CHAPTER 1

Introduction

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In modern wireless communication MIMO Systems employ two techniques for data transmission over wireless channel one is diversity technique and another is multiplexing technique. The techniques in the first group transmit replicas of same symbol with multiple radio resources. The resource here can be any kind from space, time, frequency code or combination of them. The techniques in second group with multiplexing simultaneously transmit number independent data stream over different transmit antennas. In this thesis Space Time Block Codes are analyzed as one of the diversity techniques in different MIMO systems to improve the link reliability and extend the coverage area.

1.1 Objectives

Space-time block codes (STBCs) with orthogonal designs, called orthogonal space-time block codes (OSTBCs), provide an elegant encoding and linear decoding technique while offering full diversity benefits in multiple-input multiple-output (MIMO) environments. The main objectives of the thesis are to observe bit error rate of different Orthogonal Space Time Block Codes(OSTBC) for two transmit antenna as well as OSTBC for more than two transmit antenna and arbitrary number of receive antennas. Finally, compare their performance with precoding and antenna selection technique that exploit Channel State Information(CSI) on the transmitter side to observe which technique ensure maximum utilization of limited radio equipment and good quality of data transmission.

1.2 Problem Statement & Motivation

In conventional wireless communication where single antenna is used in source and destination. Electromagnetic waves interact with obstacles like hills, buildings, canyons and consequently result in multipath fading problem at the receiver. It can cause reduction in data speed and increase the bit error rate. MIMO experiences great attenuation due to higher data rate and higher performance than conventional single antenna system. In case of uncoded MIMO system for attaining high transmission rate and spectral efficiency total bit error rate increases consequently transmission quality is degraded. Diversity technique can be used for the reduction of ill effect of multipath fading problem of wireless communication channel. The concepts of space time coding are one of the diversity techniques that uses multiple transmit and receive antennas. With data coding and signal processing at both side at transmitter and receiver space time coding has become more effective than traditional diversity technique. For improving the quality of data transmission with high data transmission rate and spectral efficiency MIMO with space time coded transmission needs much antenna equipment’s at the receiver that consequently increase the receiver circuit complexity. Such problem can be mitigated if transmitter has some channel state information so that it can make its transmission more channel adaptive using less radio equipment's.

1.3 Thesis Organization

In Our thesis we have organized the chapters in following order:

Chapter 1: introduction

This chapter contains objectives, motivation, problem statement of thesis and brief review of some terms related to the subject of the thesis has been given.

Chapter 2: Literature Review

The aim of this chapter is to review and discuss the literature on which the research presented in this thesis is based. This is particularly useful for reader with limited background on the subject.

Chapter 3: Material and Method

This chapter contains the mathematical representation of encoding of information symbol in Orthogonal Space Time Block Code's scheme for different rates and different transmit antennas, required equations for Precoding and Antenna selection techniques that improves the performance of the data transmission. It also contains mathematical representation of MIMO channel, channel noise, received vector at receiver and information extraction procedure with Maximum Likelihood decoder.

Chapter 4: Result and Discussion

In this chapter BER of Complex Orthogonal Space Time Block Codes of full rate and Generalized Complex Orthogonal Space Time Block Codes are shown and compared. Then finally comparison of OSTBC bit error performance to OSTBC with precoding and OSTBC for antenna subset selection method, that shows pre-coded OSTBC with limited feedback provide more gain over antenna subset selection method of OSTBC. We have used Mat lab 7.14.0.739 for simulation and discuss the result briefly.

Chapter 5: Conclusion and Future Works

It contains conclusion of thesis and future research topics that can be proposed.

1.4 Conclusion

MIMO allows multiple antennas to be used in transmitter and receiver. Due to attenuation losses MIMO uses a coded transmission over multiple antennas but efficient uses of radio resources are not ensured properly. It has been suggested to have channel state information at the transmitter to mitigate such problem and provide better performance of Orthogonal Space Time Block codes.

CHAPTER 2

Literature Review

CHAPTER 2

Literature Review

In the thesis for understanding MIMO in wireless communication and finding bit error rate of different OSTBC, it needs some elementary concepts on some topics and helps from other books and thesis papers. This chapter contains brief discussion over digital communication system, diversity techniques, MIMO and Space Time Coding. Finally, it provides some brief discussion on reference books and thesis papers from which the elementary concepts about thesis are obtained. All these papers and books are listed as the references.

2.1 Digital Communication system

Figure 1.1 is the block diagram of a typical digital communication system [12, p-531]. In this diagram, three basic signal processing operations are identified: source encoding, channel encoding and modulation.

In source encoding, the encoder maps digital signal generated at the source output into another signal in digital form. The mapping is one-to-one and the objective is to eliminate or reduce redundancy so as to provide an efficient representation of the source output since the source encoder mapping is one-to-one, the source decoder simply performs the inverse mapping and thereby delivers to the user destination a reproduction of the original digital source output. The primary benefit of source coding is to get reduced bandwidth requirement.

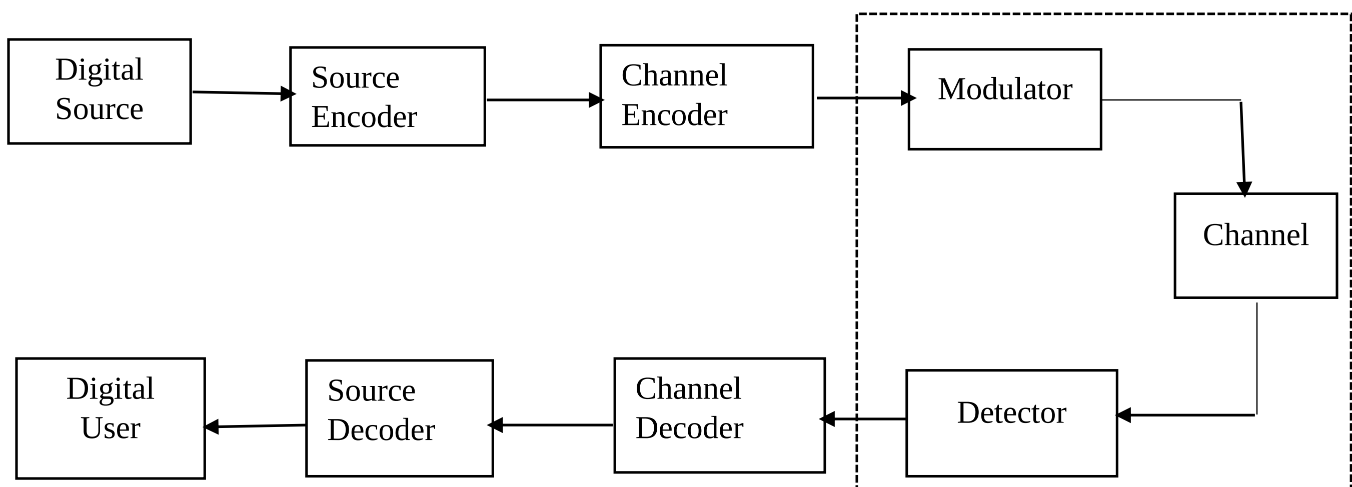


Fig 2.1 Block diagram of digital communication system.

The objective of channel encoder to map the incoming digital signal into channel input. The decoder maps the channel output into an output digital signal in such a way that the noise is minimized. So the role of the channel encoder and decoder is to provide for reliable communication over noisy channel. It introduces a controlled redundancy. Naturally, the source encoding is performed first, followed by channel encoding in the transmitter as illustrated in figure 1.1. In the receiver channel decoding is performed first, followed by source decoding. This combination provides better performance but increases circuit complexity. The digital modulation for example frequency shift keying can be used. The detector perform demodulation.

Channel encoder increases transmission bandwidth and circuit complexity. For this reason, it decreases battery life. There is one technique which can be used to overcome this problem. It is STBC that can prolong battery life and diminish the fading problem.

2.2 Wireless Channel

In wireless communication the physical paths between transmitters and receivers are called Channel. One of the distinguishing characteristics of wireless channels is the fact that there are many different paths between the transmitter and the receiver.

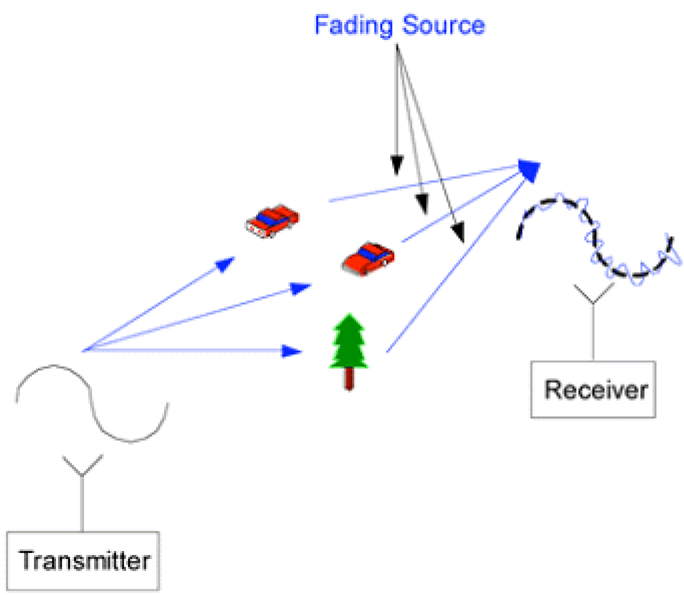


Fig 2.2: Wireless Channel with fading sources

2.2.1 Channel Model

Sometimes there are direct path between transmitter and receiver, which is called line of sight (LOS). Channel models are discussed for the case of non-line-of-sight (NLOS) and the case of line-of-sight (LOS) respectively. But practically there is so much scattering, fading encountered in real environment for these reason LOS model is not applicable. We assume Rayleigh Fading channel as NLOS model. The Rayleigh model has independent identically distributed complex, zero mean, unit variance channel elements and is given by- [11]

$$h_{i,j} = \frac{1}{\sqrt{2}}(normal(0,1) + \sqrt{-1} \cdot normal(0,1)) \tag{2.1}$$

Here $h_{i,j}$ is the Rayleigh channel model for NLOS environment.

2.2.2 Channel state Information

In MIMO wireless communications, channel state information (CSI) may be defined as the channel characteristics of communication link. This information describes how a signal propagates from the transmitter to the receiver and represents the effects such as fading, and power decay with distance. The CSI makes it possible to adapt transmissions to current channel conditions and improves the diversity technique which is a vital issue for achieving reliable communication with high data rates in multi -antenna systems. CSI needs to be estimated at the receiver and usually quantized and fed back to the transmitter .Therefore, the transmitter and receiver can have different CSI. The CSI at the transmitter and the CSI at the receiver are referred to as CSIT and CSIR, respectively.

