversity M. Whereas, combining with equal weights leads to equal gain combining (EGC) which is a special case of maximum ratio. In equal gain combining, a unit weight is used to utilize co-phased signals. The receiver needs to demodulate all M receive signals in case of MRC for a

source with M independent signals in the received antennas. The signal with the highest SNR is picked and used for decoding in the selection combining or antenna selection. Picking the signal is equivalent to choosing the corresponding antenna among all received antennas [15].

### 2.11. Wireless data trends and forecasts:

There is a fast development in wireless communication, especially in wireless data revenue, and in the devices that in the hand of consumer. Also text messages and multimedia messages become popular at last few years, the total number of mobiles also is increasing according to the number of fixed broad band connections. Information telecommunication forecasts that at the end of 2014, the 3G wireless market will include 3.3 billion subscriptions; including 2.8 billion are 3GPP family technologies [24].



**Figure2.4.** 3G Cellular Forecast 2014

### **2.11.1. Releases' Improvements of 3G America.**

3G Americas is a new global wireless trade organization focused on the wireless industry in America. It was accepted as a new Market Representation Partner (MRP) of the Third Generation Partnership Project (3GPP™). The 3rd Generation Partnership Project (3GPP) was established for the preparation and maintenance of a complete set of globally applicable technical specifications for a Third Generation (3G) mobile system based on the evolved GSM core networks and the radio access technologies supported by 3GPP partners. Rel-7 continues to build on the strong foundation of Rel-5/Rel-6 by introducing further capacity enhancing features such as MIMO for HSDPA, and allows transmission of up to two parallel data streams to a MIMO UE over a single carrier [24]. Rel-7 HSPA+ networks are sometimes also deployed with MIMO antenna systems providing yet another upgrade in performance benefits. The evolution to 3GPP Rel-7 improved support and performance for real-time conversational and interactive services such as Push-to-Talk Over Cellular (POC), picture and video sharing, and Voice and Video over Internet Protocol (VOIP) through the introduction of features like Multiple-Input Multiple-Output (MIMO). At 3GPP, released 8 not only provides CDMA technology but also provide OFDM technology through the introduction of LTE, Rel-8 improves the capability to perform 64QAM modulation with 2x2 MIMO on HSPA+, and Rel-8 develops E-DCH enhancements to the common states (URA\_PCH, CELL\_PCH and CELL\_FACH) in order to improve data rates. In Rel-8, LTE defined a new physical layer specifications consisting of an OFDMA based downlink and SC-FDMA based uplink that developed carrier bandwidths from 1.4 MHz up to 20 MHz, Rel-8 also improves the enhancement for support for packet cable access. Rel-8 introduces the enabling of a base station to schedule HSDPA transmissions over two adjacent 5 MHz carriers simultaneously to the same user. Rel-9 updated status and significant details of Rel-8, Rel-9 focuses on enhancements to HSPA+ and LTE. Rel-9 introduces dual-band HSDPA operation, where in the downlink the primary serving cell resides on a carrier in one frequency band and the secondary serving cell on a carrier in another frequency

band. The uplink transmission takes place only on one carrier, which can be configured by the network on any of the two frequency bands [24].

In Rel-9, dual-band HSDPA operation is introduced for three different band combinations, one for each ITU region:

- Band I (2100MHz) and Band VIII (900MHz)
- Band II (1900MHz) and Band IV (2100/1700MHz)
- Band I (2100MHz) and Band V (850MHz)

Rel-9 combines dual-carrier HSDPA operation with MIMO, and improves the data rate in downlink call, and doubled the uplink peak rate to 23 Mbps for the highest modulation scheme (16QAM) [24]. Release 10 is referred to LTE-Advanced technology enhancements which include carrier aggregation, multi-antenna enhancements and relays [24].

## **Chapter Three**

### **Analysis of the Matlab Demo**

**3.1. Introduction.**

**3.2. The flow chart of the code.**

**3.3. The Code's parameters.**

**3.4. The Code's Analysis.**

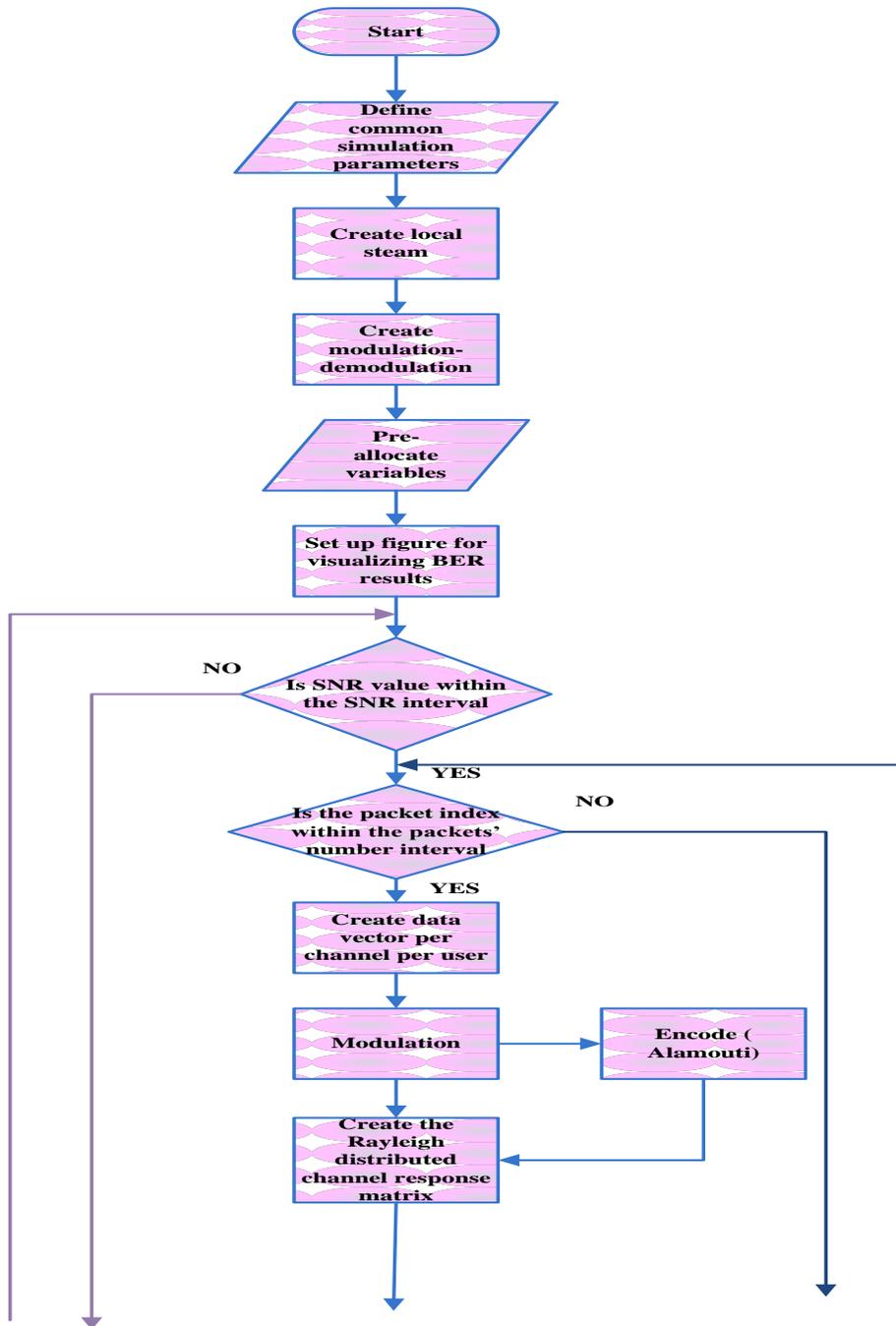
**3.5. The Resulted figures from simulating the code.**

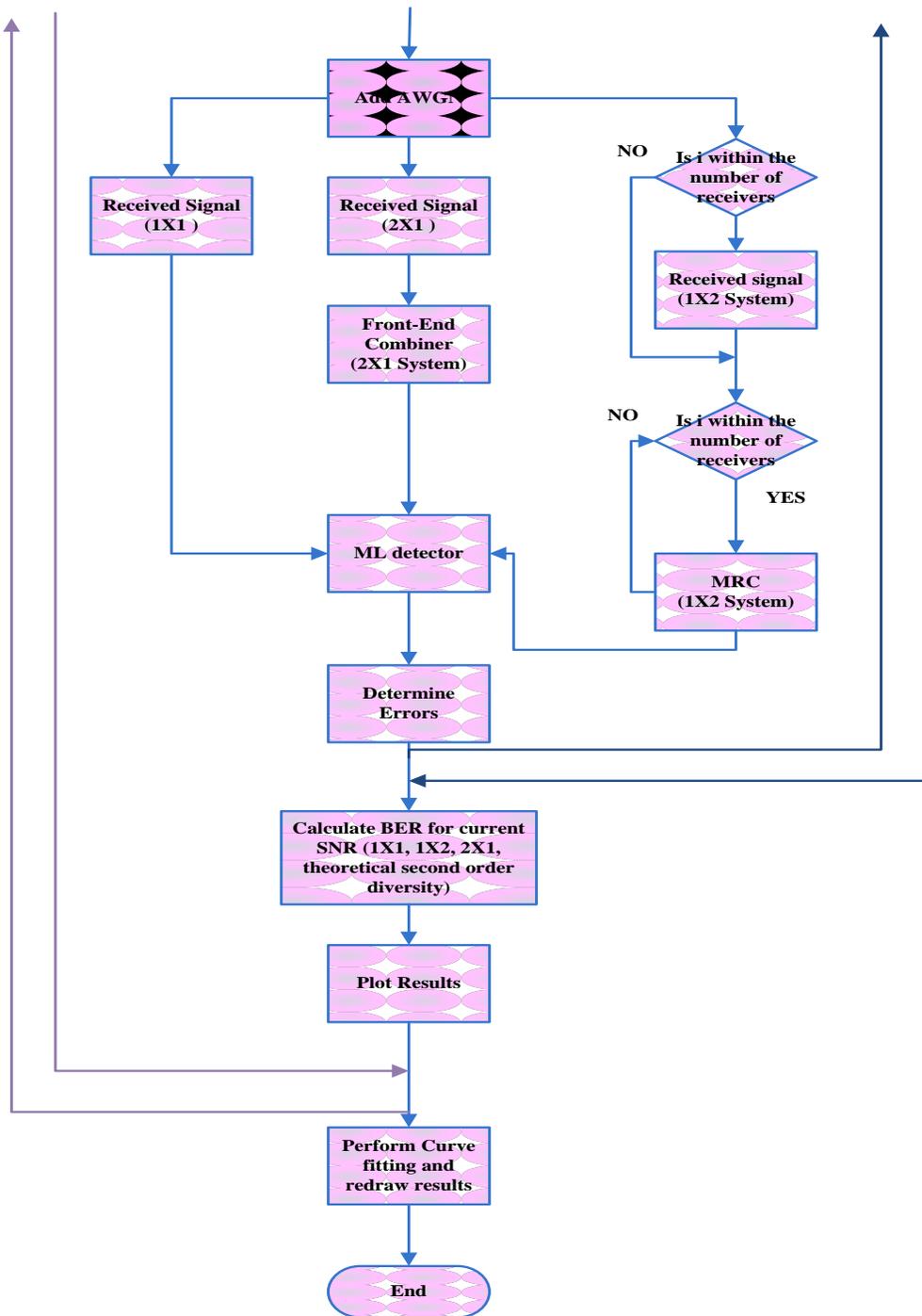
### **3.1. Introduction**

The Matlab demo shows a comparison of transmit vs. receive diversity by simulating coherent binary (BPSK) modulation over flat-fading Rayleigh channels. For transmit diversity, two transmit antennas are used and one receive antenna (2x1 notationally), while for receive diversity one transmit antenna and two receive antennas are employed (1x2 notationally).

The simulation covers an end-to-end system showing the encoded and/or transmitted signal, channel model, and reception and demodulation of the received signal. It also provides the no-diversity link (single transmit-receive antenna case) and theoretical performance of second-order diversity link for comparison. It is assumed here that the channel is known perfectly at the receiver for all systems. The simulation is run over a range of  $E_b/N_0$  points to generate BER in order to compare the different systems.

### 3.2. Code flow chart





**Figure 3.1:** Flow chart for the Diversity in 2X1, and 1X2 matlab code.

### 3.3. The Code's parameters.

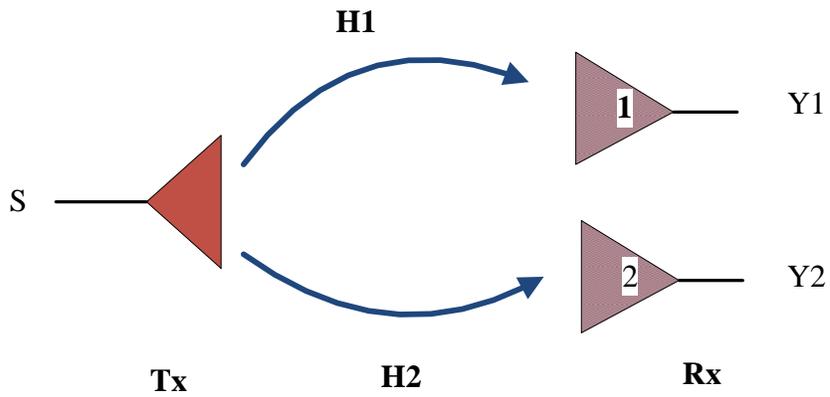
**Table 3.1:** the used parameters and their usage.

<b>Parameter</b>	<b>The usage of the parameter</b>
<b>frmLen</b>	Frame length
<b>numPackets</b>	Number of packets
<b>EbNo</b>	Signal to noise ratio (SNR)
<b>N</b>	Maximum number of Tx antennas
<b>M</b>	Maximum number of Rx antennas
<b>HStr</b>	Local random stream
<b>P</b>	Modulation order
<b>tx2</b>	Transmitter
<b>H</b>	Channel matrix
<b>r21</b>	Receiver in 2X1 System
<b>r12</b>	Receiver in 1X2 System
<b>z21</b>	Combined signal in 2X1 System
<b>z21_1</b>	Combined received signals from first transmitt antenna in 2X1 System
<b>z21_2</b>	Combined received signals from first transmitt antenna in 1X2 System
<b>z12</b>	Combined signal in 1X2 System(MRC)
<b>error11</b>	Errors in 1X1 uncoded system
<b>error21</b>	Errors in 2X1 coded system
<b>error12</b>	Errors in 1X2 coded system
<b>BER11</b>	BER for uncoded 1X1 system
<b>BER21</b>	BER for coded 2X1 System
<b>BER12</b>	BER for Maximal-ratio combined 1X2 system
<b>BERthy2</b>	Theoretical performance of 2 <sup>nd</sup> diversity

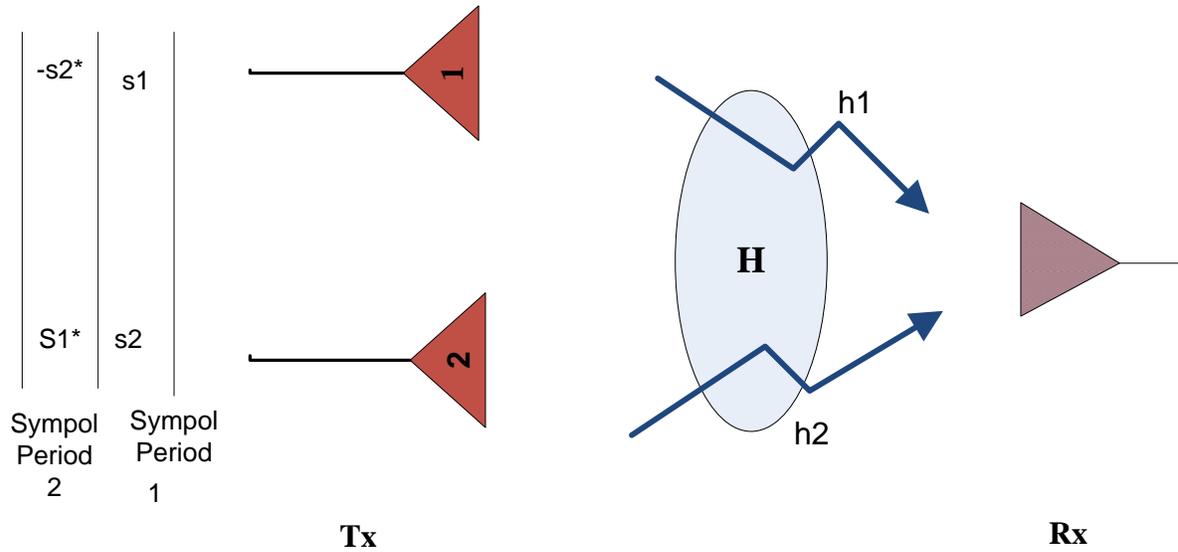
### 3.4. The Code's Analysis.



**Figure 3.2:** 1X1 Uncoded no diversity System.



**Figure 3.3:** 1X2 Receive diversity system.



**Figure 3.4:** 2X1 Transmit diversity using Alamouti scheme.

This demo discusses an end to end system, it compares the performance of three different systems: nodiversity uncoded (1X1)system as shown in figure 3.2, receive diversity (1X2) system which is shown in figure 3.3, and (2X1) diversity system using Alamouti scheme which is shown in figure 3.4, compering these systems with the theoretical diversity.

No diversity uncoded system: first the date generated by random generator as data vector per user per channel, then it is modulated using BPSK,after that it is transmitted through Rayleigh channel where AWGN is added to the transmitted signal. At receiver end, the received signal is combined and ML detector is used to detect the transmitted signal, then BER is calculated.

2X1 diversity system using Alamouti scheme: in this scheme it is assumes that the transmitter uses two transmit antennas to transmit the same signal, so after generating the data and modulating it, it is encoded using Alamouti encoder befor it is transmitted through the Rayleigh channel then AWGN is added to the signal. At receiver end, the received signal is combined and ML detector is used to detect the transmitted signal, then BER is calculated.

Receive diversity (2X1) system, here the data is not encoded before being transmitted but after it's reception it is combined using MRC, then, it passes to the ML detector. Finaly, BER is calculated after calculating the errors.