Mathematical representation of CSI are given bellow-

$$h = |h| e^{j \sin(\angle(h))} \tag{2.2}$$

At some time instant transmit voltage "1" from first transmit antenna and measure its response from three receive antennas as [0.8 0.7 0.9]

$$\begin{matrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix} \Rightarrow \begin{matrix} 0.8 & 0 & 0 \\ 0.7 & 0 & 0 \\ 0.9 & 0 & 0 \end{matrix}$$

At the same time instant, the procedure is repeated for other transmit antennas.

$$\begin{matrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix} \Rightarrow \begin{matrix} 0.8 & -0.1 & 0.6 \\ 0.7 & 0.2 & 0.8 \\ 0.9 & 0.1 & 0.7 \end{matrix}$$

From the sample CSI matrix above, transmission antenna two is not effective .Receiver feedback the CSI to the transmitter. Transmitter doesn't use antenna two for transmission that ensures best utilization of radio equipment's and saves transmit power.

2.3 Diversity

Diversity is a technique that provides less- attenuated replica of transmitted signal to receiver [1, p-15]. There are two important issues related to diversity. One issue is how to provide the replicas of transmitted signal at the receiver with the lowest possible consumption of the power, bandwidth, decoding complexity and other resources. Second issue is how to use these replicas of transmitted symbols at the receiver in order to have highest reduction in probability of error. Some schemes are required to ensure the two goals those are stated above.

2.3.1 Diversity Schemes

In Communication Diversity Scheme refers to a method for improving the reliability of message signal by using two or more communication channel of different characteristics. The following diversity schemes are used frequently in radio communication.

Time diversity

Multiple copies of a signal are transmitted at different time slots. Alternatively, a redundant forward error correction code is added and the message is spread in time by means of bit-interleaving before it is transmitted. Thus, error bursts are avoided, which simplifies the error correction [10, p-562)].

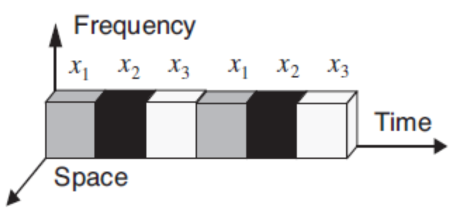


Fig 2.3: Time diversity

Frequency diversity

The signal is transmitted using several frequency channels or spread over a wide spectrum that is affected by frequency-selective fading. Frequency diversity are often used in microwave line-of-sight links using frequency division multiplexing (FDM). A spare frequency channel is usually provided for several frequency channels, each carrying an independent traffic [10, p-562].

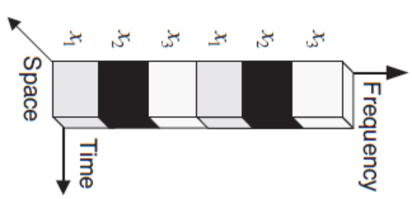


Fig 2.4: Frequency diversity

Antenna diversity

Antenna diversity, also known as space diversity or spatial diversity, is any one of several wireless diversity schemes that uses two or more antennas to improve the quality and reliability of a wireless link. [10,p-562]Antenna diversity is especially effective at mitigating these multipath situations. This is because multiple antennas offer a receiver several observations of the same signal. Each antenna will experience a different interference environment.

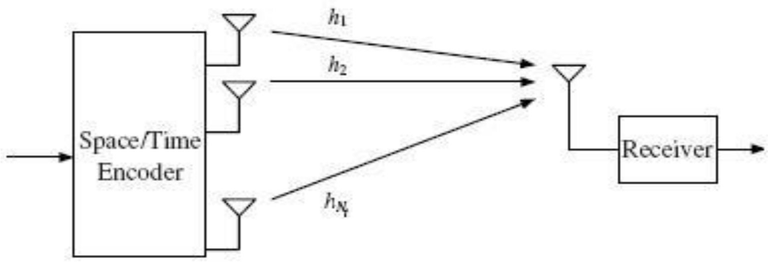


Fig 2.5 Antenna diversity

Polarization diversity

Multiple versions of a signal are transmitted and received via antennas with different polarization [10, p-562)]. Receiver antennas having different polarizations can be used to obtain diversity. An example is the use of vertical monopole and patch antennas is cellular communication. However, orthogonal polarization diversity is possible since many users are using portable units. A diversity combining technique is applied on the receiver side.

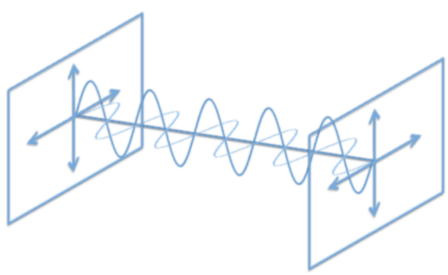


Fig 2.6: Polarization diversity

2.3.2 Diversity Gain

Diversity gain is the increase in signal-to-interference ratio due to some diversity scheme, or how much the transmission power can be reduced when a diversity scheme is introduced, without a performance loss. Diversity gain is usually expressed in decibels, and sometimes as a power ratio. A tractable definition of diversity gain is-

$$G_d = -\lim_{\gamma \to \infty} \frac{\log(P_e)}{\log(\gamma)} \tag{2.2}$$

Where P_e is the error probability at an SNR equal to γ.

2.4 Coding Gain

In Coding theory coding gain is the difference between the signal-to-noise ratio (SNR) level between the un-coded system and coded system required to reach the same Bit Error Rate (BER) levels.

If the un-coded QPSK system in AWGN environment has a bit error rate (BER) of 10^{-2} at the SNR level 4 dB, and the corresponding coded system has the same BER at an SNR of 2.5 dB, then the Coding Gain = 4 dB − 2.5 dB = 1.5 dB, due to the coded system is used.

2.5 Overview of MIMO

Multiple Input Multiple Output (MIMO) is an antenna technology for wireless communications in which multiple antennas are used at transmitter and receiver. Wireless Fidelity (Wi-Fi), Long Term Evolution (LTE), and many other latest wireless technologies use the MIMO wireless technology to provide increased link capacity and spectral efficiency with improved link reliability. For higher data rate with less fading and higher diversity, symbol transmission in MIMO system follows Orthogonal Space Time Block Code scheme.

2.5.1 Features of MIMO

Some features of MIMO system that make it interactive in modern wireless communication are given bellow:

I. **High Data rate**: MIMO use multiple transmit antenna and receive antenna at both transmitter and receiver, so that high data rate can easily be obtained in MIMO systems.
II. **Spatial Diversity:** MIMO can easily exploit spatial diversity by having several transmit and receive antennas.
III. **High Capacity:** It can significantly increase the capacity of the channel by independently sending data stream across multiple antennas.
IV. **Less Probability of Error**: It makes the decoding complexity simpler and therefore probability of error will be less.

2.5.2 Classification of MIMO On the Basis of CSI Feedback

Based on utilization of Channel State Information MIMO system can be classified in two types. Those are given bellow.

1. Open loop MIMO system 2. Close loop MIMO system

2.5.2.1 Open loop MIMO system

When the transmitter does not have any information about the channel, the system is called "open loop" system. In this case the receiver may estimate the channel and use the channel state information (CSI) for decoding.

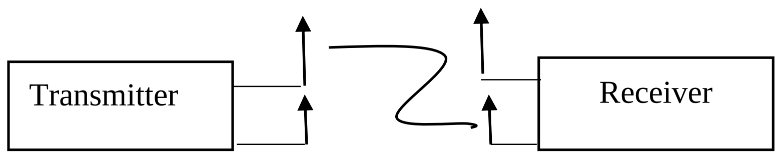
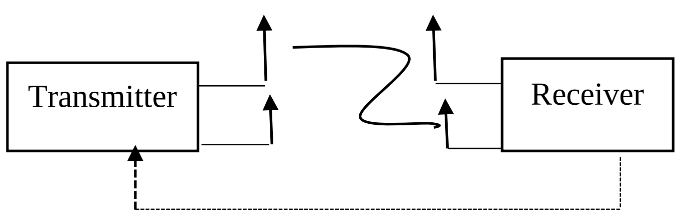


Fig: 2.8 Block diagram open loop MIMO system

2.5.2.2 Close loop MIMO system

When the receiver sends the channel state information to the transmitter through a feedback channel. The transmitter can use the information to improve the performance. In a closed-loop system, the gain achieved by processing at the transmitter and the receiver is sometimes called "array gain.". The array gains result in an increase in the average receive SNR.



CSI Feedback

Fig: 2.9 Block diagram open loop MIMO system

2.5.3 Special cases of MIMO

SISO

The simplest form of radio link can be defined in Space Time Coded MIMO Wireless communication terms as SISO - Single Input Single Output. This transmitter operates with one antenna as does the receiver. There is no diversity and no additional processing required.

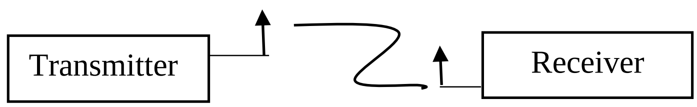


Fig 2.4: SISO - Single Input Single Output

SIMO

The SIMO or Single Input Multiple Output version occurs where the transmitter has a single antenna and the receiver has multiple antennas. This is also known as receive diversity. There are two forms of SIMO that can be used:

• **Switched diversity SIMO*:*** This form of SIMO looks for the strongest signal and switches to that antenna.

• **Maximum ratio combining SIMO:** This form of SIMO takes both signals and sums them to give a combination. In this way, the signals from both antennas contribute to the overall signal.

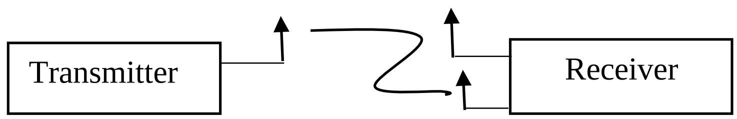


Fig 2.5: SIMO - Single Input Multiple Output

MISO

MISO is also termed transmit diversity. In this case, the same data is transmitted redundantly from the two transmitter antennas. The receiver is then able to receive the optimum signal which it can then use to receive extract the required data.

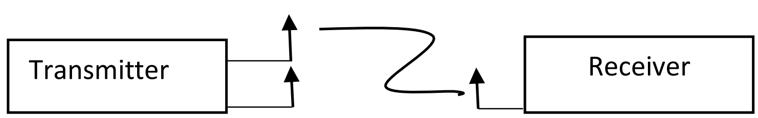


Fig 2.6: MISO - Multiple Input Single Output

2.5.3 Classification of MIMO Transmission Techniques

MIMO transmission can be sub-divided into three main categories, precoding, spatial multiplexing (SM), and diversity coding.

Precoding

It is multi-stream beamforming. In (single-stream) beamforming, the same signal is emitted from each of the transmit antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input. The benefits of beamforming are to increase the received signal gain - by making signals emitted from different antennas add up constructively and to reduce the multipath fading effect. In line-of-sight propagation, beamforming results in a well-defined directional pattern. However, conventional beams are not a good analogy in cellular networks, which are mainly characterized by multipath propagation. When the receiver has multiple antennas, the transmit beamforming cannot simultaneously maximize the signal level at all of the receive antennas, and precoding with multiple streams is often beneficial. Note that precoding requires knowledge of channel state information (CSI) at the transmitter and the receiver.

Spatial multiplexing

It requires MIMO antenna configuration. In spatial multiplexing, a high-rate signal is split into multiple lower-rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures and the receiver has accurate CSI, it can separate these streams into parallel channels. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter or receiver. Spatial multiplexing can be used without CSI at the transmitter, but can be combined with precoding if CSI is available.

Diversity coding

These techniques are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called Space-Time Coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beamforming or array gain from diversity coding. Diversity coding can be combined with spatial multiplexing and precoding when some channel knowledge is available at the transmitter.

2.6 Space Time Coding

Space Time Coding is a diversity technique which is employed to improve the reliability of data transmission in wireless communication system using multiple transmit antennas. In space time coded system multiple, redundant copies of data stream are transmitted to the receiver so that at least some of them survive the physical path between transmission and reception in a good state to allow reliable decoding [17].

Space Time codes may be split into two main types:

I. Space Time Block Code (STBC)
II. Space Time Trellis Code (STTC)

In this thesis Space Time Block Code has been discussed with precoding techniques and antenna selection techniques.

2.6.1 Space Time Block Codes (STBC)

Space Time Block Codes works on a block of data at once in which data streams are encoded in block. It is a technique used in wireless communication to transmit multiple copies of data stream over multiple transmit antennas and to exploit various received version of data stream to improve the reliability of data transfer. STBC allows the combination of data stream in receiver in an optimal way and extraction of information as much as possible. As STBC allows the transmission of multiple copies of data stream it compensate for different channel problems such as fading, scattering, refraction and so on.

STBC is represented by a matrix where each row denotes time slot and each column denotes transmit antenna. The general form of the STBC matrix are given bellow-

$$\begin{array}{cc} & \xrightarrow{\text{Transmit antenna}} \\ \text{Time slots} \downarrow & \begin{array}{ccc} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{array} \end{array}$$

Here $x_{i,j}$ is the modulated symbol to be transmitted in time slot i from j transmit antenna .The STBC in which vectors representing any pair of columns are orthogonal to each other is called Orthogonal Space Time Block Codes (OSTBC).

2.6.2.1 Features of Orthogonal Space Time Block Code

Orthogonal Space Time Block coding a type of Space Time Coding have some unique features that allow it to be used in MIMO system. Some of significant features are given bellow:

I. **Performance in Fading Environment**
Space Time Block codes utilizes multiple antennas to create spatial diversity, which allows a system to perform better in a fading environment.

II. **Decodable Complexity**
It shows good performance with minimum decodable complexity at receiving end. For decoding process, it supports Maximum Likelihood decoding.

III. **Diversity Gain**
It can achieve maximum diversity gain that provides significant role in data communication with less Bit Error Rate.

IV. **Orthogonal Design complexity**
Unfortunately, OSTBCs are difficult to design as the number of transmit antennas increases and, other than Alamouti's two-branch diversity scheme, do not achieve full rate.

2.6.1.2 Code Rate of OSTBC

Code Rate of OSTBC is a measure of how many symbols it transmits per time slot in a block [2]. If a block contains 'K' symbols and total number of time slots is denoted by T then code rate R will be-

$$R = \frac{K}{T} \tag{3.3}$$

Suppose a space time code word matrix, $G = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}$ (3.4)

It can transmit two types of symbols x_1, x_2 in a block per time slots in that case number of symbol per block is K=2 and total number of time slots are T=2.That results in code rate of one.

2.6.1.3 Different forms of OSTBC

Depending on coding rate OSTBC design varies from one to another. In my thesis performance of rate one OSTBC and the OSTBC which has code rate less than one is shown in different MIMO.

I) Alamouti OSTBC:

It is the simplest design among all of the OSTBC designs proposed by S.M Alamouti [3].It is designed for two transmit antenna and two receive antenna which has code rate of one. The Alamouti code has two important properties.

I. **Simple decoding**
   Each symbol is decoded separately using only linear processing.
II. **Maximum diversity**
   The code satisfies the rank criterion and therefore provides the maximum possible diversity.

II) Generalized OSTBC

To provide simple decoding and maximum diversity with more than two transmit antennas Tarokh et al. discovered STBC's set for three and four transmit antennas of code rate of half and code rate of three-by- four [2] [6].Only Alamouti OSTBC with two transmit antennas can attain full code rate .OSTBC with more than two transmit antenna cannot maintain full rate.

2.7 Reference Books and Papers

The books and papers that we have studied to perform our thesis are given bellow –

2.7 .1 Space-Time Coding: Theory and practice by Hamid Jafarkhani

In this thesis this chapter work as very effective source for information. Chapter one provides basic concept on MIMO, different types of wireless channel, fading, diversity, open loop and closed loop MIMO system. Chapter two contains the basic formation of code word matrix, received signal matrix, channel matrix and noise matrix. It also contains the transmission model of multiple input and multiple output channel. Chapter three gives concept over the design criteria of space time coding. Chapter four provides concepts on formation orthogonal space time codes from generalized real or generalized complex orthogonal designs, and maximum likelihood decoding and full diversity. This chapter discusses some important criteria of OSTBC, mathematically represents the formation of generator matrix and encoding and decoding of information signal using the generator matrix. Finally, it helps to show the performance of OSTBC without CSI. Lot of examples of OSTBC and simulation analysis are given in this chapter.

2.7.2 V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Trans. Inform. Theory*, vol. 45, pp. 1456–1467, July 1999.

This paper contains the diversity criterion and channel model. It introduces some real and complex orthogonal space time block codes of rate one, rate half and rate three by four and performance analysis for different transmit and receive antenna combination. It also proved that no code for more than 2 transmit antennas could achieve full-rate.

2.7.3 S.M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communication", *IEEE Jl. on Select Areas in Comm.*, Vol. 16, pp. 1451–1458, 1998.

This paper presents a simple two-branch transmit diversity scheme. Using two transmit antennas and one receive antenna the scheme provides the same diversity order as maximal-ratio receiver combining (MRRC) with one transmit antenna, and two receive antennas. It is also shown that the scheme may easily be generalized to two transmit antennas and M receive antennas to provide a diversity order of 2M. The new scheme does not require any bandwidth expansion any feedback from the receiver to the transmitter and its computation complexity is similar to MRRC.

2.7.4 MIMO – OFDM Wireless Communications by Yong Soo Cho, Jaekwon Kim, Won Young Yang, Chung -Gu Kang

The book is very useful resource for simulating algorithm .Chapter Nine of this book gives concept on MIMO system model .Chapter Ten provides sound knowledge on antenna diversity, basic equation of received signal, combining techniques of received signal in multiple antennas at receiver ,Space time block codes and generalization of space time block coding .Chapter eleven shows some analysis of how performance of STBC can be ameliorated by exploiting channel state information on transmitter sides in closed loop MIMO system.

2.7.5 Limited feedback unitary precoding for orthogonal space-time block codes by D. J. Love and R. W. Heath, in *IEEE Transactions on Signal Processing*, vol. 53, no. 1, pp. 64-73, Jan. 2005

This paper investigates a limited feedback approach that uses a codebook of precoding matrices which is known to both transmitter and receiver. It contains a comparison between the limited feedback precoding and antenna subset selection for OSTBC scheme in closed loop MIMO system.

2.7.6 Vahid Tarokh, Hamid Jafarkhani, and A. Robert Calderbank (March 1999). "Space–time block coding for wireless communications: performance results" . *IEEE Journal on Selected Areas in Communications* 17 (3): 451–460.

In this document the performance of space-time block codes, which provide a new paradigm for transmission over Rayleigh fading channels using multiple transmit antennas is shown. Data is encoded using a space-time block code, and the encoded data is split into n streams which are simultaneously transmitted using n transmit antennas. It includes the encoding and decoding algorithms for various codes and provide simulation results demonstrating their performance. It is shown that using multiple transmit antennas and space-time block coding provides remarkable performance at the expense of almost no extra processing.

2.7.7 MIMO Space-Time Block Coding (STBC): Simulations and Results, by L. M. Cortes-Pena, *Design Project: Personal and Mobile Communications, Georgia Tech* , pp. 1-8, April, 2009.

In this paper brief discussion on Multiple-Input Multiple-Output (MIMO) systems, their modeling techniques and basic introduction to Space-Time Coding (STC) are provided. The encoding and decoding techniques of the Alamouti scheme as well as other generalized complex Orthogonal Space-Time Block Codes (OSTBC) for the three and four transmit antennas are shown. Finally, these STBCs are simulated in MATLAB and the results is discussed briefly.

2.7.8 Modern Digital and Analog Communication System by B.P Lathi ,Zhi Ding

This books provides elementary knowledge about digital communication, Different modulation schemes M-ary Phase Shift keying (PSK), Quadrature Amplitude Modulation (QAM) and their signal constellation also discussed here elaborately.

2.7.9 Advanced Engineering Mathematics by H.K DASS

This book act as very useful source of Matrix concepts. It provides sound mathematical discussion about Rank of a matrix, conjugate of a matrix, Transpose of a matrix, Hermitian matrix and inverse of a matrix. It provides basic knowledge about Frobenous norm of a matrix and its application in mathematics.

2.7.10 Fuqin Xiong, "*Digital Modulation technique*",Artech house ,inc.2000,pp-1-7 & 561-563.(p-562)]

Chapter eleven of this book provide some elementary knowledge about different diversity schemes, which will be employed in MIMO communication. It also shows some digital modulation technique that is frequently used in diversity techniques. Difference between channel coding and space time coding are described in this book.

2.7.11 G. Foschini and M. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," ***Wireless personal communications,*** **vol. 6, no. 3, pp. 311–335, 1998.**

This paper introduces a channel model named as Rayleigh fading channel in NLOS environment. This paper is motivated by the need for fundamental understanding of ultimate limits of bandwidth efficient delivery of higher bit-rates in digital wireless communications and to also begin to look into how these limits might be approached.

2.7.12 Digital Communication by Simon Haykin

This book provided us the basic knowledge over digital communication. Different stage of encoding including source coding, channel coding is described elaborately in terms of different modulation techniques.

2.7.13 LTE, LTE-Advanced and WiMAX: Towards IMT-Advanced Networks by Abd-Elhamid M. Taha, Najah Abu Ali, Hossam S. Hassanein

This book describes the technologies LTE-Advanced and IEEE's 802.16m (WiMAX 2.0) and functionalities that are enabling the two standards to realize these requirements. The exposition adopted parts from the traditional ways in which the two standards are introduced, which have generally been to follow the outlines of their respective recommendations.

2.7.14 Precoding Techniques for Digital Communication Systems by C.-C. Jay Kuo, Shang-Ho Tsai, Layla Tadjpour, Yu-Hao Chang

Chapter Four of this book shows a system model and optimal precoder for unitary precoded OSTBC system. It describes that full rate OSTBC exists for arbitrary number of transmit antennas. For arbitrary number of transmit antennas we can apply additional precoding matrix to achieve the performance like full rate code with additional array gain.