### **3.5. The Resulted figures from simulating the code.**

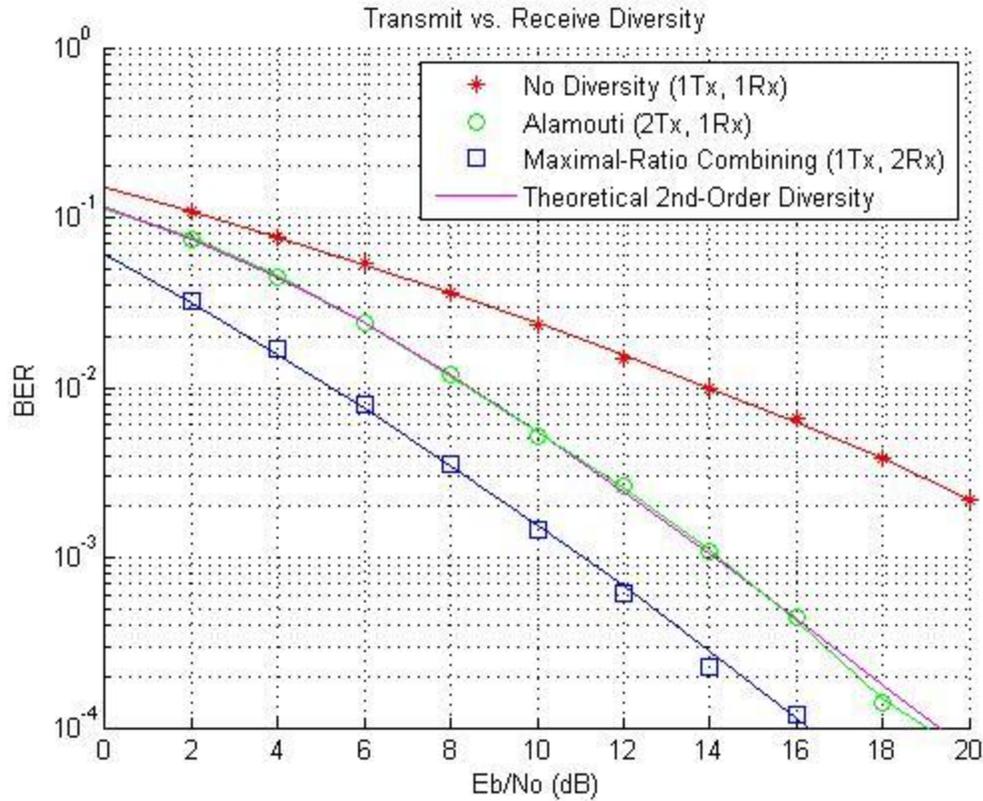
#### **3.5.1. Resulted figures from simulating the code if BPSK modulation-demodulation is used.**

Here it is assumed that binary phase shift keying (BPSK) is used as modulation scheme.

For the following figures it is assumed that  $N=M=2$ .

##### **3.5.1.1. Senario One: The analysis for the resulted figures due to changing the frame length.**

It is assumed that the number of packets equals 1000 packets and SNR varies between 0:2:20 dB, but the frame length is variable.

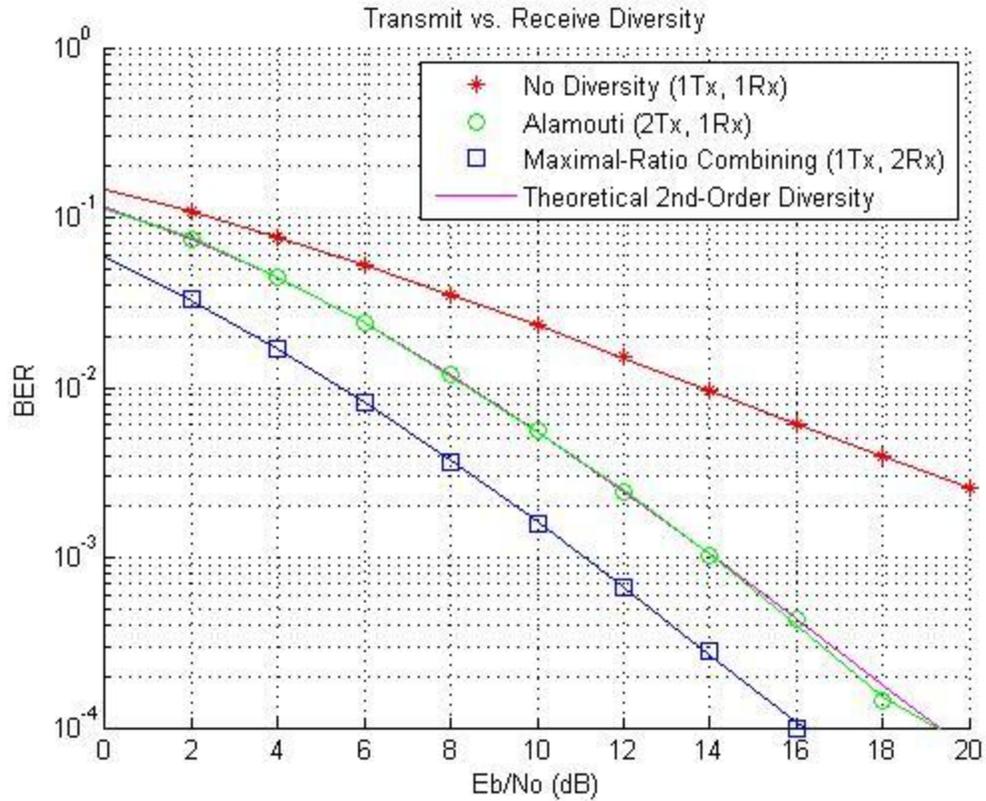


**Figure 3.5:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when the frame length equals 100.

The simulation results show that using two transmit antennas and One receive antenna provides the same diversity order as the maximal-ratio Combined (MRC) system of one transmit antenna and two receive antennas. It is clear that there is a 3dB difference in the case of MRC due to array gain.

The simulation results shows that the relationship between the BER and the SNR values. The figure shows four cases: no diversity, maximal ratio combining, Alamouti schemes, and 2<sup>nd</sup> order diversity. For the same value of  $E_b/N_0$  the no diversity has the largest value of BER.

The theoretical performance of second-order diversity link matches the transmit diversity system as it normalizes the total power across all the diversity branches.

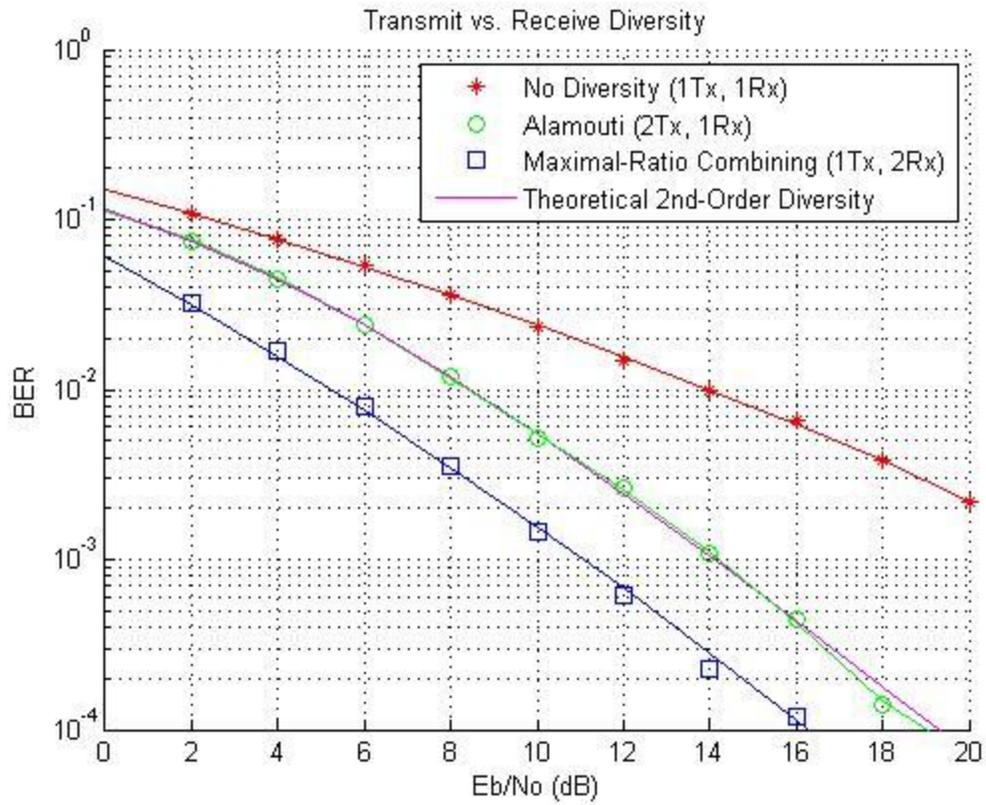


**Figure 3.6:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when the frame length equals 10000.

When the frame length is increased the four systems keeps the same diversity performance, but there is a small increase in the bit error rate for no diversity system at SNR 20dB.

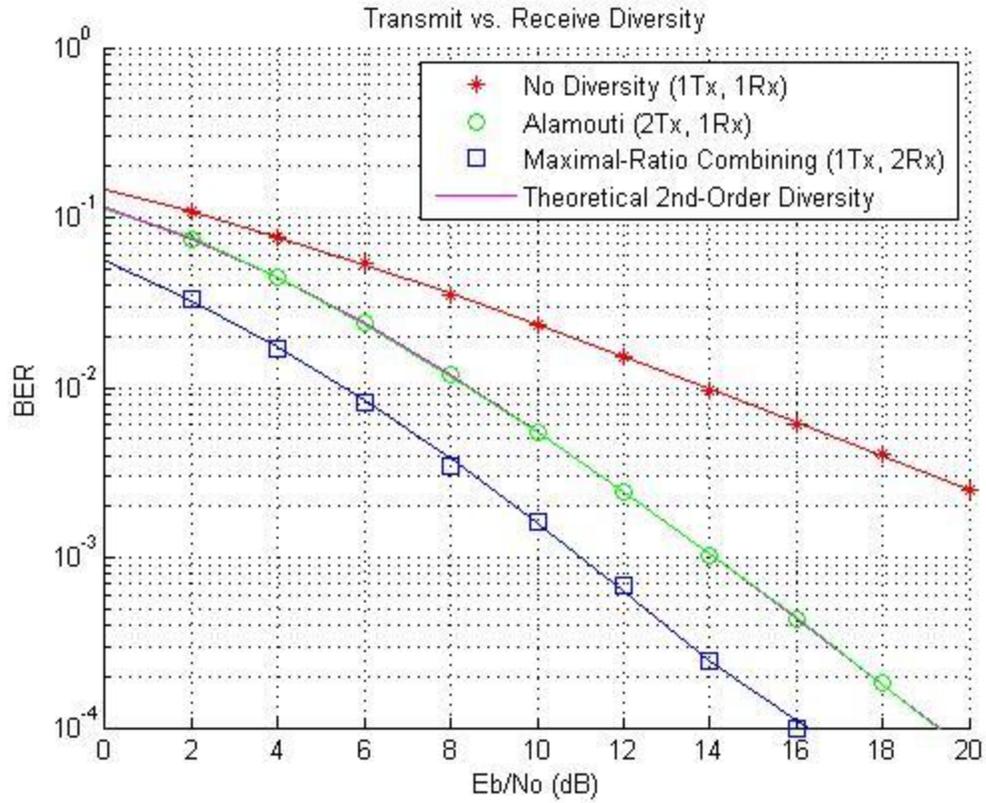
**3.5.1.2. Senario Two: The analysis for the resulted figures due to changing the number of packets.**

It is assumed that the frame length equals 100 and SNR varies between 0:2:20 dB, but the number of packets is variable.



**Figure 3.7:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when the number of packets equals 10000.

It is clear that increasing the number of packets does not affect the performance of the four systems.

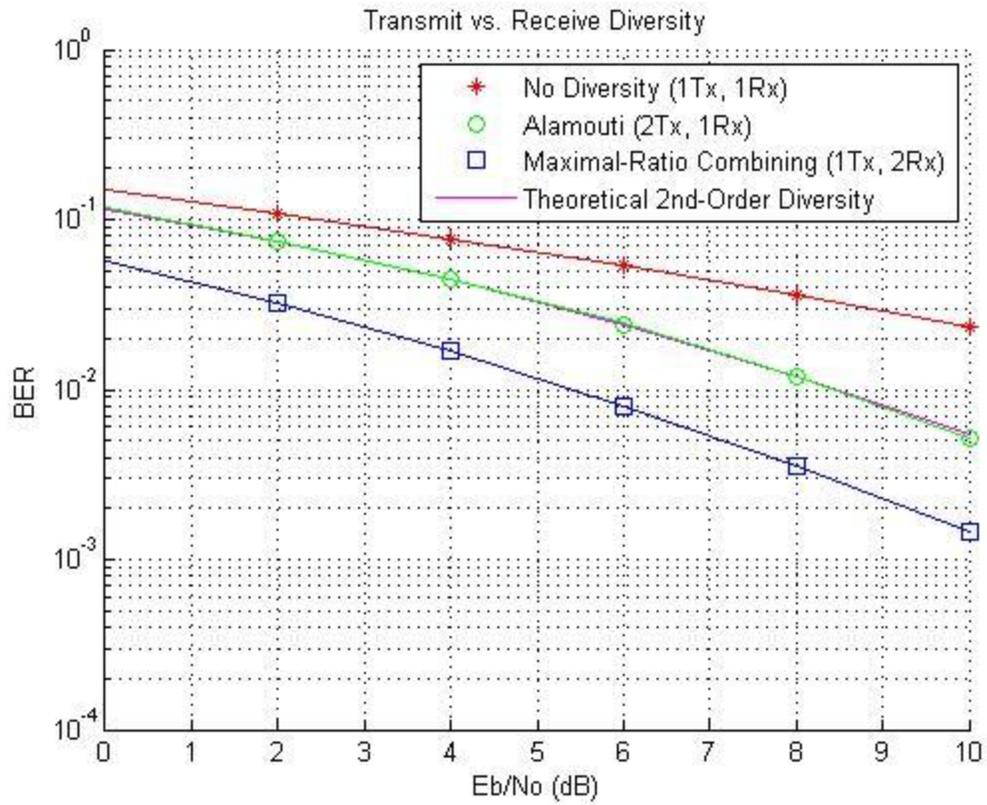


**Figure 3.8:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when the number of packets equals 20000.

It is clear that farther increase in the number of packets does not affect the performance of the four systems.

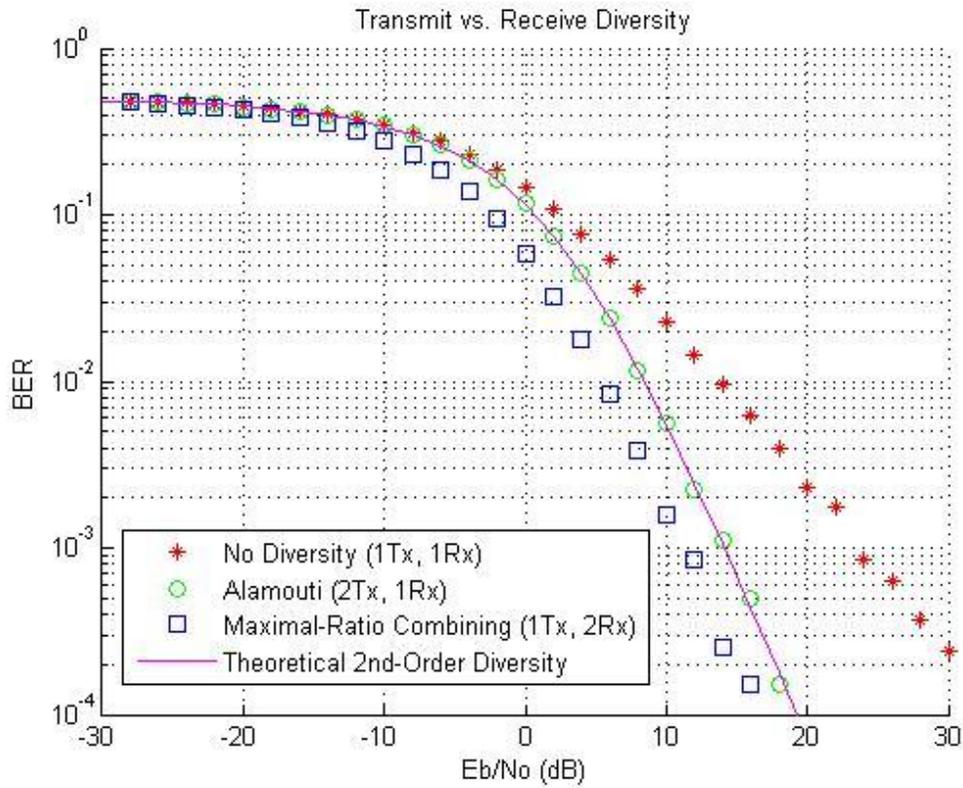
### 3.5.1.3. Scenario Three: The analysis for the resulted figures due to changing the $E_b/N_0$ .

It is assumed that the frame length equals 100 and number of packets equals 1000 packet, and SNR is variable.



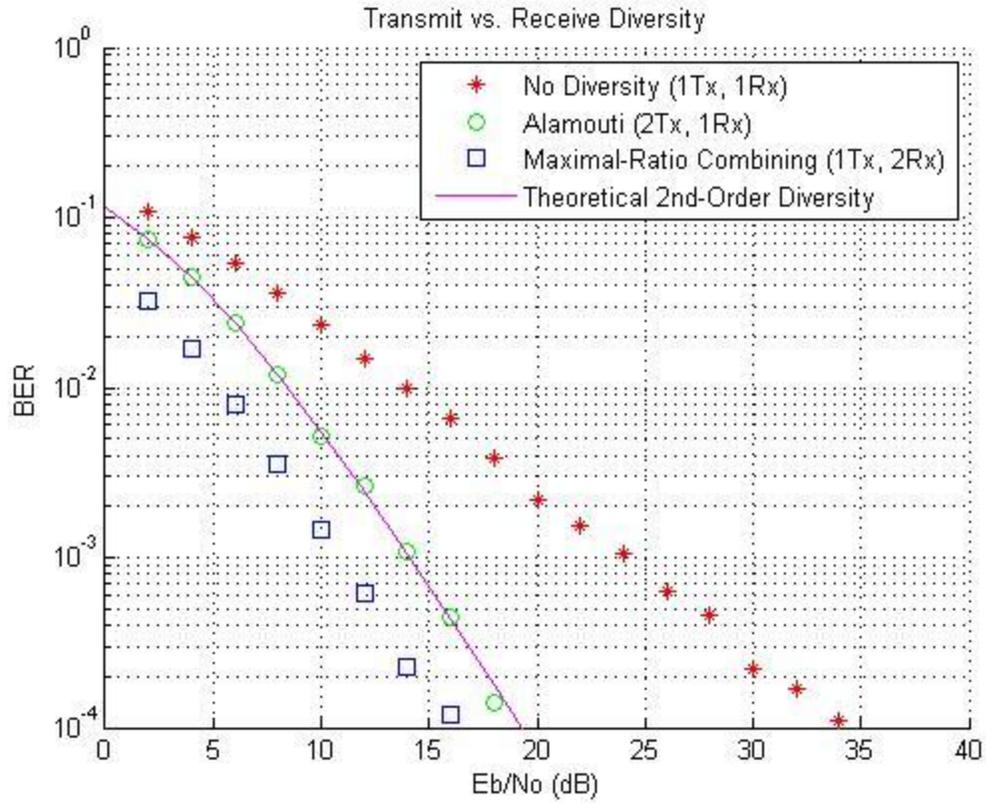
**Figure 3.9:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when  $E_b/N_0$  is in the range 0:2:10 dB.