2.7.15 Larsson, E.G., Ganesan, G., Stoica, P., and Wong, W.H. (2002) on the performance of orthogonal space-time block coding with quantized feedback. ***IEEE Communication Letters,*** **12(6), 487–489.**

This paper analyzes how Orthogonal Space-Time Block Codes (OSTBC) can be used in the presence of feedback from the receiver to the transmitter. First, it surveys how some of the feedback techniques for AWGN channels with fading can be applied to OSTBC. Then we consider a simple scheme with diagonal weighting. The optimal diagonal weighting matrix, which minimizes the probability of error, is derived. The optimal weights depend on the channel and, hence, a feedback becomes necessary. Simulations show that relatively significant gains can be achieved with the diagonal weighting scheme.

2.7.16 B. M. Hochwald, T. L. Marzetta, T. J. Richardson, W. Sweldens and R. Urbanke, "Systematic design of unitary space-time constellations," in *IEEE Transactions on Information Theory*, vol. 46, no. 6, pp. 1962-1973, Sep 2000.

This paper has proposed a systematic method for creating constellations of unitary space–time signals for multiple-antenna communication links. Unitary space–time signals, which are orthonormal in time across the antennas, have been shown to be well-tailored to a Rayleigh fading channel where neither the transmitter nor the receiver knows the fading coefficients. The signals can achieve low probability of error by exploiting multiple-antenna diversity. Because the fading coefficients are not known, the criterion for creating and evaluating the constellation is nonstandard and differs markedly from the familiar maximum Euclidean-distance norm.

2.7.17 D. A. Gore and A. J. Paulraj, "MIMO antenna subset selection with space-time coding," in *IEEE Transactions on Signal Processing*, vol. 50, no. 10, pp. 2580-2588, Oct 2002.

This paper treats multiple-input multiple-output (MIMO) antenna subset selection employing space-time coding. We consider two cases differentiated based on the type of channel knowledge used in the selection process. We address both the selection algorithms and the performance analysis. We first consider the case when the antenna subsets are selected based on exact channel knowledge (ECK). Next, we treat the case of antenna subset selection when statistical channel knowledge (SCK) is employed by the selection algorithm. This analysis is applicable to general space-time coding schemes.

2.8 Conclusion:

In modern digital communication Multiple-input multiple-output, or MIMO, is a radio communications technology or RF technology that is being mentioned and used in many new technologies these days. Wi-Fi, LTE (3G long term evolution) and many other radio, wireless and RF technologies are using the new MIMO wireless technology with space time coded system to provide maximum diversity gain, coding gain that result in increased link capacity and spectral efficiency combined with improved link reliability.

CHAPTER 3

Materials and Methods

CHAPTER 3

Materials and Methods

MIMO the advanced wireless communication technology uses Space Time Coded scheme for data transmission in transmitter. This scheme allows an easy and less decodable complexity at the receiver. Different STBC scheme and their implementation of different MIMO system are discussed here elaborately.

3.1 General System Model for Space Time Coded MIMO System for Rayleigh Fading Channel

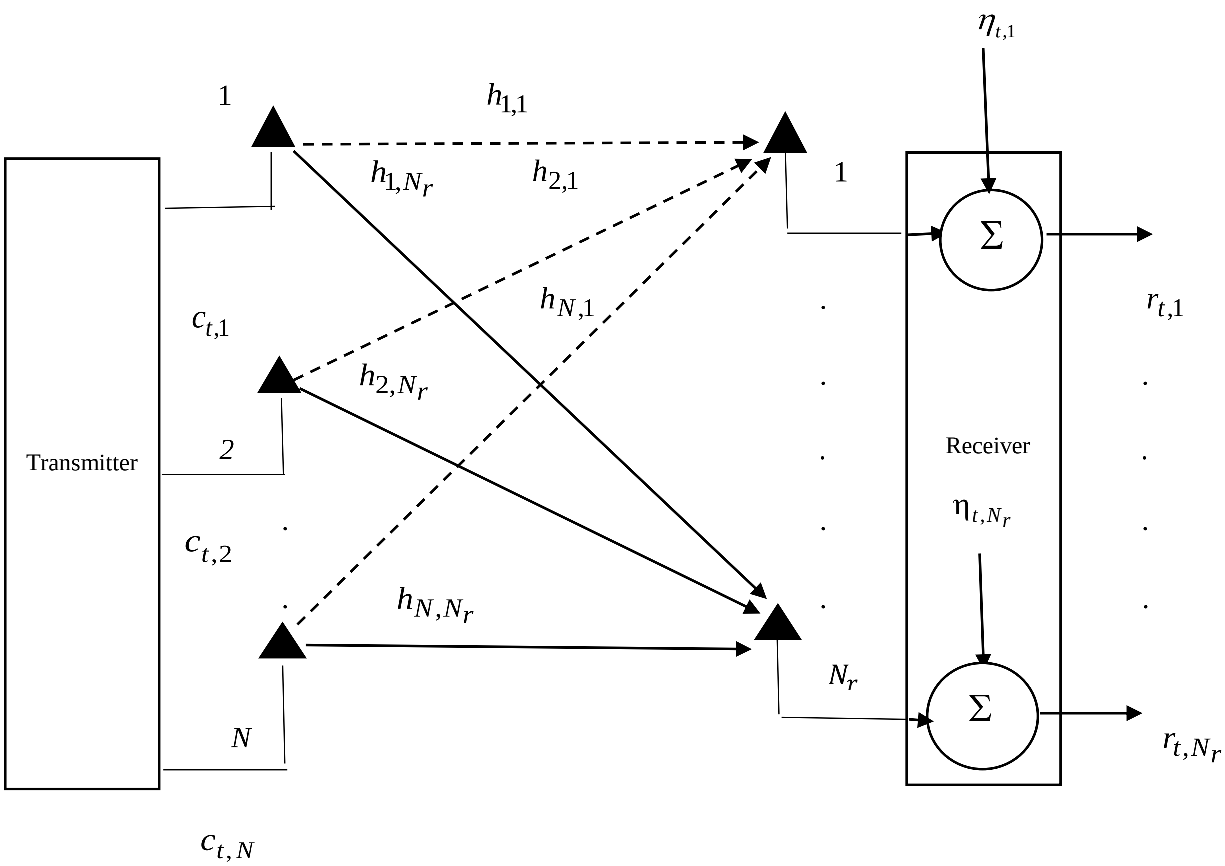


Figure 3.1: A Multiple Input Multiple Output (MIMO) System model.

MIMO is a wireless communication system in which the transmitter contains N transmit antennas and receiver including decoder contains N_r receive antennas. A single path is created for each pair of transmit and receive antenna .Each transmit antenna transmit signal through wireless channel and other end of the link it is received by receive antennas. Let assume at each time slots $t=1, 2 \ldots T$

signals $c_{t,n}$ are transmitted through the wireless channel simultaneously over $n = 1,2,3....N$ transmit antennas and it received by $n_r = 1,2, \ldots \ldots N_r$ receivers.

So, the received signal for first receive antenna will be,

$$r_{t,1} = h_{1,1}c_{t,1} + h_{2,1}c_{t,2} + \ldots\ldots + h_{N,1}c_{t,N} + \eta_{t,1} \tag{3.1}$$

After simplification, [1, p-30]

$$r_{t,n_r} = \sum_{n=1}^{N} h_{n,n_r} c_{t,n} + \eta_{t,n_r} \tag{3.2}$$

Where,

r_{t,n_r} = At time t received signal at antenna n_r.

h_{n,n_r} =The path gain from transmit antenna n to receive antenna n_r.

$c_{t,n}$ = Signal at each time slot t.

η_{t,n_r} = At time slot t the noise sample of each receive antenna.

The transmitted signal **C is** a $T \times N$ matrix and it is defined by,

$$\boldsymbol{C} = \begin{pmatrix} c_{1,1} & c_{1,2} & \cdots & c_{1,N} \\ c_{2,1} & c_{2,2} & \cdots & c_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ c_{T,1} & c_{T,2} & \cdots & c_{T,N} \end{pmatrix} \tag{3.3}$$

Matrix H denotes the path gain in a channel matrix $N \times N_r$,

$$\boldsymbol{H} = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_r} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,N_r} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N,1} & h_{N,2} & \cdots & h_{N,N_r} \end{pmatrix} \tag{3.4}$$

So, the received signal r is also a $T\times N_r$ matrix, which is given bellow-

$$\boldsymbol{r} = \begin{pmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,N_r} \\ r_{2,1} & r_{2,2} & \cdots & r_{2,N_r} \\ \vdots & \vdots & \ddots & \vdots \\ r_{T,1} & r_{T,2} & \cdots & r_{T,N_r} \end{pmatrix} \tag{3.5}$$

So, from (3.1) we get,

$$\boldsymbol{r} = \boldsymbol{C}\,\boldsymbol{H} + \boldsymbol{\mathcal{N}} \tag{3.6}$$

Where,

$\boldsymbol{r}$ = the received matrix of size $T\times N_r$

$\boldsymbol{C}$ = the Orthogonal Space Time Block Code matrix of size $T\times N$

$\boldsymbol{H}$ = the channel matrix of size $N\times N_r$

$\boldsymbol{\mathcal{N}}$ = the noise matrix of size $T\times N_r$

Here,

$$\boldsymbol{\mathcal{N}} = \begin{pmatrix} \eta_{1,1} & \eta_{1,2} & \cdots & \eta_{1,N_r} \\ \eta_{2,1} & \eta_{2,2} & \cdots & \eta_{2,N_r} \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{T,1} & \eta_{T,2} & \cdots & \eta_{T,N_r} \end{pmatrix} \tag{3.7}$$

If E_x is the average energy of each transmitted signal ,N is the number of total transmit antennas and N_0 is the average power of noise then input output relationship of MIMO channel can be simplified as- [4,p-266]

$$\boldsymbol{r} = \sqrt{\frac{E_x}{NN_0}}\,\boldsymbol{C}\,\boldsymbol{H} + \boldsymbol{\mathcal{N}} \tag{3.8}$$

3.2Orthogonal Space Time Block code in MIMO system

In this section, we first analyze the Space Time Code design criteria, real and complex orthogonal design criteria, Alamouti space-time coding technique and then generalization of space time blocks codes for three or more antennas MIMO system.

3.2.1 Data processing at OSTBC system

OSTBC system simply consist of a OSTBC encoder and decoder. To transmit *b* bits/cycle, In encoding portion we use a modulation scheme that maps every *b* bits to one symbol from a constellation with 2^bsymbols. The information source is divided into blocks of *Kb* bits. Using these *Kb* bits, the encoder picks *K* symbols $s_{1,}s_2....s_k$ from the constellation. The constellation symbols are replaced in the generator matrix ($\mathcal{G}$) of the OSTBC to generate the codeword. Then, the elements of the *t* th row of the code word are transmitted from different antennas at time slot *t*.