It's clear that the BER decreases by increasing  $E_b/N_0$  but this decrease is small for the small values of  $E_b/N_0$ .



**Figure 3.10:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when  $E_b/N_0$  is in the range -30:2:30 dB.

In the negative range of  $E_b/N_0$  it's obvious that the BER is very high since the noise power is greater than the signal power. The four systems are enhanced as the  $E_b/N_0$  values is increased; since increasing  $E_b/N_0$  reducing the BER.



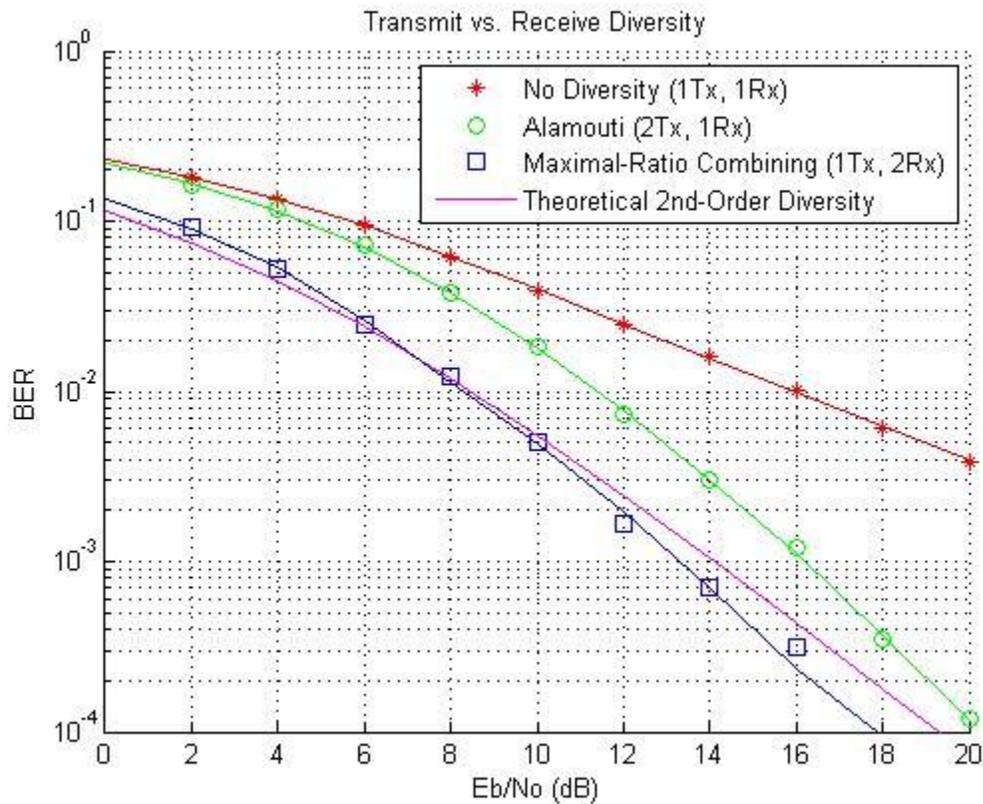
**Figure 3.11:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when  $E_b/N_0$  is in the range 0:2:40 dB.

Here the role of diversity is very clear in improving the system performance; for example we need nearly 20dB to achieve BER of order  $10^{-4}$  using Alamouti while we need more than 35dB to achieve the same BER in no diversity system.

### 3.5.1.4. Scenario four: The analysis for the resulted figures due to changing the channel.

For the following results the frame length is 100, the number of packets is 1000, and the  $E_b/N_0$  range is 0:20dB.

**Case one: The analysis for the resulted figures due to replacing the randn function with rand in the channel matrix.**

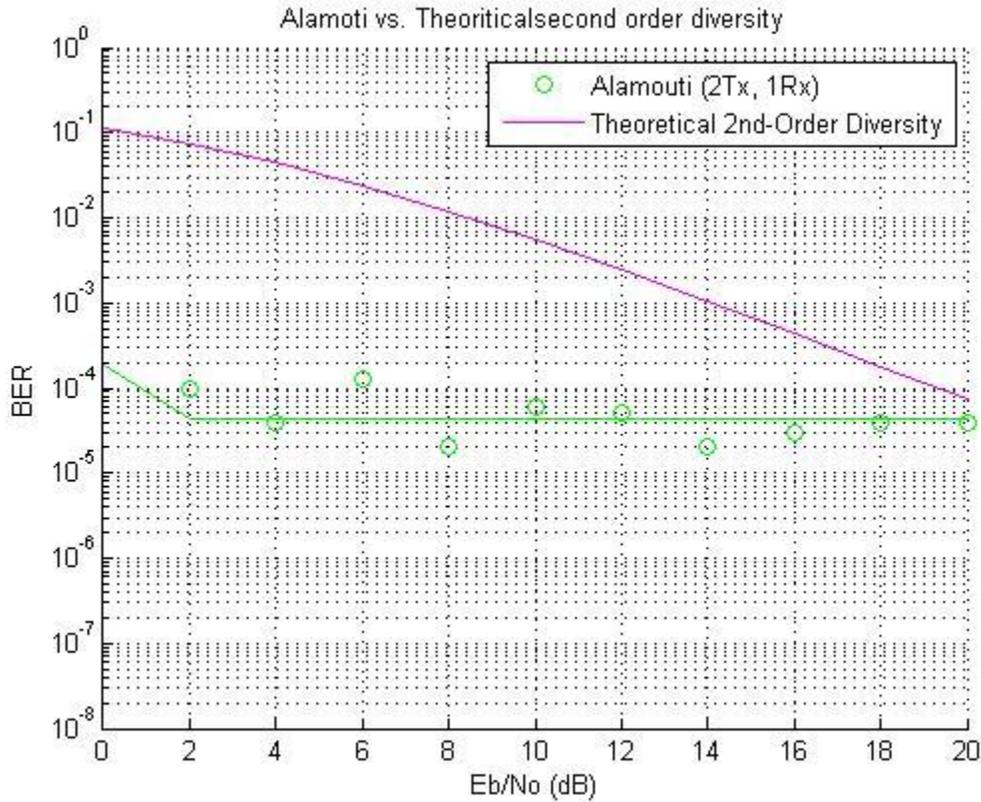


**Figure 3.12:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when rand function is used instead of randn in the channel matrix H.

When rand function is used in the channel matrix, the performance of the four systems is reduced, MRC behaves same as the theoretical 2<sup>nd</sup> order Diversity, Alamouti performance becomes worse than its performance at the original channel conditions.

**Case Two: The analysis for the resulted figures due changing the channel matrix as follows:**

$$H(1:N:end, :, :) = (\text{randn}(\text{hStr}, \text{frmLen}/2, N, M) + 1i * \text{randn}(\text{hStr}, \text{frmLen}/2, N, M)) * 10;$$

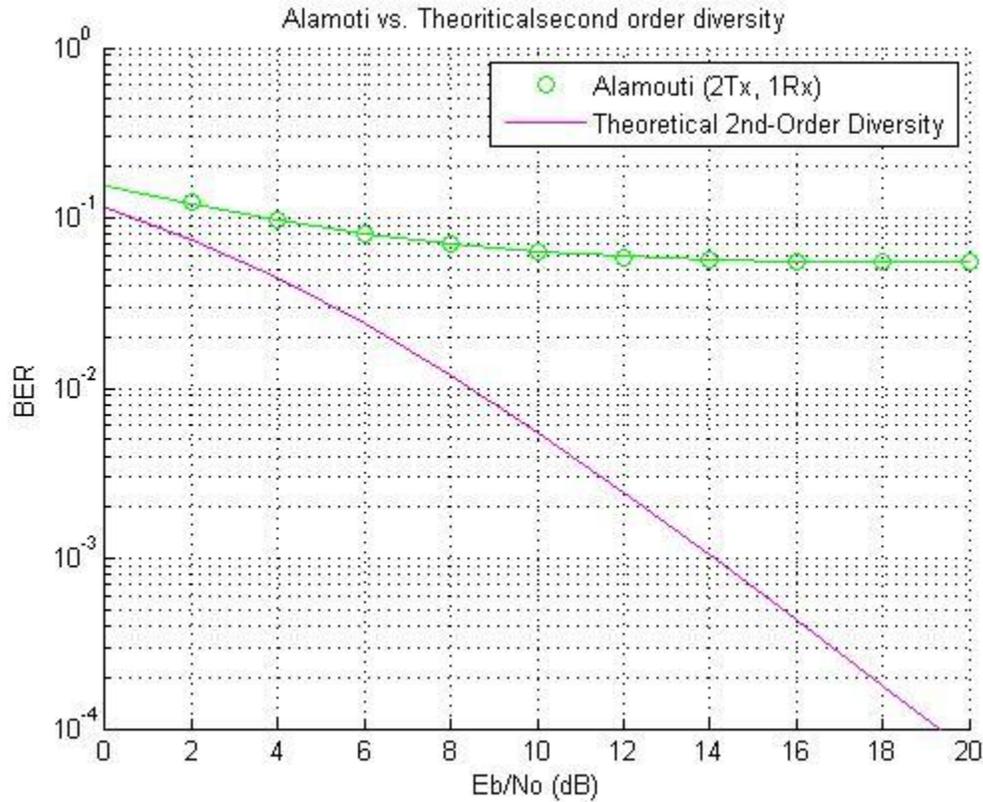


**Figure**

**3.13:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when the channel is changed.

When the channel is channel Alamouti gives small BER so better performance but its performance is doesn't change by changing the Eb/No.

**Case Three: The analysis for the resulted figures if H is assumed to change at the two symbol interval:**

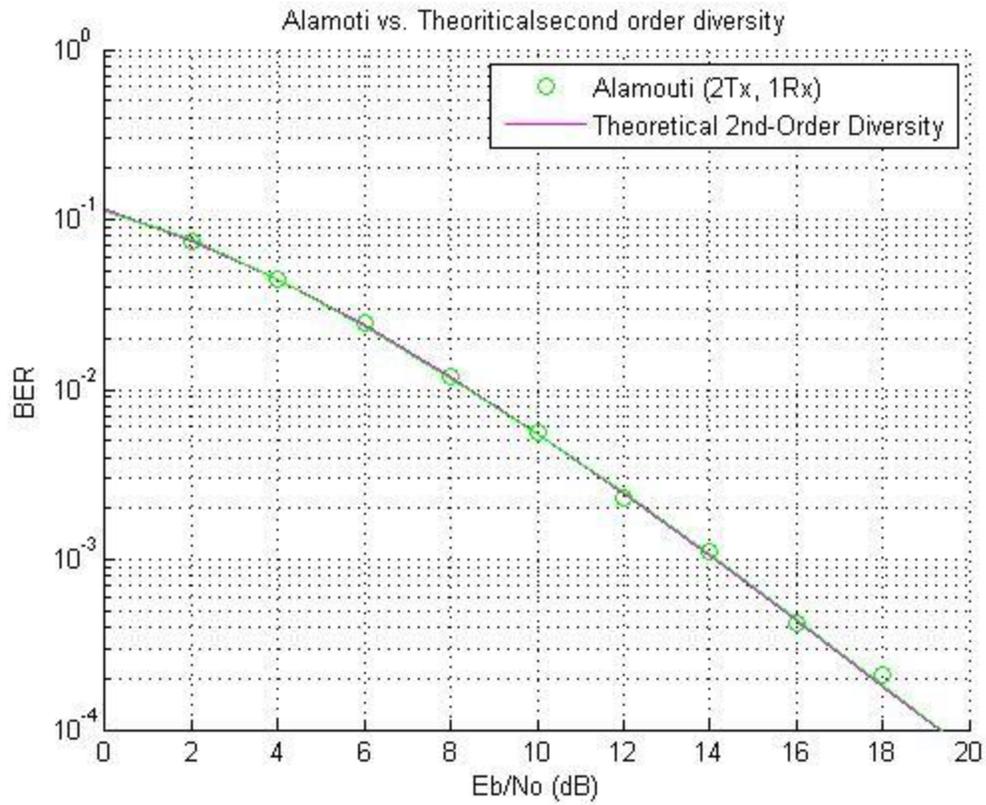


**Figure 3.14:** Comparison between the 1X1, 2X1, 1X2, and the theoretical second order diversity schemes when the channel is changed.

The performance of Alamouti become very bad when channel does not held constant for 2 symbol periods.

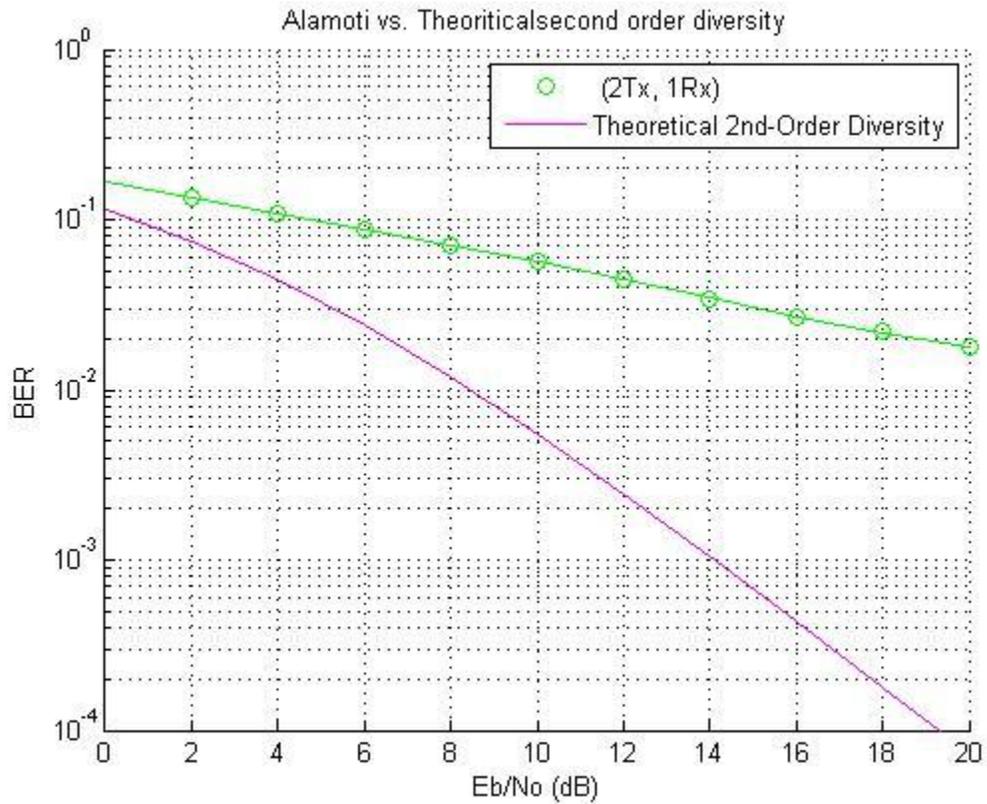
**3.5.1.5. Scenario Five: The analysis for the resulted figures due to the orthogonality of Alamouti.**

For the following results the frame length is 100, the number of packets is 1000, and the  $E_b/N_0$  range is 0:20dB.



**Figure 3.15:** Comparison between the Alamouti performance and theoretical second order diversity schemes.

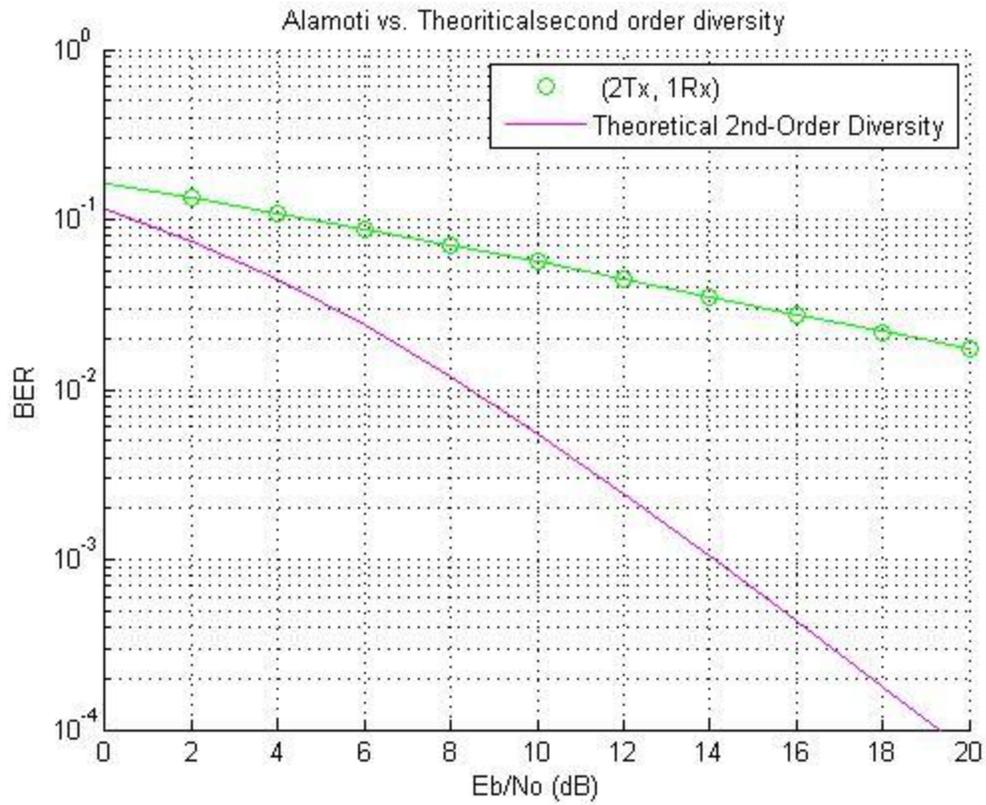
The theoretical performance of second-order diversity link matches Alamouti system.



**Figure 3.16:** The performance of Alamouti vs. theoretical second order.

The performance is decreasing and getting worse when G2 is changed. Using Alamouti achieves the orthogonality between s1 and s2 and so best performance is obtained.

Here,  $G2 = \begin{bmatrix} s1 & s2 \\ -s2^* & -s1 \end{bmatrix}$ .



**Figure 3.17:** The performance of Alamouti vs. theoretical second order.

The performance is decreasing when  $G_2$  is changed because the two symbols are not orthogonal.

Here,  $G_2 = [s_1 \ s_2; s_2^* \ s_1]$ .

**Table 3.2:** Results of simulating the Matlab code “Transmit vs. Receive Diversity”.

<b>Parameters</b>	<b>The effect on the systems</b>
<b>Fixed Parameters</b>	2X1 antenna system provides the same diversity order 1X2 antenna. MRC receive diversity has a 3 dB advantage when compared to Transmit diversity. The theoretical performance of second-order diversity link matches the transmit diversity system as it normalizes the total power across all the diversity branches.
<b>Changing the frame length</b>	Changing the frame length does not affect the systems' performances.
<b>Changing the number of packets</b>	Changing the number of packets does not affect the systems' performances.
<b>Changing the SNR range</b>	There is a considerable improvement in Alamouti and MRC performances as $E_b/N_0$ values are increased.
<b>Changing Symbols orthogonality</b>	The performance of the 2X1 system gets worse, so Alamouti gives the best performance.
<b>Changing the channel matrix</b>	The performance of the 2X1 system gets worse by changing the channel matrix.

## **Chapter Four**

### **Simulation Results**

**4.1. Introduction.**

**4.2. Flow chart**

**4.3. Constructing MIMO System for Diversity.**

**4.4. Simulation Setup.**

**4.5. Results.**

**4.6. Discussions.**

## 4.1. Introduction

This project simulates the Diversity performance of  $N \times M$  MIMO system. Diversity was achieved through the use of orthogonal space-time block coding technique (OSTBC) at the transmitter, which is a recent innovation motivated by the need for higher throughput in wireless channel [25]. Matlab is used to simulate  $N \times M$  MIMO system where  $N = 2, 3, 4, 6, 7$  and  $8$ , and  $M$  varies between  $2$  and  $10$  (or  $16$ ) and OSTBC is used to encode the BPSK modulated signal before being transmitted through flat fading Rayleigh channel. At the receiving end, the received signals were combined by Maximal Ratio Combiner (MRC) and detected by Maximum-Likelihood (ML) detector. The  $N \times M$  simulations achieved low BER without the need for high SNR values.

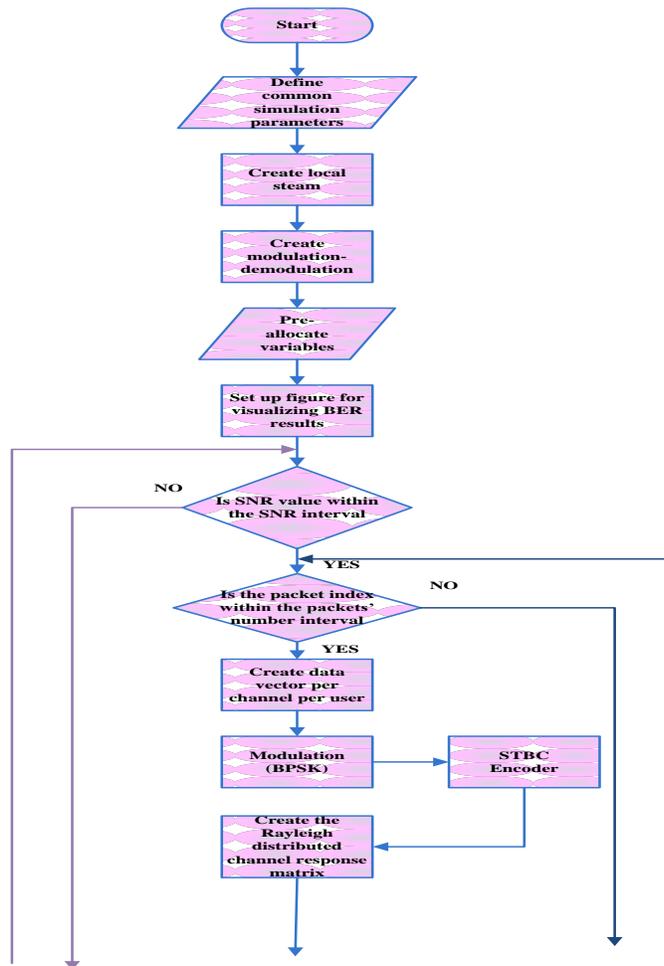
Based on the design of OSTBC a new quasi-orthogonal space time block code (STBC) was introduced for diversity usage in different MIMO configurations. Diversity was achieved through creating new STBCs for  $16 \times 16$  MIMO then based on that  $16 \times (14, 12, 10, 8, 6, 4, 2)$  were constructed. The new STBC simulations achieved  $10^{-3} - 10^{-6}$  BERs at low  $E_b/N_o$  values. Moreover other quasi-OSTBC matrices were built for  $(10, 12$  and  $14) \times M$  MIMO Systems depending on the  $16 \times 16$  matrix. These New matrices also achieve good performance under low SNR values.

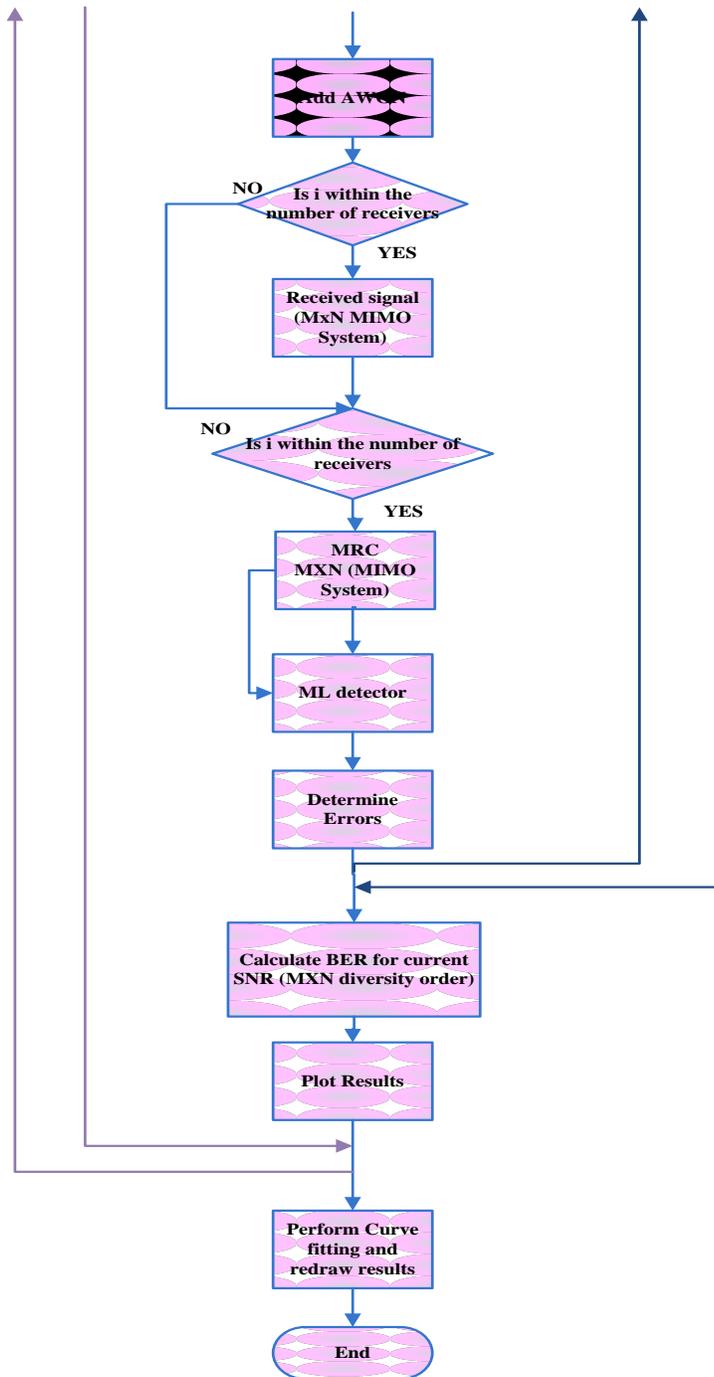
Finally, realistic scenario where the channel state information is not known at the receiver was considered, this information has to be extracted from the received signal. It is assumed that the channel estimator performs this using orthogonal pilot signals that are prepended to every packet [26]. It is assumed that the channel remains unchanged for the length of the packet (i.e., it undergoes slow fading).

## 4.2.Flow chart

### 4.2.1.The Flow chart for $M \times N$ MIMO System

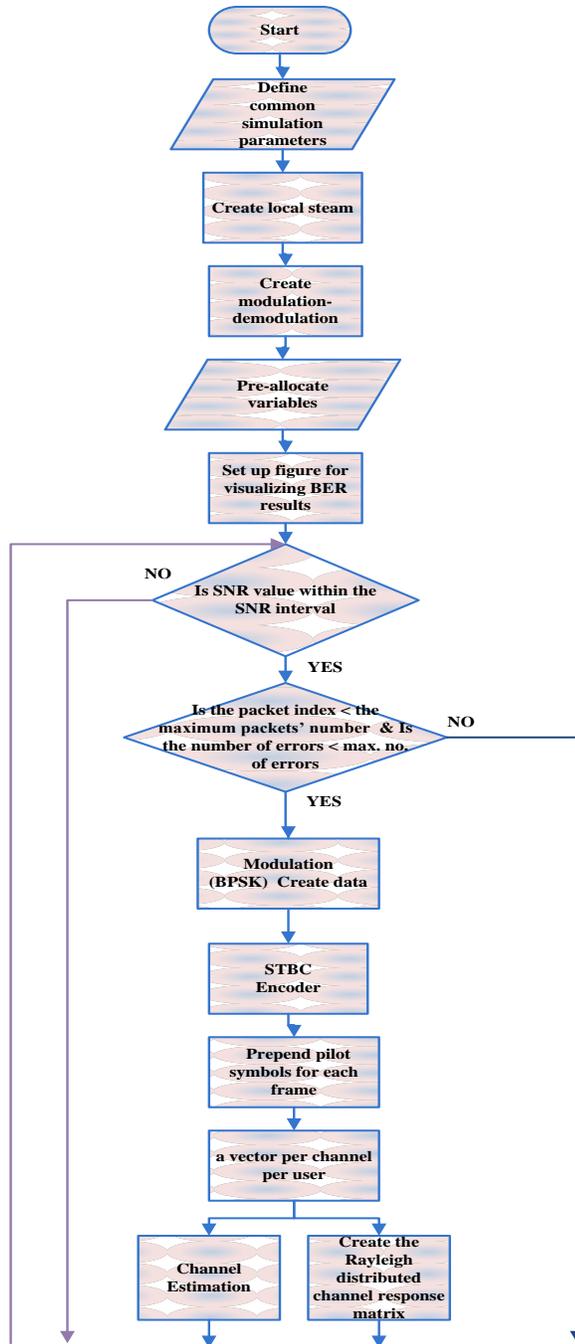
The flow chart for general  $M \times N$  MIMO System is shown in the figure below:

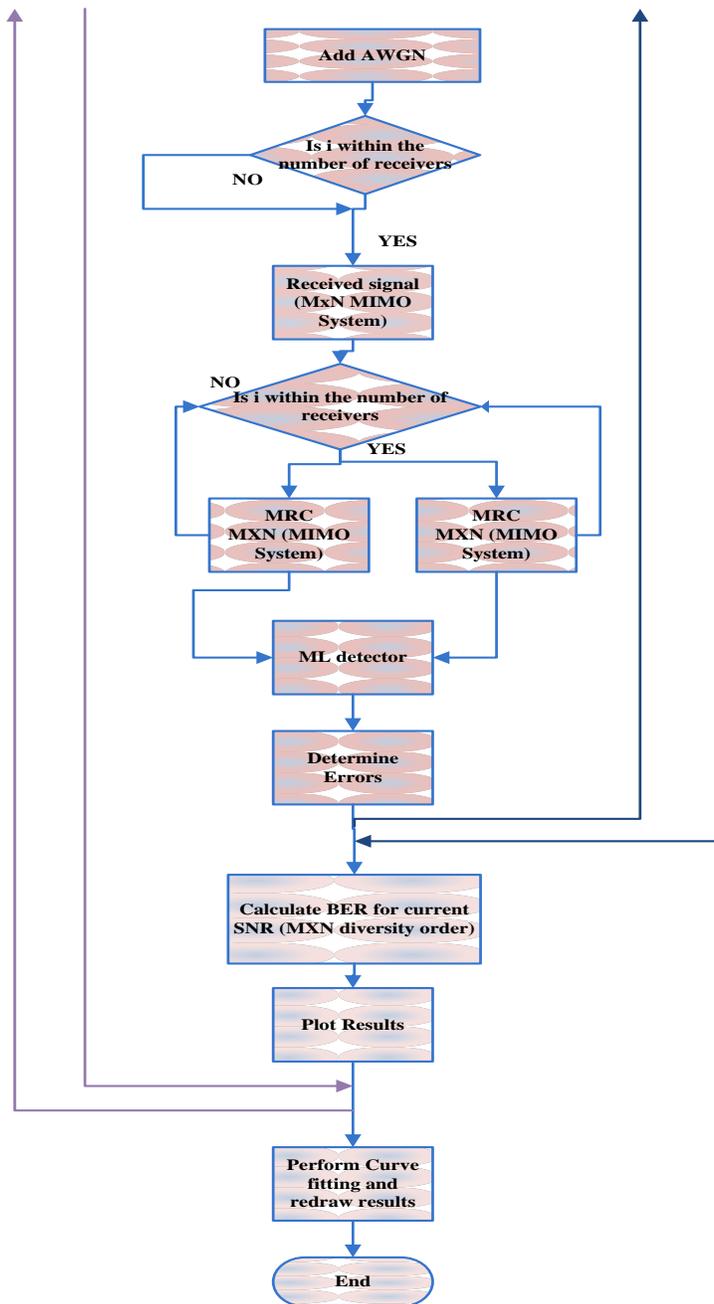




**Figure 4.1:**The Flow chart for M×N MIMO System.

**4.2.2. The Flow chart for comparing known vs. estimated channel for the receiver in  $M \times N$  MIMO System:**





**Figure 4.2:**The Flow chart of known vs. estimated channel for the receiver in  $M \times N$  MIMO System.

### 4.3. Constructing MIMO System for Diversity

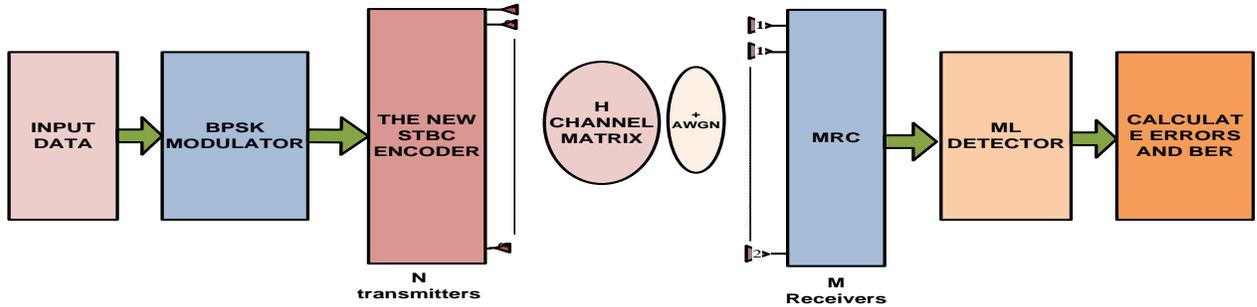
This project shows a Matlab simulation for the diversity in MIMO systems by applying both transmit and receive antenna diversity through means of Space-Time Block Coding (STBC), which are constructed from known orthogonal designs, achieving full diversity, and are easily decodable by maximum likelihood decoding via linear processing at the receiver. A MIMO system consisting of  $N$  transmit antenna elements equal to 2, 3, 4, 6, 7 and 8, and of  $M$  receive antenna elements was modeled, accordingly diversity order of  $N \times M$  can be achieved.

Then a new quasi-orthogonal STBC is constructed and based on it Matlab simulation for the diversity in MIMO systems were as shown in Fig.4.13. The quasi-orthogonal STBC was constructed through various trials on manipulating some known orthogonal designs to achieve diversity. Multiple MIMO systems consisting of  $N$  transmit antenna elements equal to sixteen, and of  $M$  receive antenna elements equal to (2, 4, 6, 8, 10, 12, 14, 16) were modeled, accordingly diversity order of  $16XM$  can be achieved.

Depending on the design of the  $16XM$  Quasi-OSTBC other MIMO systems such as (10, 12, and 14)  $XM$  was constructed.

Combining the multiple versions of the signals created by different diversity schemes is needed for improving the performance. The project applies maximal ratio combining (MRC) technique using maximum-likelihood (ML) decoder to combine these  $M$  received signals to resonate on the most likely transmitted signal. The sum of the received SNRs from these  $M$  different paths is the effective received SNR of the system with diversity  $M$ . The receiver needs to demodulate all  $M$  receive signals in case of MRC for a source with  $M$  independent signals in the receive antennas [15].

The following block diagram represents the MIMO systems:



**Figure 4.3:** Block diagram for the  $N \times M$  MIMO system.

The following matrices in which the columns represent the symbol period (time slots) and the rows represent the antennas (space) are used to generate the STBC [2,15]. These matrices are considered as the main part in building the code which is used to simulate the performance of different MIMOs.