3.2.2 Block diagram of OSTBC system

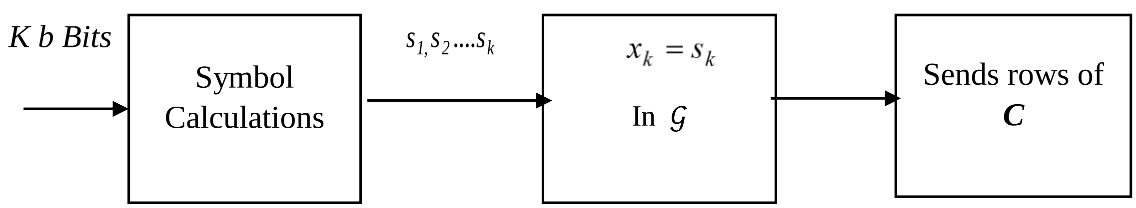


Fig 3.2: Block Diagram of OSTBC Encoder.

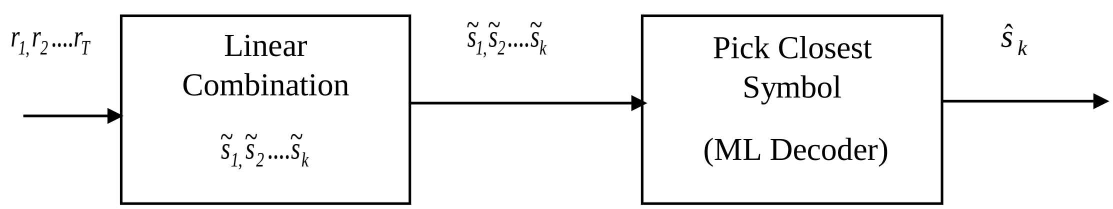


Fig 3.3: Block Diagram of OSTBC Decoder.

According to block diagrams **,**OSTBC encoder assigns the symbols from modulator $s_{1,}s_2....s_k$ to the indeterminate variable of generator matrix x_k and finally transmit the elements of code word matrix ***C*** row wise[1,p-78]. OSTBC decoder consist of a Maximum Likelihood (ML) decoder. Received signals $r_{1,}r_2....r_T$ from different time slots *t= 1,2..T* are linearly combined then the linear combinations of received signals $\tilde{s}_{1,}\tilde{s}_2....\tilde{s}_k$ are feed to the input of the Maximum Likelihood decoder and finally transmitted information symbols are recovered.[1,p-84]

3.2.3 Formation of Generator Matrix $\mathcal{G}$

Radon and Hurwitz [1, p-62] provided a real Orthogonal design. That is described below.

A set of $N \times N$ real matrix $\{B_1, B_{2,} .....B_L\}$ is a size of L Radon-Hurwitz family of matrix if:

I. The matrix B_i are orthogonal that is, $B_i^T B_i = I_N$, the identity matrices ,for all *i=1,2…N*

II. $B_i^T B_j + B_j^T B_i = 0$ for *i= 1,2…N* and *j= 1,2….N* , $i \neq j$.

For finding Hurwitz-Radon family we use Radon theorem.

Let, *N*= $2^a b$ where *N* is positive integer and a= (4c+d), c≥0, 0≤d<4 and b is odd number. The size of a Hurwitz-Radon matrix family is $\rho(N-1)$.

For a=1, N=2, c=0, d=1 so Hurwitz-Radon family has only one member. It can be said that, a Hurwitz-Radon family of size *N* -1 exists if and only if N=2, 4, 8.For example-

$$R = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$$

A 2×2 generator matrix is achieved by using a Hurwitz-Radon family of size one that is *R*.

$$\mathcal{G}_2 = x_1 I_2 + x_2 R = \begin{pmatrix} x_1 & x_2 \\ -x_2 & x_1 \end{pmatrix} \tag{3.9}$$

3.2.4 Real and complex Orthogonal Design of OSTBC

For real Orthogonal design of size N is a $N \times N$ orthogonal matrix $\mathcal{G}_N$ with real entries $x_1, -x_1, x_2, -x_2, \dots \dots, x_N, -x_N$ such that

$$\mathcal{G}_N^T \mathcal{G}_N = (x_1^2 + x_1^2 + \cdots + x_1^2) I_N$$

Where,

$\mathcal{G}_N^T$ =Transpose of generator matrix.

$\mathcal{G}_N$ =N×N Identity matrix.

A full rate code with full transmit diversity *N* will be get if in Real Orthogonal Design *K* = *N* and *T* = *N*.

For complex Orthogonal design of size *N* is $N \times N$ orthogonal matrix $\mathcal{G}_N$ with complex entries $x_1, -x_1, x_2, -x_2, \dots \dots, x_N, -x_N$ and their conjugates $x_1^*, -x_1^*, x_2^*, \dots \dots, x_{N,}^* -x_N^*$ and multiplies of these indeterminate variables by *–j* such that,

$$\mathcal{G}_N^T \mathcal{G}_N = (|x_1|^2 + |x_2|^2 + \cdots + |x_K|^2) I_N$$

If Complex Orthogonal Design $K = N$ and$T = N$.

3.3 Alamouti Space Time Block codes

It is a complex Orthogonal Space Time Block Codes. Alamouti OSTBC can work in both in 2 × 1 and 2 ×2 MIMO system. Suppose that there are 2^b signals in the constellation .At first time slot $2b$ bits arrive at the encoder and select two complex symbol s_1 and s_2 .At time t , s_1 and s_2 are transmitted from transmit antenna 1 and transmit antenna 2 respectively .Assume that each symbol has a duration of T ,at $t+T$ time slot the symbol $-s_2^*$ and s_1^* are transmitted from transmit antenna one and transmit antenna two respectively where (.)* denotes the complex conjugate of the symbol. [3]

Generator matrix for alamouti OSTBC are given by [1p-77]-

$$\mathcal{G}_{2,2,2} = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix} \qquad (3.10)$$

We use $\mathcal{G}_{N,K,T}$ to represent an OSTBC for N transmit antennas are delivering K symbol over T time periods. The code at (3.9) transmit 2 symbols over 2 time periods and the rate of the code R=1.

3.3.1 Case of 1 receive antenna

According to equation (3.6) we write the received signal in terms of transmitted signals, channel path gains, and noise as -

$$\boldsymbol{r} = \boldsymbol{C} \cdot \boldsymbol{H} + \boldsymbol{\mathcal{N}}$$

$$\Rightarrow \begin{bmatrix} r_{1,1} \\ r_{2,1} \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \cdot \begin{bmatrix} h_{1,1} \\ h_{1,2} \end{bmatrix} + \begin{bmatrix} \eta_{1,1} \\ \eta_{2,1} \end{bmatrix} \qquad (3.11)$$

Here,

$r_{1,1}$ = Received signal at 1st time slot at 1st receive antenna.

$r_{2,1}$ = Received signal at 2nd time slot 1st receive antenna.

$\eta_{1,1}$ = Additive noise at 1sttime slot 1st receive antenna.

$\eta_{2,1}$ = Additive noise at 2nd time slot 1st receive antenna.

From equation (3.11) following equations for received signal at receive antenna one for first and second time slots can be obtained which are given as follows [3].

$$r_{1,1} = h_{1,1}x_1 + h_{1,2}x_2 + \eta_{1,1} \tag{3.12}$$

$$r_{2,1} = -h_{1,1}x_2^* + h_{1,2}x_1^* + \eta_{2,1} \tag{3.13}$$

Equation (3.11) and (3.12) can be written as follows- [4, p-296]

$$\begin{bmatrix} r_{1,1} \\ r_{2,1}^* \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{1,2}^* & -h_{1,1}^* \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \eta_{1,1} \\ \eta_{2,1}^* \end{bmatrix} \tag{3.14}$$

Here, effective received matrix [4, p-303],

$$r_{eff} = \begin{bmatrix} r_{1,1} \\ r_{2,1}^* \end{bmatrix} \tag{3.15}$$

Effective channel matrix [4, p-303],

$$H_{eff} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{1,2}^* & -h_{1,1}^* \end{bmatrix} \tag{3.16}$$

Effective Noise matrix, [4, p-303],

$$\mathcal{N}_{eff} = \begin{bmatrix} \eta_{1,1} \\ \eta_{2,1}^* \end{bmatrix} \tag{3.17}$$

In receiver the received signals are linearly combined before it feed to the ML decoder. Linear combination of received signal is performed using following equation – [4, p-296]

$$\tilde{S} = H_{eff}^H \cdot r_{eff} \tag{3.18}$$

$$\Rightarrow \begin{bmatrix} \tilde{s}_1 \\ \tilde{s}_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{1,2}^* & -h_{1,1}^* \end{bmatrix}^H \cdot \begin{bmatrix} r_{1,1} \\ r_{2,1}^* \end{bmatrix}$$

Combined signals at the receiver for two transmitted symbols x_1 and x_2 are obtained as by using equation (3.18) that multiplies Hermitian of effective channel matrix with effective received matrix [3].Final equations of linear combination are given bellow-

$$\tilde{s}_1 = h_{1,1}^* r_{1,1} + h_{1,2} r_{2,1}^* \tag{3.19}$$

$$\tilde{s}_2 = h_{1,2}^* r_{1,1} - h_{1,1} r_{2,1}^* \tag{3.20}$$

Alamouti OSTBC can be used for multiple receive antennas in the receiver end, in following section that has been discussed with some mathematical equations.

3.3.2 Case of two receive antenna

Similarly, for the case of two receive antennas, the received signals are obtained as follows [3]. -

$$r_{1,1} = h_{1,1}x_1 + h_{1,2}x_2 + \eta_{1,1} \tag{3.21}$$

$$r_{2,1} = -h_{1,1}s_2^* + h_{1,2}s_1^* + \eta_{2,1} \tag{3.22}$$

$$r_{1,2} = h_{2,1}s_1 + h_{2,2}s_2 + \eta_{1,2} \tag{3.23}$$

$$r_{2,2} = -h_{2,1}s_2^* + h_{2,2}s_1^* + \eta_{2,2} \tag{3.24}$$

Using equation (3.18) linearly combined signal for two transmitted symbol x_1 and x_2 are obtained using following equations [3].-

$$\tilde{s}_1 = h_{1,1}^* r_{1,1} + h_{1,2} r_{2,1}^* + h_{2,1}^* r_{1,2} + h_{2,2} r_{2,2}^* \tag{3.25}$$

$$\tilde{s}_2 = h_{1,2}^* r_{1,1} + h_{1,1} r_{2,1}^* + h_{2,2}^* r_{1,2} + h_{1,1} r_{2,2}^* + h_{1,1} r_{2,2}^* \tag{3.26}$$

3.3.3 Decoding decision metric for N_r receive antennas

The ML decoder decision metric decodes in favor of, s_1 and s_2 over all possible values of, s_1 and s_2 such that (3.27) and (3.28) are minimized where ψ is given by equation (3.31) [2] [6]-

$$\left|\left[\sum_{i=1}^{N_r}\left(r_{1,i}h_{i,1}^* + r_{2,i}^* h_{i,2}\right)\right] - s_1\right|^2 + \psi|s_1|^2 \tag{3.27}$$

$$\left|\left[\sum_{i=1}^{N_r}\left(r_{1,i}h_{i,2}^* - r_{2,i}^* h_{i,1}\right)\right] - s_2\right|^2 + \psi|s_2|^2 \tag{3.28}$$

$$\psi = \left(-1 + \sum_{i=1}^{N_r}\sum_{j=1}^{N}\left|h_{i,j}\right|^2\right) \tag{3.29}$$

Alamouti OSTBC is used with 2 transmit antennas and 1 receive antenna while obtaining the full diversity of 2. This is an important characteristic of Alamouti OSTBC as it reduces the effect of fading at mobile base stations while only requiring extra antenna elements at the base station rather than multiple antennas at the receiver make it more economical [3].In the thesis Alamouti OSTBC are also used in case of more than two receive antennas as OSTBC works only for transmit diversity not receive diversity. If we want to use more than two transmit antenna then we need to generalize the OSTBC for three, four or more transmit antennas. The details discussion over Generalized OSTBC has been given in the following section.