➤ **Two transmit-M receive antenna diversity (Full rate G2) [1]:**

$$\mathbf{G}_{2\text{-Alamouti}} = \begin{bmatrix} s1 & -s2^* \\ s2 & s1^* \end{bmatrix}$$

..... (1)

➤ **Three transmit-M receive antenna diversity (3/8 rate S3) [16]:**

$$\mathbf{G}_{3\text{-transmitters}} = \begin{bmatrix} s1 & -s2 & -s3 & 0 \\ s2 & s1 & 0 & -s3 \\ s3 & 0 & s1 & s2 \end{bmatrix} \dots\dots\dots (2)$$

$$\mathbf{S3} = [\mathbf{G3}, \mathbf{G3}^*] \dots\dots\dots (3)$$

➤ **Four transmit-M receive antenna diversity (Half rate S4) [16]:**

$$\mathbf{G}_{4\text{-transmitters}} = \begin{bmatrix} s1 & -s2 & -s3 & -s4 \\ s2 & s1 & s4 & -s3 \\ s3 & -s4 & s1 & s2 \\ s4 & s3 & -s2 & s1 \end{bmatrix} \dots\dots\dots (4)$$

$$\mathbf{S4} = [\mathbf{G4}, \mathbf{G4}^*] \dots\dots\dots (5)$$

- Six transmit-M receive antenna diversity (3/8 rate S6):

$$G_{6\text{-transmitters}} = \begin{bmatrix} s1 & -s2 & -s3 & -s4 & -s5 & -s6 & 0 & 0 \\ s2 & s1 & s4 & -s3 & s6 & -s5 & 0 & 0 \\ s3 & -s4 & s1 & s2 & 0 & 0 & s5 & s6 \\ s4 & s3 & -s2 & s1 & 0 & 0 & -s6 & s5 \\ s5 & -s6 & 0 & 0 & s1 & s2 & -s3 & -s4 \\ s6 & s5 & 0 & 0 & -s2 & s1 & s4 & -s3 \end{bmatrix}$$

$$S6 = [G6, G6^*] \dots\dots\dots (6)$$

- Seven transmit-M receive antenna diversity (7/16 rate S7) [16]:

$$G_{7\text{-transmitters}} = \begin{bmatrix} s1 & -s2 & -s3 & -s4 & -s5 & -s6 & -s7 & 0 \\ s2 & s1 & s4 & -s3 & s6 & -s5 & 0 & s7 \\ s3 & -s4 & s1 & s2 & -s7 & 0 & s5 & s6 \\ s4 & s3 & -s2 & s1 & 0 & s7 & -s6 & s5 \\ s5 & -s6 & s7 & 0 & s1 & s2 & -s3 & -s4 \\ s6 & s5 & 0 & -s7 & -s2 & s1 & s4 & -s3 \\ s7 & 0 & -s5 & s6 & s3 & -s4 & s1 & -s2 \end{bmatrix}$$

$$\dots\dots\dots(7)$$

$$S7 = [G7, G7^*] \dots\dots\dots(8)$$

➤ **Eight transmit- M receive antenna diversity (Half rate S8) [16]:**

$$\mathbf{G}_{8\text{-transmitters}} = \begin{bmatrix} s_1 & -s_2 & -s_3 & -s_4 & -s_5 & -s_6 & -s_7 & -s_8 \\ s_2 & s_1 & s_4 & -s_3 & s_6 & -s_5 & -s_8 & s_7 \\ s_3 & -s_4 & s_1 & s_2 & -s_7 & -s_8 & s_5 & s_6 \\ s_4 & s_3 & -s_2 & s_1 & -s_8 & s_7 & -s_6 & s_5 \\ s_5 & -s_6 & s_7 & s_8 & s_1 & s_2 & -s_3 & -s_4 \\ s_6 & s_5 & s_8 & -s_7 & -s_2 & s_1 & s_4 & -s_3 \\ s_7 & s_8 & -s_5 & s_6 & s_3 & -s_4 & s_1 & -s_2 \\ s_8 & -s_7 & -s_6 & -s_5 & s_4 & s_3 & s_2 & s_1 \end{bmatrix} \dots\dots\dots (9)$$

$$\mathbf{S8} = [\mathbf{G8}, \mathbf{G8}^*] \dots\dots\dots (10)$$

G3 is constructed by eliminating the fourth row from G4 and transmitting zero instead of  $s_4$  reducing S3 rate to 3/8. The same way is followed in constructing G7 (S7's rate is 7/16) and G6 (S6's rate is 3/8) from G8 by eliminating the eighth or eight and seventh rows respectively, where  $s_8$  is replaced by zeros in G7 and both  $s_8$  and  $s_7$  are replaced by zeros in G6.

$$\mathbf{S} \times \mathbf{S}^* = \text{diagonal matrix} = n\mathbf{I} \dots\dots\dots (11)$$

Where  $n = 2 \sum_1^N S_i S_i^*$  and  $\mathbf{I}$  is the identity matrix, this ensures that S is orthogonal.

The MIMO output given by:

$$\mathbf{Y} = \mathbf{H}^T \times \mathbf{S} + \mathbf{N} \dots\dots\dots (12)$$

Where:

$\mathbf{S}$ : Is the input data matrix formulated above as orthogonal STBC.

$\mathbf{N}$ : Zero Mean Circularly Symmetric Complex Gaussian noise matrix.

$H$ : Is an i.i.d complex matrix consisting of frequency flat-fading Rayleigh channels representing the channel response between transmit antenna and receive antenna.

➤ **Ten transmit- M receive antenna diversity (5/16 S10):**

$$\mathbf{G}_{10\text{-transmitters}} = \begin{bmatrix}
 s1 & s2 & s3 & s4 & s5 & s6 & s7 & s8 & s9 & s10 & 0 & 0 & 0 & 0 & 0 & 0 \\
 s2 & -s1 & s4 & -s3 & s6 & -s5 & -s8 & s7 & s10 & -s9 & 0 & 0 & 0 & 0 & 0 & 0 \\
 s3 & -s4 & -s1 & s2 & -s7 & -s8 & s5 & s6 & 0 & 0 & -s9 & s10 & 0 & 0 & 0 & 0 \\
 s4 & s3 & s2 & -s1 & -s8 & s7 & -s6 & s5 & 0 & 0 & s10 & s9 & 0 & 0 & 0 & 0 \\
 s5 & -s6 & s7 & s8 & -s1 & s2 & -s3 & -s4 & 0 & 0 & 0 & 0 & -s9 & s10 & 0 & 0 \\
 s6 & s5 & s8 & -s7 & -s2 & -s1 & s4 & -s3 & 0 & 0 & 0 & 0 & -s10 & s9 & 0 & 0 \\
 s7 & s8 & -s5 & s6 & s3 & -s4 & -s1 & -s2 & 0 & 0 & 0 & 0 & 0 & 0 & s9 & -s10 \\
 s8 & -s7 & -s6 & -s5 & s4 & s3 & s2 & -s1 & 0 & 0 & 0 & 0 & 0 & 0 & s10 & s9 \\
 s9 & -s10 & 0 & 0 & 0 & 0 & 0 & 0 & -s1 & s2 & s3 & -s4 & s5 & -s6 & -s7 & -s8 \\
 s10 & s9 & 0 & 0 & 0 & 0 & 0 & 0 & -s2 & -s1 & -s4 & -s3 & s6 & -s5 & -s8 & s7 \\
 0 & 0 & s9 & -s10 & 0 & 0 & 0 & 0 & -s3 & s4 & s1 & s2 & s7 & -s8 & -s5 & -s6 \\
 0 & 0 & s10 & s9 & 0 & 0 & 0 & 0 & -s4 & -s3 & -s2 & s1 & s8 & -s7 & -s6 & s5
 \end{bmatrix}$$

.....(13)

$\mathbf{S10} = [\mathbf{G10}, \mathbf{G10}^*]$ .....(14)

➤ **Twelve transmit- M receive antenna diversity (6/16 S12):**

$$G_{12\text{-transmitters}} = \begin{bmatrix} s1 & s2 & s3 & s4 & s5 & s6 & s7 & s8 & s9 & s10 & -s11 & -s12 & 0 & 0 & 0 & 0 \\ s2 & -s1 & s4 & -s3 & s6 & -s5 & -s8 & s7 & s10 & -s9 & s12 & -s11 & 0 & 0 & 0 & 0 \\ s3 & -s4 & -s1 & s2 & -s7 & -s8 & s5 & s6 & s11 & s12 & -s9 & s10 & 0 & 0 & 0 & 0 \\ s4 & s3 & s2 & -s1 & -s8 & s7 & -s6 & s5 & s12 & -s11 & s10 & s9 & 0 & 0 & 0 & 0 \\ s5 & -s6 & s7 & s8 & -s1 & s2 & -s3 & -s4 & 0 & 0 & 0 & 0 & -s9 & s10 & s11 & -s12 \\ s6 & s5 & s8 & -s7 & -s2 & -s1 & s4 & -s3 & 0 & 0 & 0 & 0 & -s10 & s9 & s12 & s11 \\ s7 & s8 & -s5 & s6 & s3 & -s4 & -s1 & -s2 & 0 & 0 & 0 & 0 & -s11 & s12 & s9 & -s10 \\ s8 & -s7 & -s6 & -s5 & s4 & s3 & s2 & -s1 & 0 & 0 & 0 & 0 & -s12 & s11 & s10 & s9 \\ s9 & -s10 & -s11 & -s12 & 0 & 0 & 0 & 0 & -s1 & s2 & s3 & -s4 & s5 & -s6 & -s7 & -s8 \\ s10 & s9 & -s12 & s11 & 0 & 0 & 0 & 0 & -s2 & -s1 & -s4 & -s3 & s6 & -s5 & -s8 & s7 \\ s11 & s12 & s9 & -s10 & 0 & 0 & 0 & 0 & -s3 & s4 & s1 & s2 & s7 & -s8 & -s5 & -s6 \\ s12 & -s11 & s10 & s9 & 0 & 0 & 0 & 0 & -s4 & -s3 & -s2 & s1 & s8 & -s7 & -s6 & s5 \end{bmatrix} \dots(15)$$

➤ **S12= [G12, G12\*] .....**(16)

➤ **Fourteen transmit- M receive antenna diversity(7/16 S14): :**

$$G_{14\text{-transmitters}} = \begin{bmatrix} s1 & s2 & s3 & s4 & s5 & s6 & s7 & s8 & s9 & s10 & -s11 & -s12 & s13 & -s14 & 0 & 0 \\ s2 & -s1 & s4 & -s3 & s6 & -s5 & -s8 & s7 & s10 & -s9 & s12 & -s11 & s14 & -s13 & 0 & 0 \\ s3 & -s4 & -s1 & s2 & -s7 & -s8 & s5 & s6 & s11 & s12 & -s9 & s10 & 0 & 0 & -s13 & -s14 \\ s4 & s3 & s2 & -s1 & -s8 & s7 & -s6 & s5 & s12 & -s11 & s10 & s9 & 0 & 0 & -s14 & s13 \\ s5 & -s6 & s7 & s8 & -s1 & s2 & -s3 & -s4 & s13 & s14 & 0 & 0 & -s9 & s10 & s11 & -s12 \\ s6 & s5 & s8 & -s7 & -s2 & -s1 & s4 & -s3 & s14 & -s13 & 0 & 0 & -s10 & s9 & s12 & s11 \\ s7 & s8 & -s5 & s6 & s3 & -s4 & -s1 & -s2 & 0 & 0 & -s13 & s14 & -s11 & s12 & s9 & -s10 \\ s8 & -s7 & -s6 & -s5 & s4 & s3 & s2 & -s1 & 0 & 0 & s14 & s13 & -s12 & s11 & s10 & s9 \\ s9 & -s10 & -s11 & -s12 & -s13 & -s14 & 0 & 0 & -s1 & s2 & s3 & -s4 & s5 & -s6 & -s7 & -s8 \\ s10 & s9 & -s12 & s11 & -s14 & s13 & 0 & 0 & -s2 & -s1 & -s4 & -s3 & s6 & -s5 & -s8 & s7 \\ s11 & s12 & s9 & -s10 & 0 & 0 & -s13 & -s14 & -s3 & s4 & s1 & s2 & s7 & -s8 & -s5 & -s6 \\ s12 & -s11 & s10 & s9 & 0 & 0 & s14 & -s13 & -s4 & -s3 & -s2 & s1 & s8 & -s7 & -s6 & s5 \\ s13 & s14 & 0 & 0 & s9 & -s10 & s11 & s12 & -s5 & s6 & s7 & -s8 & -s1 & s2 & s3 & -s4 \\ s14 & -s13 & 0 & 0 & s10 & s9 & -s12 & s11 & -s6 & -s5 & -s8 & -s7 & -s2 & s1 & s4 & s3 \end{bmatrix} \dots(17)$$

$$\mathbf{S14} = [\mathbf{G14}, \mathbf{G14}^*] \dots \dots \dots (18)$$

➤ **Sixteen transmit- M receive antenna diversity (Half rate S16):**

The main step to achieve transmit diversity is to formulate the new STBC called (**G16**) for 16x16 MIMO. Accordingly this project also suggested the following code matrix **S16** which is a combination of the **G16** together with its conjugate; so as transmitting sixteen different symbols with their conjugates through different 32 time slots along the same antenna:

$$\mathbf{S16} = [\mathbf{G16}, \mathbf{G16}^*] \dots \dots \dots (19)$$

Where

**G16:** is the new quasi-orthogonal STBC designed as follows:

$$\begin{bmatrix} s1 & s2 & s3 & s4 & s5 & s6 & s7 & s8 & s9 & s10 & -s11 & -s12 & s13 & -s14 & -s15 & -s16 \\ s2 & -s1 & s4 & -s3 & s6 & -s5 & -s8 & s7 & s10 & -s9 & s12 & -s11 & s14 & -s13 & -s16 & s15 \\ s3 & -s4 & -s1 & s2 & -s7 & -s8 & s5 & s6 & s11 & s12 & -s9 & s10 & s15 & -s16 & -s13 & -s14 \\ s4 & s3 & s2 & -s1 & -s8 & s7 & -s6 & s5 & s12 & -s11 & s10 & s9 & s16 & -s15 & -s14 & s13 \\ s5 & -s6 & s7 & s8 & -s1 & s2 & -s3 & -s4 & s13 & s14 & -s15 & -s16 & -s9 & s10 & s11 & -s12 \\ s6 & s5 & s8 & -s7 & -s2 & -s1 & s4 & -s3 & s14 & -s13 & s16 & -s15 & -s10 & s9 & s12 & s11 \\ s7 & s8 & -s5 & s6 & s3 & -s4 & -s1 & -s2 & s15 & s16 & -s13 & s14 & -s11 & s12 & s9 & -s10 \\ s8 & -s7 & -s6 & -s5 & s4 & s3 & s2 & -s1 & s16 & -s15 & s14 & s13 & -s12 & s11 & s10 & s9 \\ s9 & -s10 & -s11 & -s12 & -s13 & -s14 & -s15 & -s16 & -s1 & s2 & s3 & -s4 & s5 & -s6 & -s7 & -s8 \\ s10 & s9 & -s12 & s11 & -s14 & s13 & s16 & -s15 & -s2 & -s1 & -s4 & -s3 & s6 & -s5 & -s8 & s7 \\ s11 & s12 & s9 & -s10 & s15 & s16 & -s13 & -s14 & -s3 & s4 & s1 & s2 & s7 & -s8 & -s5 & -s6 \\ s12 & -s11 & s10 & s9 & s16 & -s15 & s14 & -s13 & -s4 & -s3 & -s2 & s1 & s8 & -s7 & -s6 & s5 \\ s13 & s14 & -s15 & -s16 & s9 & -s10 & s11 & s12 & -s5 & s6 & s7 & -s8 & -s1 & s2 & s3 & -s4 \\ s14 & -s13 & -s16 & s15 & s10 & s9 & -s12 & s11 & -s6 & -s5 & -s8 & -s7 & -s2 & s1 & s4 & s3 \\ s15 & -s16 & s13 & -s14 & -s11 & s12 & s9 & s10 & -s7 & s8 & s5 & s6 & -s3 & s4 & s1 & -s2 \\ s16 & s15 & s14 & s13 & -s12 & -s11 & -s10 & s9 & -s8 & -s7 & -s6 & s5 & -s4 & s3 & s2 & s1 \end{bmatrix}$$

$$\dots \dots \dots (20)$$

G14 is constructed by eliminating the last two rows from G16 and transmitting zero instead of  $s_{16}, s_{15}$  reducing S14 rate to 7/16. The same way is followed in constructing G12(S12's rate is 6/16) and G10 (S10's rate is 5/16) from G16 by eliminating the last four and six rows respectively, where  $s_{16}, s_{15}, s_{14}$  and  $s_{13}$  are replaced by zeros in G12 and  $s_{16}, s_{15}, s_{14}, s_{13}, s_{12}$  and  $s_{11}$  are replaced by zeros in G10.

The MIMO output will be given by:

$$\mathbf{Y} = \mathbf{H}^T * \mathbf{S} + \mathbf{N} \dots\dots\dots (21)$$

Where:

$S$ : Is the input data matrix formulated above as quasi-orthogonal STBC.

$N$ : Zero Mean Circularly Symmetric Complex Gaussian noise matrix.

$H$ : Is an i.i.d complex matrix consisting of frequency flat-fading Rayleigh channels representing the channel response between transmit antenna and receive antenna.

#### 4.4.Simulation Setup

The simulation covers an end to end  $N \times M$  MIMO system, giving that the channel state information (CSI) is unknown to the transmitter and perfectly known to the receiver. The Matlab code was feed with 1920 packet each with frames transmitted as 192 symbols in case of (2-4 and 6-8)  $\times M$  Systems over 2 time slots in Alamouti case, 8 times slots in S3 and S4, 16 time slots in S6-S8 and 432 symbols over 32 time slots in S16 through each

antenna. It is considered that STBC used to encode the transmitted symbols; transmitting different symbols through different antennas and different time slots as follows: the first column of  $\mathbf{S}$  will be transmitted through the  $N$  antenna array elements at the transmitter during the first symbol period, then the symbols of column two of  $\mathbf{S}$  will be transmitted from the same  $N$  antenna array elements during the following symbol period, and this process continuous till all columns are transmitted.

#### **4.4.1. Main steps for the Matlab Code**

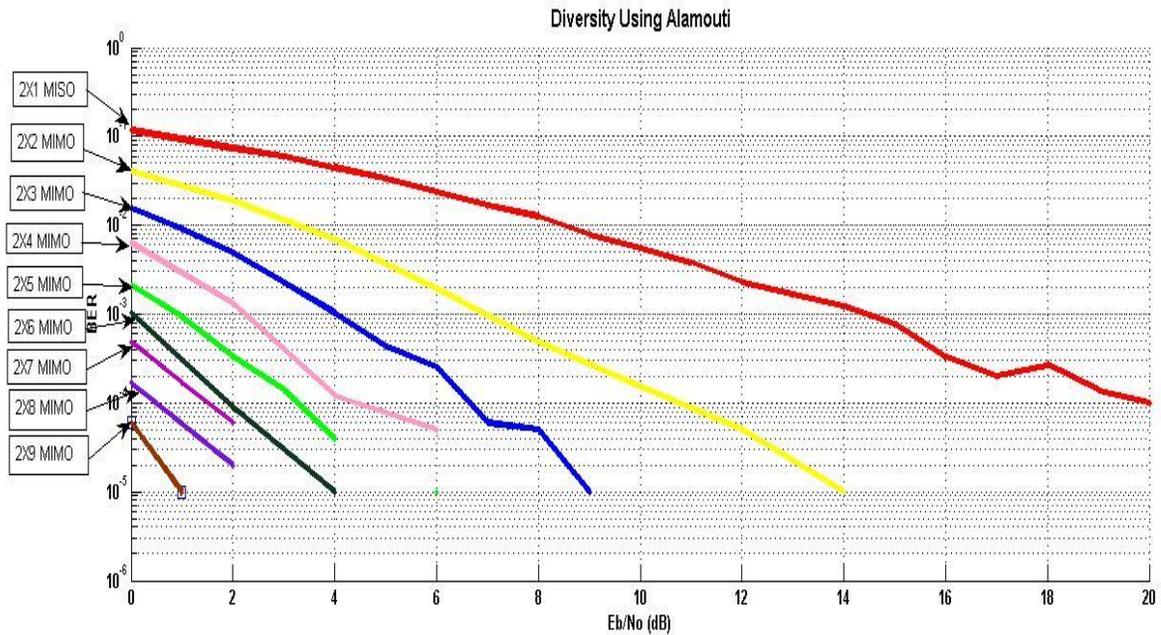
1. The Matlab code begins by initializing the simulation parameters such as transmitted, received and combined data signals.
2. The data to be transmitted per channel was modulated using BPSK modulator.
3. Then the data was encoded by STBC encoder and transmitted through Flat fading Rayleigh channel.
4. Then frequency flat Rayleigh fading channel is formulated incorporating AWGN will be added to the signal.
5. At the receiving end Maximal Ratio Combiner (MRC) was used to combine the received signal replicas.
6. After that the signal was detected using Maximum-Likelihood (ML) detector.

7. Finally errors were determined and BER was calculated for different  $E_b/N_0$  values to show performance of Diversity in the NXM MIMO systems.

#### **4.5.Results**

Here we measure the performance of (2, 3, 4, 6, 7, 8,10,12,14 and 16)×M MIMO systems. It is assumed that the channel is unknown at transmitters and perfectly known for all MIMO receivers.

The simulation run over a range of  $E_b/N_0$  points to generate BER results in order to note the achieved diversity order and estimate BER performance for space-time block coded system shown in Eq.(1),(3),(5) and (8) using 2,3,4,6,7,8, and 16 transmit and (2-10 or 16) receive antennas. A Matlab code was designed which runs over a range of  $E_b/N_0$  values generating verity of BER estimations for the system shown in Fig. 4.3.

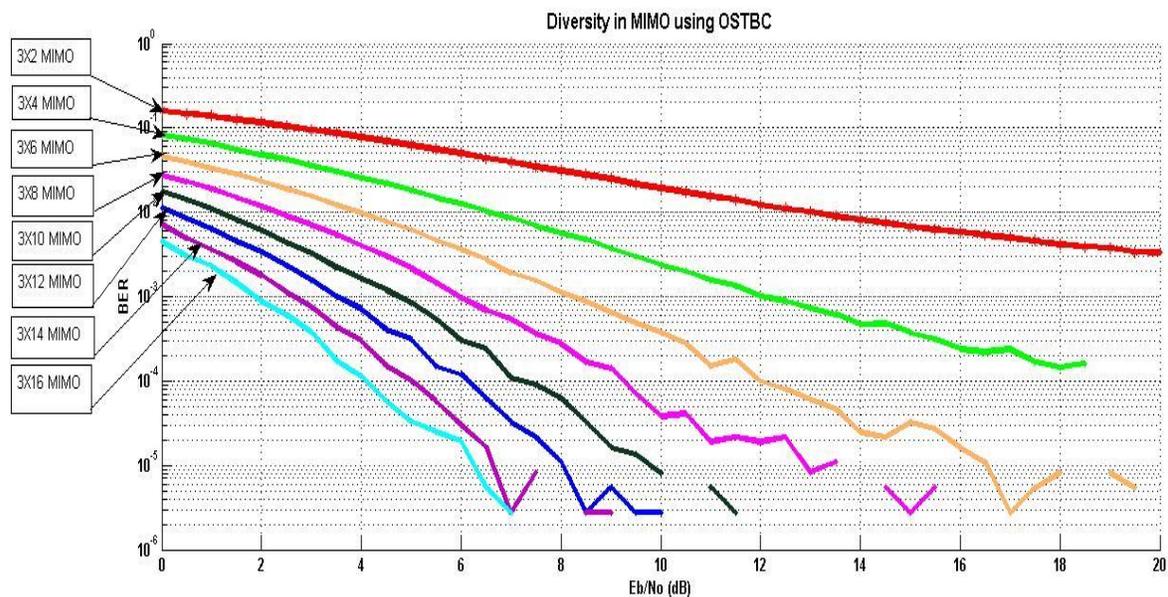


**Figure 4.4:** BER performance of the  $2 \times M$  by means of Alamouti OSTBC scheme under flat fading Rayleigh channel.

The results of the simulation are shown in Fig. 4.4 above.  $2 \times 1$  MISO system: Alamouti STBC started near  $10^{-0.93}$  BER and achieved low BER around  $10^{-4}$  at 20 dB  $E_b/N_0$ . The case of  $2 \times 2$  the results started at  $10^{-1.39}$  and achieved low BER  $1 \times 10^{-5}$  at 14 dB.

Regarding the  $2 \times (3, 4, 5, 6, 7, 8$  and  $9)$  MIMO configurations: the Alamouti STBC initiated the performance at BERs of  $10^{-1.82}$ ,  $10^{-2.2}$ ,  $10^{-2.68}$ ,  $10^{-2.99}$ ,  $10^{-3.3}$ ,  $10^{-3.77}$  and  $6 \times 10^{-5}$  at very low  $E_b/N_0$ .

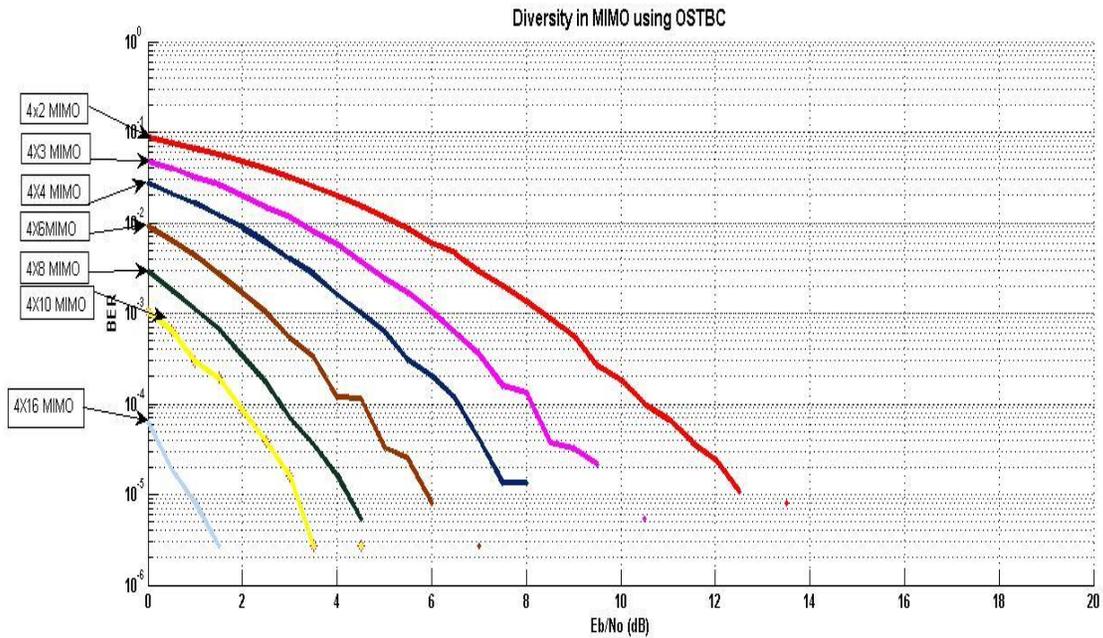
While increasing the  $E_b/N_0$ , the system resulted on much better low BER levels between  $1 \times 10^{-5}$  to  $6 \times 10^{-5}$  between 1 and 8 dB  $E_b/N_0$  for  $2 \times (4-9)$ .



**Figure 4.5:** BER performance of the  $3 \times M$  by means of OSTBC scheme under flat fading Rayleigh channel.

The results of the simulation are shown in Fig.4.5 above.  $3 \times 2$  MIMO system: OSTBC started at  $10^{-0.79}$  BER and achieved low BER around  $10^{-2.47}$  at 20 dB  $E_b/N_0$ . The case of  $3 \times 4$  the results started at  $10^{-1.08}$  and  $10^{-3.79}$  BER at 18.5 dB.

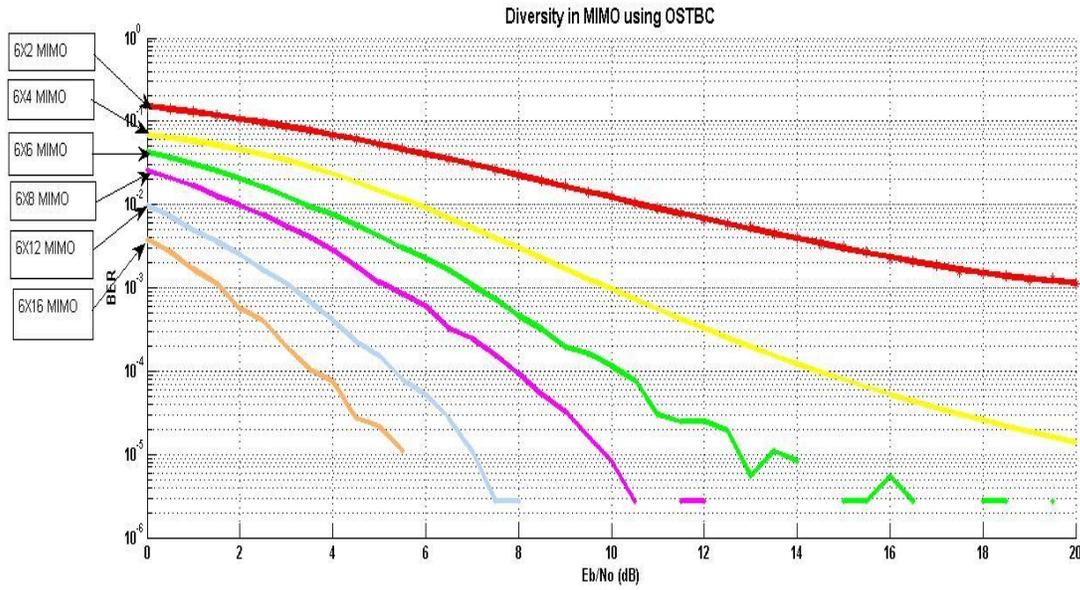
Regarding the  $2 \times (6, 8, 10, 12, 14$  and  $16)$  MIMO configurations: the OSTBC initiated the performance at BERs of  $10^{-1.33}$ ,  $10^{-1.55}$ ,  $10^{-1.75}$ ,  $10^{-1.94}$ ,  $10^{-2.13}$  and  $10^{-2.35}$  at very low  $E_b/N_0$ . While increasing the  $E_b/N_0$  the system resulted on much better low BER around  $1 \times 10^{-6}$  between 6 and 12 dB  $E_b/N_0$  values.



**Figure 4.6:** BER performance of the  $4 \times M$  by means of OSTBC scheme under flat fading Rayleigh channel.

The results of the simulation are shown in Fig4.6 above.  $4 \times 2$  MIMO system: OSTBC started near  $10^{-1.05}$  BER and achieved low BER around  $8.138 \times 10^{-6}$  at 13.5 dB  $E_b/N_0$ . The case of  $4 \times 3$  the results started at  $10^{-1.32}$  and  $5.425 \times 10^{-6}$  BER at 10.5 dB.

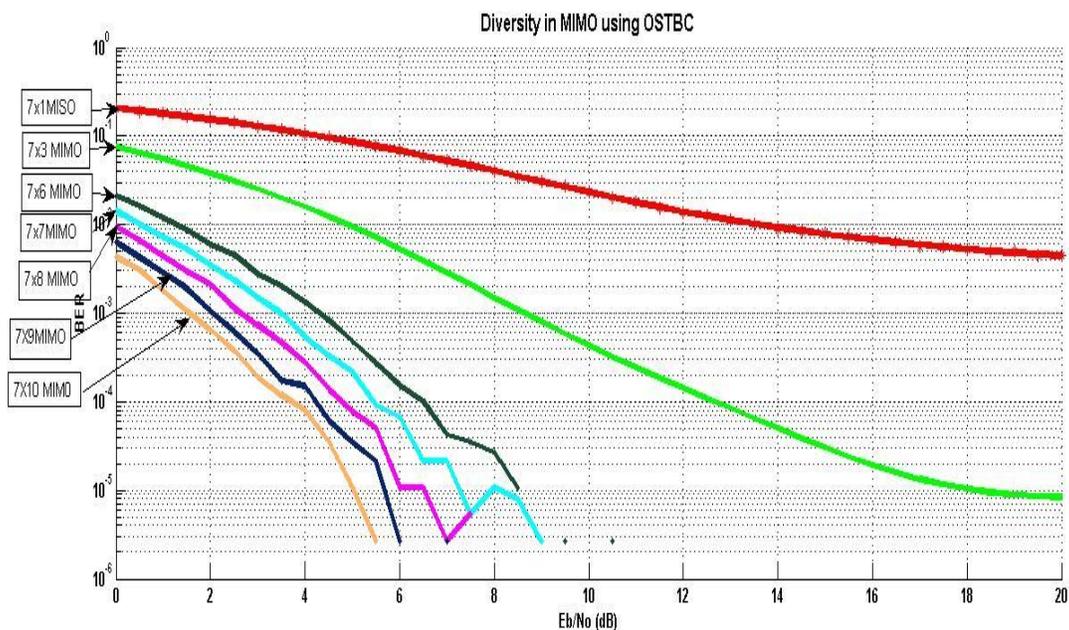
Regarding the  $4 \times 4$ ,  $4 \times 6$ ,  $4 \times 8$ ,  $4 \times 10$  and  $4 \times 16$  MIMO configurations: the OSTBC initiated the performance at BERs of  $10^{-1.56}$ ,  $10^{-2.03}$ ,  $10^{-2.53}$ ,  $10^{-2.98}$  and  $6.239 \times 10^{-5}$  at very low  $E_b/N_0$ . While increasing the  $E_b/N_0$  the system resulted on much better low BER around  $10^{-5}$ - $10^{-6}$  at 1.5-8 dB  $E_b/N_0$ .



**Figure 4.7:** BER performance of the  $6 \times M$  by means of OSTBC scheme under flat fading Rayleigh channel.

The results of the simulation are shown in Fig. 4.7 above.  $6 \times 2$  MIMO system: OSTBC started near  $10^{-0.81}$  BER and achieved low BER around  $10^{-2.94}$  at 20 dB  $E_b/N_o$ . In the case of  $6 \times 4$  the results started at  $10^{-1.16}$  and achieved much lower BER of  $1.409 \times 10^{-5}$  at 20 dB.

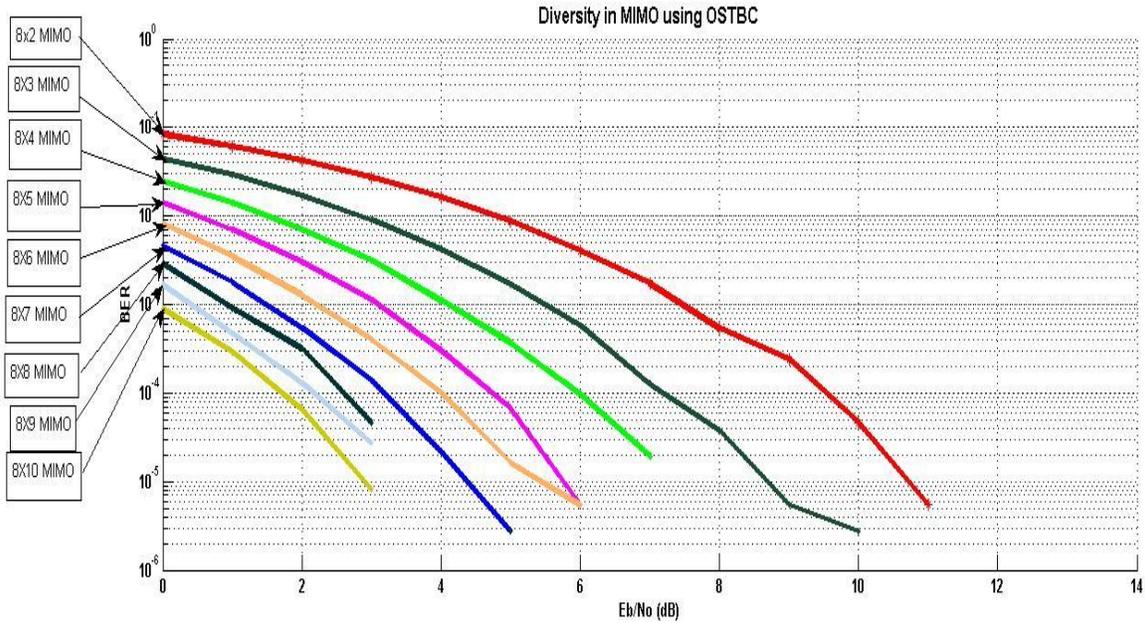
Regarding the  $6 \times 6$ ,  $6 \times 8$ ,  $6 \times 12$  and  $6 \times 16$  MIMO configurations: the OSTBC initiated the performance at BERs of  $10^{-1.36}$ ,  $10^{-1.58}$ ,  $10^{-2.01}$  and  $10^{-2.42}$  at very low  $E_b/N_o$ . While increasing the  $E_b/N_o$  the system resulted on much better low BER around  $2.713 \times 10^{-6}$  at 8-20  $E_b/N_o$  for  $6 \times 16$  the BER around  $1.085 \times 10^{-5}$  at 5.5 dB.



**Figure 4.8:** BER performance of the  $7 \times M$  by means of OSTBC scheme under flat fading Rayleigh channel.

The results of the simulation are shown in Fig.4.8 above.  $7 \times 1$  MISO system: OSTBC started near  $10^{-0.68}$  BER and achieved low BER around  $10^{-2.35}$  at 20 dB  $E_b/N_0$ . The case of  $7 \times 3$  the results started at  $10^{-1.12}$  and achieved much lower BER of  $8.334 \times 10^{-6}$  at 20 dB.