3.4 Generalized Orthogonal Space Time Block codes

In previous section it is seen that due to orthogonally of alamouti code for two transmit antenna it is possible to implement ML decoding by simple linear processing. This Idea was generalized for arbitrary number of transmit antenna using the general orthogonal design method [2].In following section generalized OSTBC are discussed for two different code rates.

3.4.1 OSTBC for *N*=4 with rate 1/2

$$\mathcal{G}_{448}=\begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{pmatrix} \tag{3.30}$$

The code in (3.34) transmit 4 symbols over 8 time slots and the rate of the code *R*=1/2[2][6].The code takes *4b* bits at each block to select constellation symbol s_1,s_2,s_3,s_4 .Then assign s_k in x_k,for *k* =1 ,2,3,4 in $\mathcal{G}_{448}$ finally codeword matrix **C** is formed and transmitted row wise from antennas *N*= 1,2,3,4 at time slots *t*.

3.4.1.1 Case of 1 receive antenna

From equation (3.6) the received signal can be written in term of noise, channel and code word matrix -

$$\boldsymbol{r} = \mathbf{C} \cdot \mathbf{H} + \boldsymbol{\mathcal{N}}$$

So, Received signal matrix for eight time slots at first receive antenna are given bellow-

$$\begin{bmatrix} r_{1,1} \\ r_{2,1} \\ r_{3,1} \\ r_{4,1} \\ r_{5,1} \\ r_{6,1} \\ r_{7,1} \\ r_{8,1} \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{bmatrix} \cdot \begin{bmatrix} h_{1,1} \\ h_{1,2} \\ h_{1,3} \\ h_{1,4} \end{bmatrix} + \begin{bmatrix} \eta_{1,1} \\ \eta_{2,1} \\ \eta_{3,1} \\ \eta_{4,1} \\ \eta_{5,1} \\ \eta_{6,1} \\ \eta_{7,1} \\ \eta_{8,1} \end{bmatrix} \tag{3.31}$$

From equation (3.31) following equations for received signal can be obtained-

$$r_{1,1} = h_{1,1}x_1 + h_{1,2}x_2 + h_{1,3}x_3 + h_{1,4}x_4 + \eta_{1,1} \tag{3.32}$$

$$r_{2,1} = h_{1,2}x_1 - h_{1,1}x_2 + h_{1,4}x_3 - h_{1,3}x_4 + \eta_{2,1} \tag{3.33}$$

$$r_{3,1} = h_{1,3}x_1 - h_{1,4}x_2 - h_{1,1}x_3 + h_{1,2}x_4 + \eta_{3,1} \tag{3.34}$$

$$r_{4,1} = h_{1,4}x_1 + h_{1,3}x_2 - h_{1,2}x_3 - h_{1,1}x_4 + \eta_{4,1} \tag{3.35}$$

$$r_{5,1} = h_{1,1}x_1^* + h_{1,2}x_2^* + h_{1,3}x_3^* + h_{1,4}x_4^* + \eta_{5,1} \tag{3.36}$$

$$r_{6,1} = h_{1,2}x_1^* - h_{1,1}x_2^* + h_{1,4}x_3^* - h_{1,3}x_4^* + \eta_{6,1} \tag{3.37}$$

$$r_{7,1} = h_{1,3}x_1^* - h_{1,4}x_2^* - h_{1,1}x_3^* + h_{1,2}x_4^* + \eta_{7,1} \tag{3.38}$$

$$r_{8,1} = h_{1,4}x_1^* + h_{1,3}x_2^* - h_{1,2}x_3^* - h_{1,1}x_4^* + \eta_{8,1} \tag{3.39}$$

From these equations of received signal the following equation may be written as multiplication of transmitted symbol and effective channel matrix. [4, p-303]-

$$\begin{bmatrix} r_{1,1} \\ r_{2,1} \\ r_{3,1} \\ r_{4,1} \\ r_{5,1}^* \\ r_{6,1}^* \\ r_{7,1}^* \\ r_{8,1}^* \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & h_{1,4} \\ h_{1,2} & -h_{1,1} & h_{1,4} & -h_{1,3} \\ h_{1,3} & -h_{1,4} & -h_{1,1} & h_{1,2} \\ h_{1,4} & h_{1,3} & -h_{1,2} & -h_{1,1} \\ h_{1,1}^* & h_{1,2}^* & h_{1,3}^* & h_{1,4}^* \\ h_{1,2}^* & -h_{1,1}^* & h_{1,4}^* & -h_{1,3}^* \\ h_{1,3}^* & -h_{1,4}^* & -h_{1,1}^* & h_{1,2}^* \\ h_{1,4}^* & h_{1,3}^* & -h_{1,2}^* & -h_{1,1}^* \end{bmatrix} . \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} \eta_{1,1} \\ \eta_{2,1} \\ \eta_{3,1} \\ \eta_{4,1} \\ \eta_{5,1}^* \\ \eta_{6,1}^* \\ \eta_{7,1}^* \\ \eta_{8,1}^* \end{bmatrix} \tag{3.40}$$

From equation (3.40) effective channel matrix H_{eff}, effective received signal matrix r_{eff} and effective noise matrix $\mathcal{N}_{eff}$ are obtained. From those matrix linear combination of received symbol are finally formed at the receiver. These linearly combined signals are used in maximum likelihood decoder and which are given bellow-

$$\text{Effective channel matrix, } H_{eff} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & h_{1,4} \\ h_{1,2} & -h_{1,1} & h_{1,4} & -h_{1,3} \\ h_{1,3} & -h_{1,4} & -h_{1,1} & h_{1,2} \\ h_{1,4} & h_{1,3} & -h_{1,2} & -h_{1,1} \\ h_{1,1}^* & h_{1,2}^* & h_{1,3}^* & h_{1,4}^* \\ h_{1,2}^* & -h_{1,1}^* & h_{1,4}^* & -h_{1,3}^* \\ h_{1,3}^* & -h_{1,4}^* & -h_{1,1}^* & h_{1,2}^* \\ h_{1,4}^* & h_{1,3}^* & -h_{1,2}^* & -h_{1,1}^* \end{bmatrix} \tag{3.41}$$

Similarly the effective received signal matrix can be obtained. Which is simply obtained from equation (3.40). The 8×1 effective received signal matrix has been given as bellows-

$$\text{Effective received signal matrix, } r_{eff} = \begin{bmatrix} r_{1,1} \\ r_{2,1} \\ r_{3,1} \\ r_{4,1} \\ r_{5,1}^* \\ r_{6,1}^* \\ r_{7,1}^* \\ r_{8,1}^* \end{bmatrix} \tag{3.42}$$

$$\text{Effective Noise signal matrix, } \mathcal{N}_{eff} = \begin{bmatrix} \eta_{1,1} \\ \eta_{2,1} \\ \eta_{3,1} \\ \eta_{4,1} \\ \eta_{5,1}^* \\ \eta_{6,1}^* \\ \eta_{7,1}^* \\ \eta_{8,1}^* \end{bmatrix} \tag{3.43}$$

In receiver the received signals are linearly combined before it feed to the ML decoder. Linear combination of received signal is performed by multiplying Hermitian of effective channel matrix with effective received signal matrix. According to equation (3.23) – [4,296]

$$\tilde{S} = H_{eff}^{H} \cdot r_{eff}$$

So from the above equation linear combination of received symbols $\tilde{s}_{1,}\tilde{s}_2, \tilde{s}_3, \tilde{s}_4$ may be written as given bellow.

$$\tilde{s}_1 = r_{1,1}h_{1,1}^* + r_{2,1}h_{1,2}^* + r_{3,1}h_{1,3}^* + r_{4,1}h_{1,4}^* + r_{5,1}^*h_{1,1} + r_{6,1}^*h_{1,2} + r_{7,1}^*h_{1,3} + r_{8,1}^*h_{1,4} \tag{3.44}$$

$$\tilde{s}_2 = r_{1,1}h_{1,2}^* - r_{2,1}h_{1,1}^* - r_{3,1}h_{1,4}^* + r_{4,1}h_{1,3}^* + r_{5,1}^*h_{1,2} - r_{6,1}^*h_{1,1} - r_{7,1}^*h_{1,4} + r_{8,1}^*h_{1,3} \tag{3.45}$$

$$\tilde{s}_3 = r_{1,1}h_{1,3}^* + r_{2,1}h_{1,1}^* - r_{3,1}h_{1,1}^* - r_{4,1}h_{1,2}^* + r_{5,1}^*h_{1,3} + r_{6,1}^*h_{1,4} - r_{7,1}^*h_{1,1} - r_{8,1}^*h_{1,2} \tag{3.46}$$

$$\tilde{s}_4 = r_{1,1}h_{1,4}^* - r_{2,1}h_{1,3}^* + r_{3,1}h_{1,2}^* - r_{4,1}h_{1,1}^* + r_{5,1}^*h_{1,4} - r_{6,1}^*h_{1,3} - r_{7,1}^*h_{1,2} + r_{8,1}^*h_{1,1} \tag{3.47}$$

For receive antennas more than one we need to generalized the above equation for multiple number of receive antennas. The more we increase the receive diversity the more accurately we can retrieve information signal from the combination of received symbol.