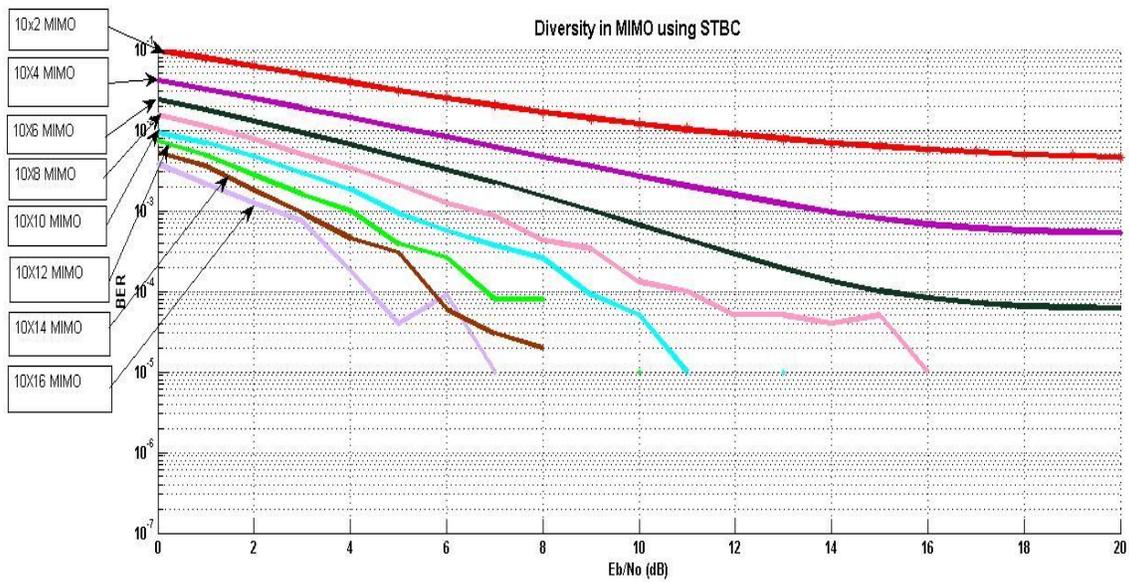
Regarding the  $7 \times 6$ ,  $7 \times 7$ ,  $7 \times 8$ ,  $7 \times 9$  and  $7 \times 10$  MIMO configurations: the OSTBC initiated the performance at BERs of  $10^{-1.67}$ ,  $10^{-1.85}$ ,  $10^{-2.02}$ ,  $10^{-2.2}$  and  $10^{-2.37}$  at very low  $E_b/N_0$ . While increasing the  $E_b/N_0$  the system resulted on much better low BER levels between  $10^{-5}$  to  $2.657 \times 10^{-6}$  and at 4-9  $E_b/N_0$  for  $M = 6-10$ .



**Figure 4.9:** BER performance of the  $8 \times M$  by means of OSTBC scheme under flat fading Rayleigh channel.

The results of the simulation are shown in Fig. 4.9 above.  $8 \times 2$  MIMO system: OSTBC started near  $10^{-1.07}$  BER and achieved low BER around  $5.925 \times 10^{-6}$  at 11 dB  $E_b/N_o$ . The case of  $8 \times 3$  the results started at  $10^{-1.34}$  and achieved much lower BER of  $2.713 \times 10^{-6}$  at 10 dB.

Regarding the  $8 \times (4, 5, 6, 7, 8, 9$  and  $10)$  MIMO configurations: the OSTBC initiated the performance at BERs of  $10^{-1.61}$ ,  $10^{-1.85}$ ,  $10^{-2.08}$ ,  $10^{-2.34}$ ,  $10^{-2.54}$ ,  $10^{-2.77}$  and  $10^{-3.05}$  at very low  $E_b/N_o$ . While increasing the  $E_b/N_o$  the system resulted on much better low BER levels between  $10^{-5}$  to  $2.657 \times 10^{-6}$  and at 2-6  $E_b/N_o$  for  $M = 6-10$ .

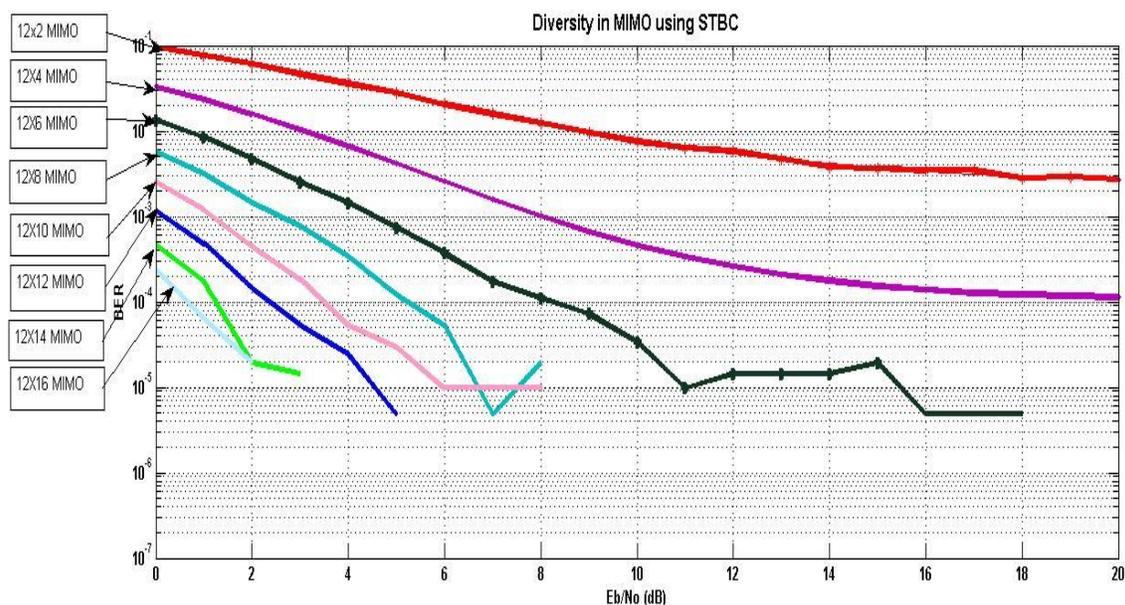


**Figure 4.10:** BER performance of the  $10 \times M$  STBC for various MIMOs.

MIMOs.

The results of the simulation are shown in Fig. 4.10 above.  $10 \times 2$  MIMO system: STBC started near  $10^{-1}$  BER and achieved low BER around  $10^{-2.34}$  at 20 dB  $E_b/N_o$ . The case of  $10 \times 4$  the results started at  $10^{-1.34}$  and achieved much lower BER of  $10^{-1.27}$  at 20 dB.

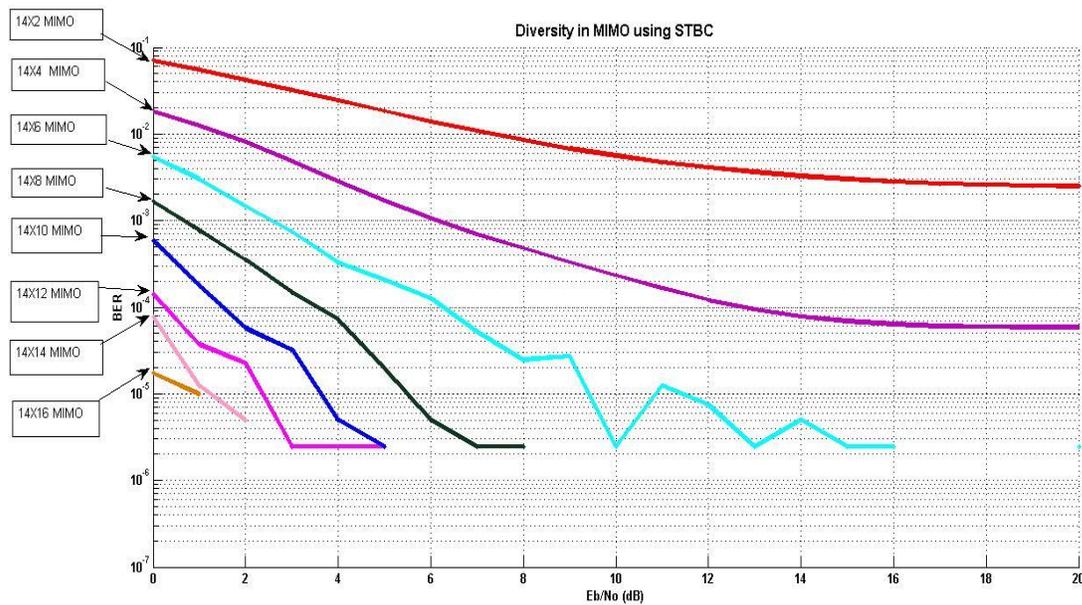
Regarding the  $10 \times (6, 8, 10, 12, 14 \text{ and } 16)$  MIMO configurations: the STBC initiated the performance at BERs of  $10^{-1.61}$ ,  $10^{-1.81}$ ,  $10^{-2.02}$ ,  $10^{-2.13}$ ,  $10^{-2.27}$  and  $10^{-2.42}$  at very low  $E_b/N_o$ . While increasing the  $E_b/N_o$  the system resulted on much better low BER levels around  $10^{-5}$  at 2-16  $E_b/N_o$ .



**Figure 4.11:** BER performance of the  $12 \times M$  STBC for various MIMOs.

The results of the simulation are shown in Fig. 4.11 above.  $12 \times 2$  MIMO system: STBC started near  $10^{-1.021}$  BER and achieved low BER around  $10^{-2.57}$  at 20 dB  $E_b/N_o$ . The case of  $12 \times 4$  the results started at  $10^{-1.478}$  and achieved much lower BER of  $10^{-3.94}$  at 20 dB. The case of  $12 \times 6$  the results started at  $10^{-1.87}$  and achieved much lower BER of  $4.823 \times 10^{-6}$  at 18 dB.

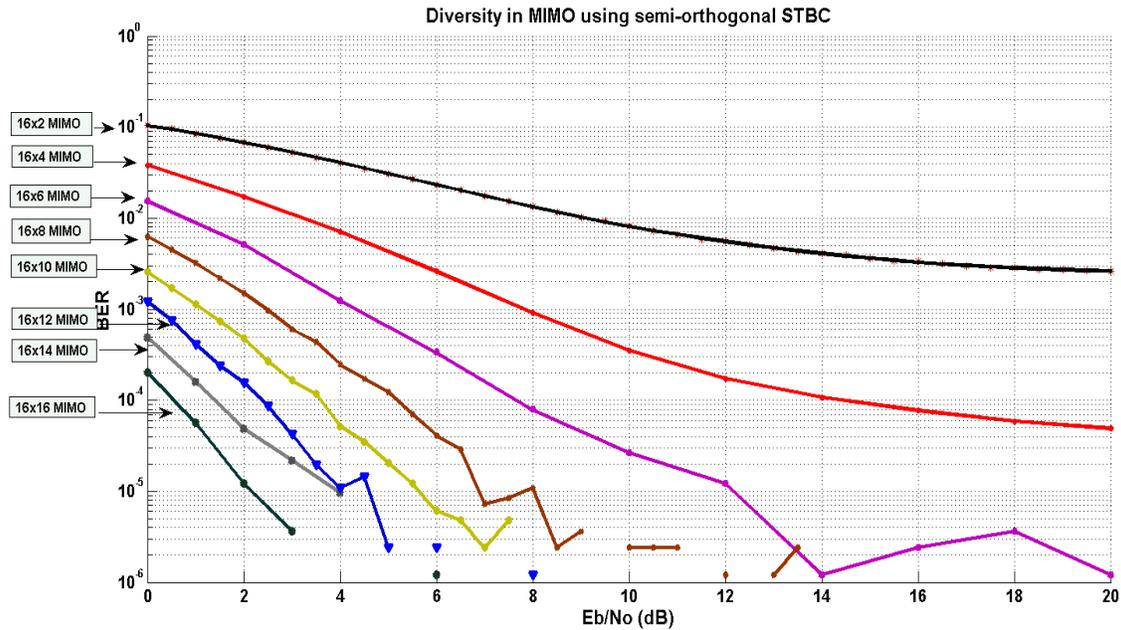
Regarding the  $12 \times 8$ ,  $12 \times 10$ ,  $12 \times 12$ ,  $12 \times 14$  and  $12 \times 16$  MIMO configurations: the STBC initiated the performance at BERs of  $10^{-2.24}$ ,  $10^{-2.98}$ ,  $10^{-2.93}$ ,  $10^{-3.34}$  and  $10^{-3.63}$  at very low  $E_b/N_o$ . While increasing the  $E_b/N_o$  the system resulted on much better low BER levels between  $1.929 \times 10^{-5}$  to  $9.645 \times 10^{-6}$  and at 2-8  $E_b/N_o$  for  $M = 8, 10, 12, 14, 16$ .



**Figure 4.12:** BER performance of the  $14 \times M$  STBC for various MIMOs.

The results of the simulation are shown in Fig.10 bellow.  $14 \times 2$  MIMO system: STBC started near  $10^{-1.146}$  BER and achieved low BER around  $10^{-2.603}$  at 20 dB  $E_b/N_0$ . The case of  $14 \times 4$  the results started at  $10^{-1.74}$  and achieved much lower BER of  $5846 \times 10^{-5}$  at 20 dB. The case of  $14 \times 6$  the results started at  $10^{-2.264}$  and achieved much lower BER of  $2.48 \times 10^{-6}$  at 16 dB.

Regarding the  $14 \times 8$ ,  $14 \times 10$ ,  $14 \times 12$ ,  $14 \times 14$  and  $14 \times 16$  MIMO configurations: the STBC initiated the performance at BERs of  $10^{-2.775}$ ,  $10^{-3.227}$ ,  $10^{-3.8496}$ ,  $1.688 \times 10^{-5}$  and  $1.736 \times 10^{-5}$  at very low  $E_b/N_0$ . While increasing the  $E_b/N_0$  the system resulted on much better low BER levels between  $9.921 \times 10^{-6}$  to  $2.48 \times 10^{-6}$  and at 1-8  $E_b/N_0$  for  $M = 8, 10, 12, 14, 16$ .

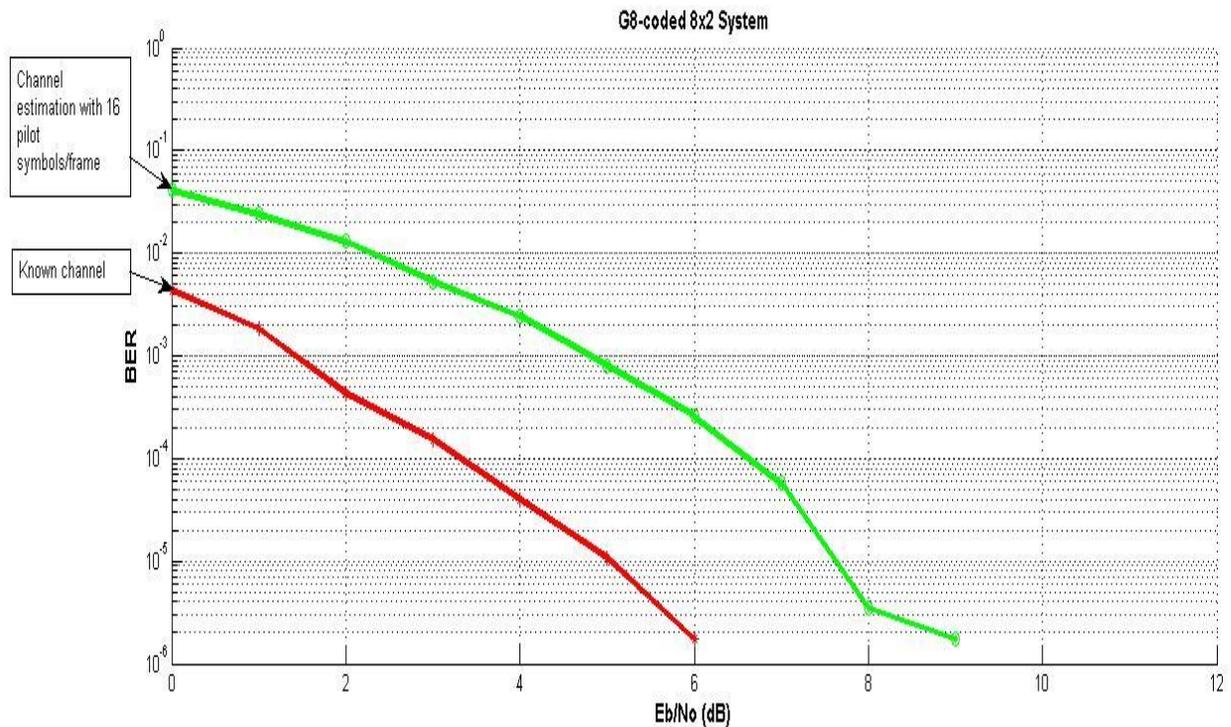


**Figure 4.13:** BER performance of the new Quasi-Orthogonal STBC for various MIMOs.

The results of the simulation are shown in Fig. 4.13 above. 16x2 MIMO system: the quasi-orthogonal STBC started near  $10^{-1}$  BER and achieved low BER around  $10^{-2.58}$  at 20 dB  $E_b/N_o$ . The case of 16x4 and 16x6 configurations: the results started at  $10^{-1.42}$  and  $10^{-1.81}$  BER and achieved  $10^{-4.31}$  and  $10^{-5.92}$  low BER levels at 20 dB  $E_b/N_o$  respectively. So far the results from 16x4 and 16x6 configurations suggesting that this transmit diversity system which applied the new quasi-orthogonal STBC defined in  $\mathbf{S}$  is performing well and produced quite low BER levels at low  $E_b/N_o$  too.

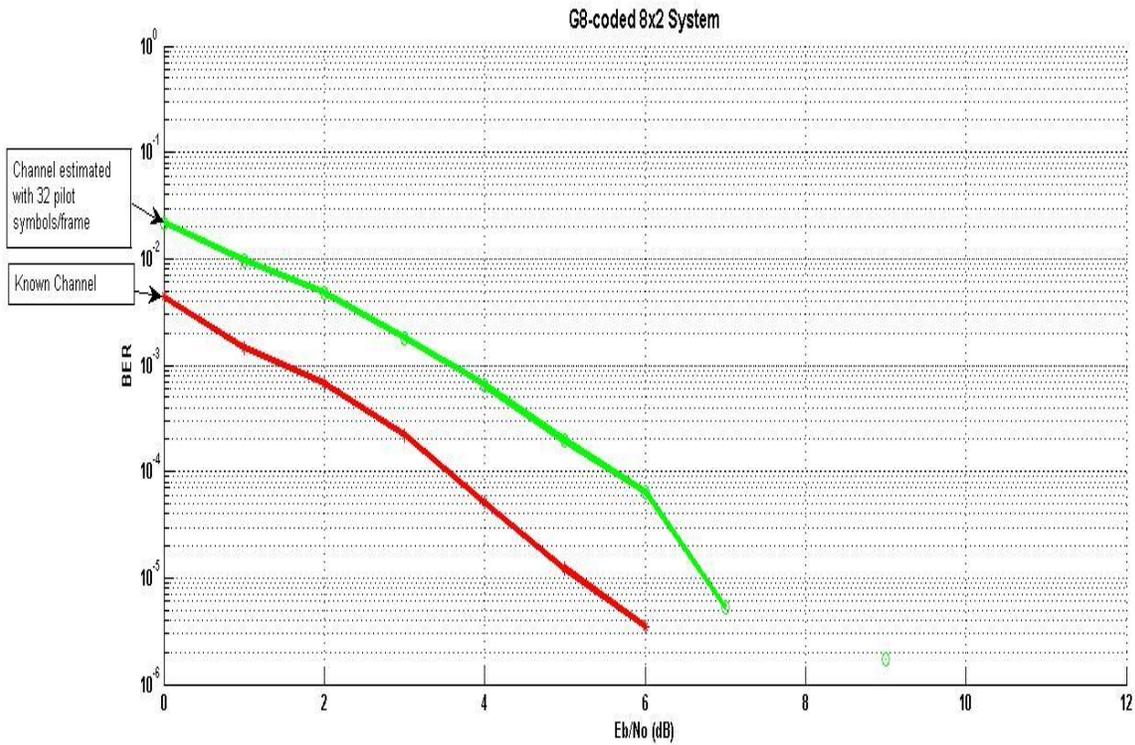
Regarding the 16x8, 16x10, 16x12, 16x14, and 16x16 MIMO configurations: the proposed quasi-orthogonal STBC initiated the performance at BERs of  $10^{-2.21}$ ,  $10^{-2.59}$ ,  $10^{-2.92}$ ,  $10^{-3.31}$ ,

and  $10^{-3.7}$  at very low  $E_b/N_o$ . While increasing the  $E_b/N_o$  the system resulted on much better low BER levels between  $10^{-5}$  to  $10^{-6}$  and at 4-10  $E_b/N_o$ .