3.4.1.2 Generalized Case of N_r receive antennas

We had considered one receive antenna, for the case of N_r receive antennas linear combination of received symbol can be generalized as given bellow-

$$\tilde{s}_1 = \sum_{m=1}^{N_r} (r_{1,m}h_{m,1}^* + r_{2,m}h_{m,2}^* + r_{3,m}h_{m,3}^* + r_{4,m}h_{m,4}^* + r_{5,m}^*h_{m,1} + r_{6,m}^*h_{m,2} + r_{7,m}^*h_{m,3} + r_{8,m}^*h_{m,4})$$

$$\tilde{s}_2 = \sum_{m=1}^{N_r} (r_{1,m}h_{m,2}^* - r_{2,m}h_{m,1}^* - r_{3,m}h_{m,4}^* + r_{4,m}h_{m,3}^* + r_{5,m}^*h_{m,2} - r_{6,m}^*h_{m,1} - r_{7,m}^*h_{m,4} + r_{8,m}^*h_{m,3})$$

$$\tilde{s}_3 = \sum_{m=1}^{N_r} (r_{1,m}h_{m,3}^* + r_{2,m}h_{m,1}^* - r_{3,m}h_{m,1}^* - r_{4,m}h_{m,2}^* + r_{5,m}^*h_{m,3} + r_{6,m}^*h_{m,4} - r_{7,m}^*h_{m,1} - r_{8,m}^*h_{m,2})$$

$$\tilde{s}_4 = \sum_{m=1}^{N_r} (r_{1,m}h_{m,4}^* - r_{2,m}h_{m,3}^* + r_{3,m}h_{m,2}^* - r_{4,m}h_{m,1}^* + r_{5,m}^*h_{m,4} - r_{6,m}^*h_{m,3} - r_{7,m}^*h_{m,2} + r_{8,m}^*h_{m,1})$$

3.4.1.3 Decoding decision metric for N_r receive antennas

The ML decoder decision metric decodes in favor of s_1, s_2, s_3 and s_4 over all possible values of s_1, s_2, s_3 and s_4 such that (3.48), (3.49), (3.50) and (3.51) are minimized as given bellow-

$$|s_1 - \sum_{m=1}^{N_r} (r_{1,m}h_{m,1}^* + r_{2,m}h_{m,2}^* + r_{3,m}h_{m,3}^* + r_{4,m}h_{m,4}^* + r_{5,m}^*h_{m,1} + r_{6,m}^*h_{m,2} + r_{7,m}^*h_{m,3} + r_{8,m}^*h_{m,4})|^2 + (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2) |s_1|^2 \quad (3.48)$$

$$|s_2 - \sum_{m=1}^{N_r} (r_{1,m}h_{m,2}^* - r_{2,m}h_{m,1}^* - r_{3,m}h_{m,4}^* + r_{4,m}h_{m,3}^* + r_{5,m}^*h_{m,2} - r_{6,m}^*h_{m,1} - r_{7,m}^*h_{m,4} + r_{8,m}^*h_{m,3})|^2 + (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2) |s_2|^2 \quad (3.49)$$

$$|s_3 - \sum_{m=1}^{N_r} (r_{1,m}h_{m,3}^* + r_{2,m}h_{m,1}^* - r_{3,m}h_{m,1}^* - r_{4,m}h_{m,2}^* + r_{5,m}^*h_{m,3} + r_{6,m}^*h_{m,4} - r_{7,m}^*h_{m,1} - r_{8,m}^*h_{m,2})|^2 + (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2) |s_3|^2 \quad (3.50)$$

$$|s_4 - \sum_{m=1}^{N_r} (r_{1,m}h_{m,4}^* - r_{2,m}h_{m,3}^* + r_{3,m}h_{m,2}^* - r_{4,m}h_{m,1}^* + r_{5,m}^*h_{m,4} - r_{6,m}^*h_{m,3} - r_{7,m}^*h_{m,2} + r_{8,m}^*h_{m,1})|^2 + (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2) |s_4|^2 \quad (3.51)$$

3.4.2 OSTBC for *N*=3 with rate 1/2

Half rate can also be obtained for three transmit antennas, which is simply obtained by removing a column of previous code. It has been seen that after removing one column it transmit four type of symbol over eight time slots .As a result code rate will be the same as it was. The full diversity rate 1/2 code for transmit antennas three is given by following matrix [2], [6]:

$$\mathcal{G}_{348} = \begin{pmatrix} x_1 & x_2 & x_3 \\ -x_2 & x_1 & -x_4 \\ -x_3 & x_4 & x_1 \\ -x_4 & -x_3 & x_2 \\ x_1^* & x_2^* & x_3^* \\ -x_2^* & x_1^* & -x_4^* \\ -x_3^* & x_4^* & x_1^* \\ -x_4^* & -x_3^* & x_2^* \end{pmatrix} \tag{3.52}$$

3.4.2.1 Generalized Case of N_r receive antennas

For three transmit antennas, linear combination of received symbol can be generalized as given bellow-

$\tilde{s}_1 = \sum_{m=1}^{N_r} (r_{1,m}h_{m,1}^* + r_{2,m}h_{m,2}^* + r_{3,m}h_{m,3}^* + r_{5,m}^*h_{m,1} + r_{6,m}^*h_{m,2} + r_{7,m}^*h_{m,3})$

$\tilde{s}_2 = \sum_{m=1}^{N_r} (r_{1,m}h_{m,2}^* - r_{2,m}h_{m,1}^* + r_{4,m}h_{m,3}^* + r_{5,m}^*h_{m,2} - r_{6,m}^*h_{m,1} + r_{8,m}^*h_{m,3})$

$\tilde{s}_3 = \sum_{m=1}^{N_r} (r_{1,m}h_{m,3}^* - r_{3,m}h_{m,1}^* - r_{4,m}h_{m,2}^* + r_{5,m}^*h_{m,3} - r_{7,m}^*h_{m,1} - r_{8,m}^*h_{m,2})$

$\tilde{s}_4 = \sum_{m=1}^{N_r} (-r_{2,m}h_{m,3}^* + r_{3,m}h_{m,2}^* - r_{4,m}h_{m,1}^* - r_{6,m}^*h_{m,3} - r_{7,m}^*h_{m,2} + r_{8,m}^*h_{m,1})$

3.4.2.2 Decoding decision metric for N_r receive antennas

The ML decoder decision metric decodes in favor of s_1, s_2, s_3 and s_4 over all possible values of s_1, s_2, s_3 and s_4 such that (3.53), (3.54), (3.55) and (3.56) are minimized as given bellow-

$$|s_1 - \sum_{m=1}^{N_r}(r_{1,m}h_{m,1}^* + r_{2,m}h_{m,2}^* + r_{3,m}h_{m,3}^* + r_{5,m}^*h_{m,1} + r_{6,m}^*h_{m,2} + r_{7,m}^*h_{m,3})|^2$$
$$+ (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2)|s_1|^2 \tag{3.53}$$

$$|s_2 - \sum_{m=1}^{N_r} (r_{1,m}h_{m,2}^* - r_{2,m}h_{m,1}^* + r_{4,m}h_{m,3}^* + r_{5,m}^*h_{m,2} - r_{6,m}^*h_{m,1} + r_{8,m}^*h_{m,3})|^2$$
$$+ (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2)\ |s_2|^2 \tag{3.54}$$

$$|s_3 - \sum_{m=1}^{N_r} (r_{1,m}h_{m,3}^* - r_{3,m}h_{m,1}^* - r_{4,m}h_{m,2}^* + r_{5,m}^*h_{m,3} - r_{7,m}^*h_{m,1} - r_{8,m}^*h_{m,2})|^2$$
$$+ (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2)|s_3|^2 \tag{3.55}$$

$$|s_4 - \sum_{m=1}^{N_r} (-r_{2,m}h_{m,3}^* + r_{3,m}h_{m,2}^* - r_{4,m}h_{m,1}^* - r_{6,m}^*h_{m,3} - r_{7,m}^*h_{m,2} + r_{8,m}^*h_{m,1})|^2$$
$$+ (-1 + 2\sum_{m=1}^{N_r} \sum_{n=1}^{N} |h_{n,m}|^2)\ |s_4|^2 \tag{3.56}$$

Another OSTBC which has highest coding rate of Three-by-Four are mathematically discussed in the following section.

3.4.3 OSTBC for *N*=4 with rate 3/4

If a decoding complexity at the receiver is compromised, however, higher coding rates can be achieved by the following Space Time Block Codes:

$$\mathcal{G}_{434} = \begin{pmatrix} x_1 & x_2 & \frac{x_3}{\sqrt{2}} & \frac{x_3}{\sqrt{2}} \\ -x_2^* & x_1^* & \frac{x_3}{\sqrt{2}} & -\frac{x_3}{\sqrt{2}} \\ \frac{x_3^*}{\sqrt{2}} & \frac{x_3^*}{\sqrt{2}} & \frac{-x_1 - x_1^* + x_2 - x_2^*}{2} & \frac{-x_2 - x_2^* + x_1 - x_1^*}{2} \\ \frac{x_3^*}{\sqrt{2}} & -\frac{x_3^*}{\sqrt{2}} & \frac{x_2 + x_2^* + x_1 - x_1^*}{2} & -\frac{x_1 + x_1^* + x_2 - x_2^*}{2} \end{pmatrix} \qquad (3.57)$$

The code in (3.6) transmit three symbols over four time slots and the rate of the code R=3/4 [2] [6]. The code take *4b* bits at each block to select constellation symbol s_1,s_2,s_3,s_4 .Then assign s_k in x_k,for *k =1 ,2,3,4* in $\mathcal{G}_{434}$ finally codewords matrix ***C*** is formed and transmitted row wise from antennas *N= 1,2,3,4* at time slots *t*. It performs like previous half rate OSTBC to combine the received signal using same process according to equation (3.35) and (3.22). To retrieve information message combined symbol is finally feed to the ML decoder.

3.4.3.1 Decoding decision metric for N_r receive antennas

The ML decoder decision metric decodes in favor of s_1, s_2, s_3 and $s_4$over all possible values of s_1, s_2, s_3 and s_4 such that (3.58), (3.59), (3.60) are minimized as given bellow, where a parameter ψ is given by equation (3.33)-[2]

$$\left|\left[\sum_{i=1}^{N_r}\left(r_{1,i}\ h_{i,1}^* + r_{2,i}\ h_{i,2}^* + \frac{(r_{4,i} - r_{3,i})(h_{i,3}^* - h_{i,4}^*)}{2} - \frac{(r_{3,i} + r_{4,i})^*(h_{i,3}^* + h_{i,4}^*)}{2}\right)\right] - s_1\right|^2 + \psi|s_1|^2 \qquad (3.58)$$

$$\left|\left[\sum_{i=1}^{N_r}\left(r_{1,i}\ h_{i,2}^* - r_{2,i}\ h_{i,1}^* + \frac{(r_{4,i} + r_{3,i})(h_{i,3}^* - h_{i,4}^*)}{2} + \frac{(-r_{3,i} + r_{4,i})^*(h_{i,3} + h_{i,4})}{2}\right)\right] - s_1\right|^2 + \psi|s_2|^2 \qquad (3.59)$$

$$\left|\left[\sum_{i=1}^{N_r}\left(\frac{(r_{1,i} - r_{2,i})h_{i,3}^*}{\sqrt{2}} + \frac{(r_{1,i} - r_{2,i})h_{i,4}}{\sqrt{2}} + \frac{r_{3,i}^*(h_{i,1} + h_{i,2})}{\sqrt{2}} + \frac{r_{4,i}^*(h_{i,1} - h_{i,2})}{\sqrt{2}}\right)\right] - s_3\right|^2 + \psi|s_3|^2 \qquad (3.60)$$

3.4.4 OSTBC for *N*=3 with rate 3/4

OSTBC for three transmit antennas with Three-by-Four rate can be obtained easily by eliminating most right column of equation (3.57). It has been seen that after removing one column it transmit three type of symbols over four time slots .As a result code rate will be the same as it was.