**Figure 4.14:** Comparison between BER performance of the  $8 \times 2$  by means of OSTBC scheme with and without (known) channel estimation.

When the channel is unknown to the receiver and it estimates it using pilot signals it achieves a good performance but it is less than that in the case of known channel. It appears from the above figure that with 16 pilot symbols for each 192 symbols of data in case of  $8 \times 2$ , channel estimation causes less than 3dB degradation in performance for the selected  $E_b/N_o$  range.



**Figure 4.15:** Comparison between BER performance of the  $8 \times 2$  by means of OSTBC scheme with and without (known) channel estimation when the number of pilots increased.

It is clear that increasing the number of pilot signals from 16 to 32 pilots per 192 symbols improves the performance of the system. Increasing the pilots causes an improvement of 1-2 dB in performance.

In this comparison, we keep the transmitted SNR per symbol to be the same in both cases.

#### 4.6. Discussions

As shown in the previous figures: as the number of receivers and/or transmitters increases the orthogonal code provided much better BER low levels at low  $E_b/N_o$ . However, despite these encouraging results from the use of higher number of receivers and transmitters, it can be suggested that such configurations are limited to base stations or fixed users terminals mainly to overcome the complexities of their deployment.

Increasing the number of receive antennas also increases array gain and so improving BER. Using STBC improves BER by achieving Space time diversity and the additional coding gain.

Also it is obvious that increasing orthogonality in STBC improves diversity; i.e the performance of the OSTBC “S8” in  $8 \times M$  system is better than that for the quasi-orthogonal STBC “S16” in  $16 \times M$  system although  $16 \times M$  system has larger number of antennas than that of  $8 \times M$  system.

The rate of the STBC plays a role in reducing BER. It is clear that the performance of Alamouti encoder which is the only full rate STBC encoder achieves a better BER than that of the half rate S4 and S8 when they have same diversity order. For example, Diversity order of 8 can be achieved in  $2 \times 4$  and  $4 \times 2$  systems but its clear that while Alamouti

achieves a BER of order  $10^{-5}$  when  $E_b/N_o$  values is between 4 and 6 in 2x4, S4 achieves the same BER order when  $E_b/N_o$  values is between 10 and 12.

Pilot signals are used in extracting information about the channel when it is not perfectly known to the receiver. Channel estimation gives good performance but it is less than that of the Known channel. This performance is improved with an increase in the number of pilot symbols per frame but adds to the overhead of the link.

## **CHAPTER 5**

### **CONCLUSION**

#### **5.1 Introduction**

#### **5.2 Conclusions**

#### **5.3 Challenges**

#### **5.4 Recommendation (Future Work)**

## 5.1 Introduction

In this chapter we introduce our Conclusions that are concluded after noting the simulation results, then the challenges that are faced during doing this project are introduced. Finally, some ideas are proposed to develop this project.

## 5.2 Conclusions

Here we introduce the conclusions of the logical simulation results that are presented in the previous chapter. These results may differ from the real environment but it is very similar to it.

1. Full diversity of order  $M \times N$  was achieved in  $(2, 4, 8) \times M$  MIMO systems which results from the product of the number of transmit and receive antennas. This project applied OSTBC encoding which resulted on encouraging output when encoding symbols at the transmitter to achieve diversity. The project showed that  $(2, 3, 4, 6, 7, 8) \times M$  MIMO system achieved good performance at low BER under low  $E_b/N_0$  values when the channel is perfectly known at the receiver.
2. This project also suggested a new quasi-orthogonal STBC applied on multi configurations of MIMOs. The project showed that  $16 \times M$  MIMO systems achieved adequate performance at low BER under low  $E_b/N_0$  values when the channel is perfectly known at the receiver. High transmit diversity orders became possible through this new STBC code, which opens additional opportunities to enhance the overall MIMO systems' performance and gain.
3. High order Diversity for  $10, 12, 14 \times M$  achieved benefiting from the new quasi-OSTBC and gives a good performance at low BER.

4. Orthogonality and rate of STBC affects the Systems' performance; increasing orthogonality or rate or both improves BER.
5. Using STBC in achieving Diversity in MIMO achieves diversity gain in addition to coding gain.
6. Increasing the number of transmit antennas and/or receive antennas increases diversity gain which improves the systems' performance by decreasing BER at low  $E_b/N_o$  values.
7. Increasing the number of receive antennas improves BER by increasing both diversity and array gains.
8. Channel estimation is needed to estimate the channel when the receiver does not know the channel perfectly. The performance of Diversity system when the channel is estimated by using pilot signals is less than that when the channel is perfectly known to the receiver. The BER in the case of channel estimation is improved by increasing the number of pilot signals but this also increases overheads.

### **5.3 Challenges**

In this section, the most challenges that are faced during the project are introduced.

1. The most important issue in this project is finding the suitable OSTBC matrix which takes a lot of time to find. Also finding an OSTBC matrix for large number of antennas such as 16 ant matrix.
2. Another challenge was the availability of such results especially for high order diversity systems to compare our results with it.
3. The simulation speed was low for high order Diversity system.

4. The complexity of transmitter designs especially the design of STBC for large number of transmitters in addition to receiver complexity.
5. In ability to unify the frame length for all the MIMO cases.
6. Flows, faults and problem from personal devises as well as the loss of data because of viruses.

#### **5.4 Recommendation (Future Work)**

Some ideas for future work are suggested down here:

1. Showing the effect of changing the modulation order in PSK and using different modulation schemes on diversity in MIMO.
2. Trying to increase the rate of STBC and note there effect on diversity.
3. Developing codes to simulate higher diversity order such as  $20 \times M$ ,  $24 \times M$  and  $32 \times M$  MIMO System.
4. Design a code that combines both Diversity and Multiplexing and note Diversity-Multiplexing tradeoff.

# MATLAB SIMULATION FOR DIVERSITY IN $8 \times 2$ MIMO SYSTEM USING OSTBC

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**ABSTRACT:** This paper simulates the Diversity performance of  $8 \times 2$  MIMO system. Diversity was achieved through the use of orthogonal space-time block coding technique (OSTBC) at the transmitter, which is a recent innovation motivated by the need for higher throughput in wireless channel [4]. Matlab is used to simulate  $8 \times 2$  MIMO system, and OSTBC to encode the BPSK modulated signal before being transmitted through flat fading Rayleigh channel. At the receiving end, the received signals were combined by Maximal Ratio Combiner (MRC) and detected by Maximum-Likelihood (ML) detector. The  $8 \times 2$  simulations achieved low BER without the need for high SNR values.

## INTRODUCTION

MIMO systems use multiple antennas at both transmitter and receiver, so both transmit and receive diversity are applied to mitigate fading resulting from signal fluctuations through the wireless channel [1][2]. Based on the degree at which the multiple data replicas are faded independently, the system provides diversity gains representing the difference in SNR at the output of the diversity combiner compared to that of single branch diversity at certain probability level [3].

One of the recent diversity techniques widely used now is the so called transmit diversity applying space-time coding at the base station, which will be able to achieve maximum diversity order, maximum coding gain, and the highest possible throughput [4]. It is achieved by distributing the transmitted symbols over time and space (ST coding); where the design accuracy of ST codes depend on the amount of channel state information (CSI) knowledge at transmitter and/or receiver [2]. The transmit antenna diversity is present in MIMO channels, in which the signal to be transmitted needs to be pre-processed or pre-coded [1]. An additional enhancement to the ST coding relied on orthogonal space time coding designs, which was applied by Tarokh based on the work of Alamouti [5]. Orthogonal space-time block codes (OSTBCs) is an attractive technique for being used in 3G and 4G in wireless communication [6]. It is a simple and a valid technique that combines: coding, modulation, transmit and receive diversity, and based on linear encoding and decoding processing [7].

## CONSTRUCTING MIMO SYSTEM FOR DIVERSITY

This paper shows a Matlab simulation for the diversity in MIMO systems by applying both transmit and receive antenna diversity through means of

Orthogonal Space-Time Block Coding (OSTBC), which are constructed from known orthogonal designs, achieving full diversity, and are easily decodable by maximum likelihood decoding via linear processing at the receiver. A MIMO system consisting of  $N$  transmit antenna elements equal to eight, and of  $M$  receive antenna elements equal to two was modeled, accordingly diversity order of 16 can be achieved. Combining the multiple versions of the signals created by different diversity schemes is needed for improving the performance. The paper applies maximal ratio combining (MRC) technique using maximum-likelihood (ML) decoder to combine these  $M$  received signals to resonate on the most likely transmitted signal. The sum of the received SNRs from these  $M$  different paths is the effective received SNR of the system with diversity  $M$ . The receiver needs to demodulate all  $M$  receive signals in case of MRC for a source with  $M$  independent signals in the receive antennas [8]. The following block diagram represents the system.

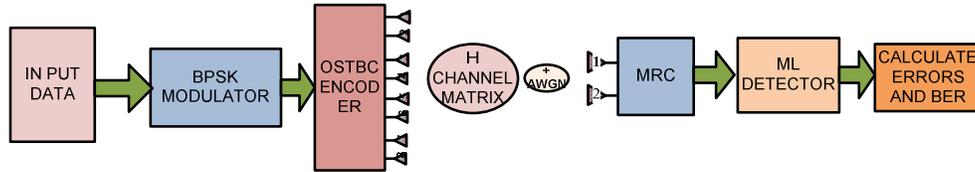


Figure (1): Block diagram for the Simulated MIMO system.

Based on the following orthogonal space-time block code given by [8]:

$$G_{8\text{-transmitters}} = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 & s_5 & s_6 & s_7 & s_8 \\ -s_2 & s_1 & -s_4 & s_3 & -s_6 & s_5 & s_8 & -s_7 \\ -s_3 & s_4 & s_1 & -s_2 & s_7 & s_8 & -s_5 & -s_6 \\ -s_4 & -s_3 & s_2 & s_1 & s_8 & -s_7 & s_6 & -s_5 \\ -s_5 & s_6 & -s_7 & -s_8 & s_1 & -s_2 & s_3 & s_4 \\ -s_6 & -s_5 & -s_8 & s_7 & s_2 & s_1 & -s_4 & s_3 \\ -s_7 & -s_8 & s_5 & -s_6 & -s_3 & s_4 & s_1 & s_2 \\ -s_8 & s_7 & s_6 & s_5 & -s_4 & -s_3 & -s_2 & s_1 \end{bmatrix} \dots \dots \dots (1)$$

The paper suggested the following complex orthogonal space-time block code, which is constructed from the above orthogonal matrix together with its conjugate; so transmitting eight different symbols with their conjugates through different sixteen time slots along the same antenna.

$$S = [G_8, G_8^*] \dots \dots \dots (2)$$

$$S = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 & s_5 & s_6 & s_7 & s_8 & s_1^* & s_2^* & s_3^* & s_4^* & s_5^* & s_6^* & s_7^* & s_8^* \\ -s_2 & s_1 & -s_4 & s_3 & -s_6 & s_5 & s_8 & -s_7 & -s_2^* & s_1^* & -s_4^* & s_3^* & -s_6^* & s_5^* & s_8^* & -s_7^* \\ -s_3 & s_4 & s_1 & -s_2 & s_7 & s_8 & -s_5 & -s_6 & -s_3^* & s_4^* & s_1^* & -s_2^* & s_7^* & s_8^* & -s_5^* & -s_6^* \\ -s_4 & -s_3 & s_2 & s_1 & s_8 & -s_7 & s_6 & -s_5 & -s_4^* & -s_3^* & s_2^* & s_1^* & s_8^* & -s_7^* & s_6^* & -s_5^* \\ -s_5 & s_6 & -s_7 & -s_8 & s_1 & -s_2 & s_3 & s_4 & -s_5^* & s_6^* & -s_7^* & -s_8^* & s_1^* & -s_2^* & s_3^* & s_4^* \\ -s_6 & -s_5 & -s_8 & s_7 & s_2 & s_1 & -s_4 & s_3 & -s_6^* & -s_5^* & -s_8^* & s_7^* & s_2^* & s_1^* & -s_4^* & s_3^* \\ -s_7 & -s_8 & s_5 & -s_6 & -s_3 & s_4 & s_1 & s_2 & -s_7^* & -s_6^* & s_5^* & -s_8^* & -s_3^* & s_4^* & s_1^* & s_2^* \\ -s_8 & s_7 & s_6 & s_5 & -s_4 & -s_3 & -s_2 & s_1 & -s_8^* & s_7^* & s_6^* & s_5^* & -s_4^* & -s_3^* & -s_2^* & s_1^* \end{bmatrix}$$

Giving that

$$S \times S^* = \text{diagonal matrix} = nI$$

where  $n = 2 \sum_1^8 S_i S_i^*$ ,

Which ensures that S is orthogonal.

The MIMO output given by:

$$Y = H^T \times S + N \dots\dots\dots(3)$$

Where:

- S:** is the input data matrix formulated as an OSTBC giving above in equation (2)
- N:** Zero Mean Circularly Symmetric Complex Gaussian noise matrix
- H:** is an i.i.d complex matrix consisting of  $h(i,j)$  flat-fading Rayleigh channels representing the channel response between transmit antenna ( $i$ ) and receive antenna ( $j$ ) for the considered subcarrier, equals:

$$H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{31} & h_{32} \\ h_{41} & h_{42} \\ h_{51} & h_{52} \\ h_{61} & h_{62} \\ h_{71} & h_{72} \\ h_{81} & h_{82} \end{bmatrix} \dots\dots\dots(4)$$

### SIMULATION SETUP

The simulation covers an end to end 8x2 MIMO system, giving that the channel state information (CSI) is unknown to the transmitter and perfectly known to the receiver. The Matlab code was fed with 1920 packet each with 192 frames transmitted as 192 symbols over 16 time slots through each antenna. It is considered here that OSTB used to encode the transmitted symbols; transmitting different symbols through different antennas and different time slots. Here eight different symbols  $s_1 - s_8$  were transmitted simultaneously from antenna elements 1-8. During the first transmission interval,  $s_1, s_2, s_3, s_4, s_5, s_6, s_7$  and  $s_8$  are transmitted, where  $s_1$  is transmitted from the first antenna,  $s_2$  from the second antenna and so on. During the next transmission interval,  $-s_2, s_1, -s_4, s_3, -s_6, s_5, s_8$

and  $s_7$  are transmitted, where in  $s_2$  is transmitted from the first antenna,  $s_1$  from the second antenna and so on.

### Main steps for the Matlab Code:

1. The Matlab code begins by initializing the simulation parameters such as transmitted, received and combined data signals.
2. The data to be transmitted per channel was modulated using BPSK modulator.
3. Then the data was encoded by OSTBC encoder and transmitted through Flat fading Rayleigh channel.
4. Then AWGN is added to the signal.
5. At the receiving end Maximal Ratio Combiner (MRC) was used to combine the received signal replicas.
6. After that the signal was detected using Maximum-Likelihood (ML) detector.
7. Finally errors were determined and BER was calculated for different  $E_b/N_0$  values to show performance of Diversity in  $8 \times 2$  MIMO system.

## RESULTS

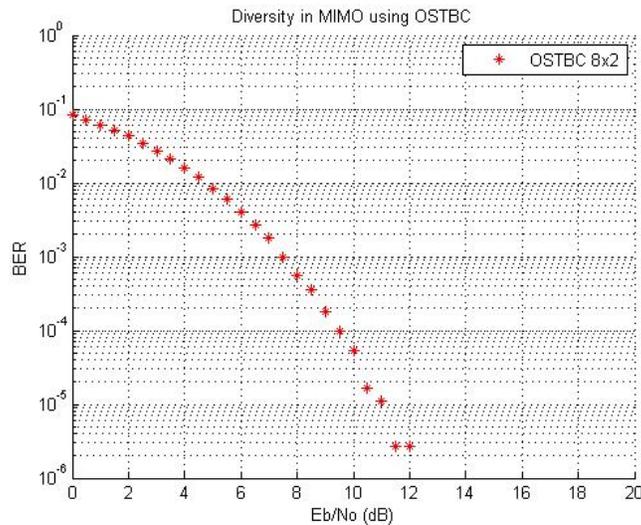


Figure (2): The BER performance of  $8 \times 2$  by means of OSTBC scheme under flat fading Rayleigh channel.

Here we measure the performance of  $8 \times 2$  MIMO system. It is assumed here that the channel is known perfectly at the receiver for all systems. The simulation run over a range of  $E_b/N_0$  points to generate BER results in order to note the achieved diversity order and estimate BER performance for an orthogonal space-time block

coded system shown in Eq.(2) using eight transmit and two receive antennas. As shown in figure (2) the 8x2 MIMO system achieved low BER without at low  $E_b/N_o$  values, for example BER of  $10^{-6}$  is achieved using 12 dB suggesting the applied OSTBC resulted on adequate transmit diversity at minimal power levels.

## CONCLUSION

Full diversity of order 16 was achieved in  $8 \times 2$  MIMO system which results from the product of the number of transmit and receive antennas. This paper applied OSTBC encoding which resulted on encouraging output when encoding symbols at the transmitter to achieve diversity. The paper showed that  $8 \times 2$  MIMO system achieved good performance at low BER under low  $E_b/N_o$  values when the channel is perfectly known at the receiver.

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