$$\mathcal{G}_{334} = \begin{pmatrix} x_1 & x_2 & \frac{x_3}{\sqrt{2}} \\ -x_2^* & x_1^* & \frac{x_3}{\sqrt{2}} \\ \frac{x_3^*}{\sqrt{2}} & \frac{x_3^*}{\sqrt{2}} & \frac{-x_1 - x_1^* - x_2 - x_2^*}{2} \\ \frac{x_3^*}{\sqrt{2}} & -\frac{x_3^*}{\sqrt{2}} & \frac{x_2 + x_2^* + x_1 - x_1^*}{2} \end{pmatrix} \tag{3.61}$$

3.4.4.1 Decoding decision metric for *M* receive antennas

ML decoding follows similar process for decoding in favor of s_1,s_2,s_3 so as to minimize (3.62),(3.63),(3.64) to retrieve information signals.

$$\left|\left[\sum_{i=1}^{N_r}\left(r_{1,i}\, h_{i,1}^* + r_{2,i}\, h_{i,2}^* + \frac{(r_{4,i} - r_{3,i})(h_{i,3}^*)}{2} - \frac{(r_{3,i} + r_{4,i})^* (h_{i,3}^*)}{2}\right)\right] - s_1\right|^2 + \psi|s_1|^2 \tag{3.62}$$

$$\left|\left[\sum_{i=1}^{N_r}\left(r_{1,i}\; h_{i,2}^* - r_{2,i}\; h_{i,1}^* + \frac{(r_{4,i} + r_{3,i})(h_{i,3}^*)}{2} + \frac{(-r_{3,i} + r_{4,i})^* (h_{i,3})}{2}\right)\right] - s_2\right|^2 + \psi|s_2|^2 \tag{3.63}$$

$$\left|\left[\sum_{i=1}^{N_r}\left(\frac{(r_{1,i} - r_{2,i})h_{i,3}^*}{\sqrt{2}} + \frac{r_{3,i}^*(h_{i,1} + h_{i,2})}{\sqrt{2}} + \frac{r_{4,i}^*(h_{i,1} - h_{i,2})}{\sqrt{2}}\right)\right] - s_3\right|^2 + \psi|s_3|^2 \tag{3.64}$$

3.5 Orthogonal Space Time Block Codes with Exploiting Channel state information

Utilization of Channel Sate Information for channel adaptive transmission in close loop MIMO is becoming more important in modern wireless communication. Base Transceiver Station (BTS) utilizes channel state information (CSI) for enabling simple spatial diversity technique that increase effective SNR and reduce the hardware complexity. Transmission of data is performed using OSTBC scheme so as to increase the diversity gain and to improve the error performance. Exploitation of CSI at the transmitter are mainly performed using unitary precoding and antenna selection precoding techniques.

3.6 CSI Feed Back Technique

In modern MIMO system receiver knows the channel state information .It sends the full or partial CSI to the transmitter using pilot signals through TDD channel. Pilot signals can be sent using codebook at both side of the communication link which is named as unitary precoding. Each codebook consist of multiple number of precoding matrices receiver just select the index of optimum precoding matrix that is best suited to the wireless channel and transmit the index value to the transmitter. Another method is antenna selection where there are couple of antennas at the transmitter and each antenna denotes a channel towards the receiver .Receiver knows the channel and calculate the corresponding antennas for which channel path gain is maximum .Then it just sends back the index value which is representing the best suited antenna tuned to the channel .The index value is used by transmitter to select the transmit antennas out of given multiple number of transmit antennas.

3.7 Precoded OSTBC System with Unitary Precoding

Pre-coder design based on incomplete channel information is called unitary precoding. Schematic block diagram of precoded OSTBC system with unitary precoding is given bellow-

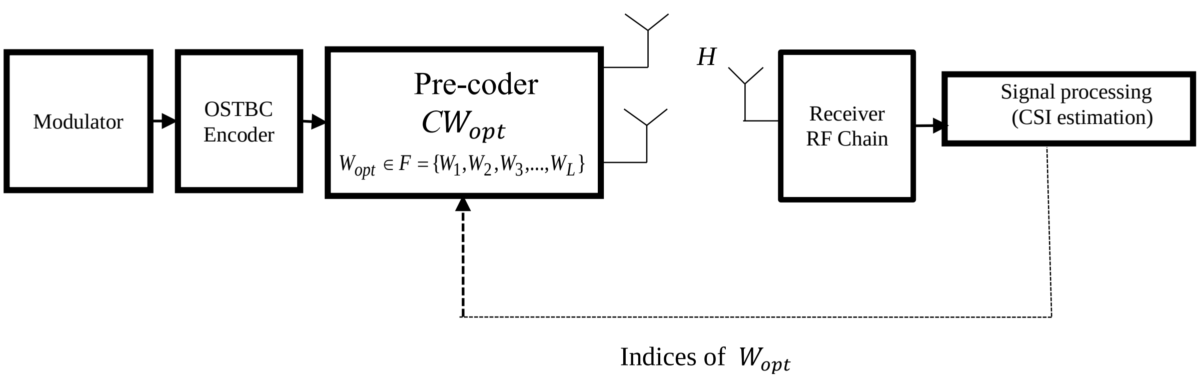


Figure 3.4: Feedback of CSI with using codebook.

Each index of codebook can be represented with F_B bits, which allows for a total number of L = 2^{F_B} codewords in the codebook [4]. Note that L is referred to as a codebook size. Let W_i denote the i th codewords $i=1, 2..., L$ .For a given codebook $F = \{W_1, W_2, W_3...,W_L\}$. The codewords is selected by a mapping function $f(\cdot)$ for a given channel condition H, the codebook method can be represented as

$$W_{opt} = f(H) \in F = \{W_1, W_2, W_3, ..., W_L\} \tag{3.65}$$

Here W_{opt} is the code word or optimum precoding matrix that best represents H for a given mapping function $f(\cdot)$ .Consider a close loop MIMO system with N_T transmit antennas, and N_r receive antennas .where channel element h. Let M data symbols can be mapped into N_T transmit antennas where C denote a space time code word with a length of M, and$M \leq N_T$. In the precoded OSTBC systems, the space-time codework C is multiplied by a precoding matrix W, which is chosen from the codebook F= {W_1, W_2, W_3... W_L}. The objective is to choose an appropriate code word that improves the overall system performance such as channel capacity or error performance. Assuming that N_T channels remain static over T, the received signal r can be be expressed as

$$r = \sqrt{\frac{E_x}{N_0 N_T}} hWC + \boldsymbol{\mathcal{N}} \tag{3.66}$$

3.7.1Code word Selection Criterion

For a given channel h and precoding matrix W, it is required to consider pairwise code word error probability$\Pr(C_i \rightarrow C_j|H)$. Which means that the space-time code word C_i is transmitted whereas C_j with $j \neq i$ is decoded. The upper bound of the pairwise error probability is given as [4, p-291].

$$\Pr(C_i \rightarrow C_j|H) = Q\left(\sqrt{\frac{\rho\left\|HWE_{ij}\right\|_F^2}{2N_T}}\right) \leq exp\left(-\frac{\rho\left\|HWE_{ij}\right\|_F^2}{4N_T}\right) \tag{3.67}$$

Where ρ is the signal-to-noise ratio (SNR), given as $\rho = E_x/N_0$ and E_{ij} is the error matrix between The code wordsC_i and C_j, which is defined as $E_{ij} = C_i - C_j$ for given STBC scheme. From Equation (3.67), we see that $\left\|HWE_{ij}\right\|_F^2$ needs to be maximized in order to minimize the pairwise Error probability [15]. Therefore, we can state following code word selection criterion:

$$\begin{aligned} W_{opt} &= \underset{W\epsilon F,\, i \neq j}{\arg max} \left\|HWE_{ij}\right\|_F^2 \\ &= \underset{W\epsilon F,\, i \neq j}{\arg max} T_r\left(HWE_{ij}E_{ij}^H W^H H^H\right) \\ &= \underset{W\epsilon F}{\arg max} T_r(HWW^H H^H) \\ &= \underset{W\epsilon F}{\arg max} \|HW\|_F^2 \end{aligned} \tag{3.68}$$

In the course of deriving Equation (3.67), we have used the fact that the error matrix of OSTBC has the property of $E_{ij}E_{ij}^H = aI$ with constant a. When the constraint $W\epsilon F$ is not imposed, the above optimum solution W_{opt} is not unique, because $\left\|HW_{opt}\right\|_F^2 = \left\|HW_{opt}Z\right\|_F^2$ where Z is a unitary matrix. The unconstrained optimum solution of Equation (3.8) can be obtained by a Singular value decomposition (SVD) of channel $H = U\Sigma V^H$ where the diagonal entry of Σ is in Descending order. It is shown that optimum solution of equation (3.8) is expressed by left most M

Column of **V** [5], that is –

$$W_{opt} = [\, v_1 v_2 \ldots v_M \,] \equiv \overline{V} \tag{3.69}$$

Since $\overline{\mathbf{V}}$ is unitary, $\lambda_i(W_{opt}) = 1$, *i=1, 2...... M*, where $\lambda_{\mathbf{i}}(\mathbf{A})$, denotes the *i* th largest eigenvalue of the matrix **A.**

3.7.2 Codebook design criterion

To design a codebook, we will propose a distortion measure that is a function of the channel and then find a codebook that minimizes the average distortion. This distortion function must differ, however, from the distortion functions commonly used in vector quantization such as mean squared error. The total effective power $\|HW\|_F^2$, which according to (3.6) relates to the BER. The distortion loss in received channel power is expressed as [5]-

$$\min_{W \epsilon F} (\|HW_{opt}\|_F^2 - \|HW\|_F^2) \tag{3.70}$$

The expected value of distortion can be written as-

$$E\{\min_{W \epsilon F} (\|HW_{opt}\|_F^2 - \|HW\|_F^2)\} \tag{3.71}$$

The expectation is with regards to the random channel *H* [5]**.**Equation (3.63) is upper bounded as-

$$\min_{W \epsilon F} \|HW_{opt}\|_F^2 - \|HW\|_F^2)$$

$$= \min_{W \epsilon F} \left(tr(\overline{\Sigma}\overline{\Sigma}^T) - tr(\Sigma V^H W W^H V \Sigma^T) \right)$$

$$\leq \min_{W \epsilon F} \left(tr(\overline{\Sigma}\overline{\Sigma}^T) - tr(\overline{\Sigma}\overline{V}^H W W^H \overline{V}\overline{\Sigma}^T) \right)$$

$$= \min_{W \epsilon F} tr\left((\overline{\Sigma}^T \overline{\Sigma}(I_M - \overline{V}^H W W^H \overline{V}) \right)$$

$$\leq \lambda_1^2\{H\} \min_{W \epsilon F} \left(tr(I_M - \overline{V}^H W W^H \overline{V}) \right)$$

$$= \lambda_1^2\{H\} \min_{W \epsilon F} \frac{1}{2} \left\| \overline{V}\overline{V}^H - W W^H \right\|_F^2$$

So, $\min_{W \epsilon F} (\|HW_{opt}\|_F^2 - \|HW\|_F^2) \leq \lambda_1^2\{H\} \min_{W \epsilon F} \frac{1}{2} \left\| \overline{V}\overline{V}^H - W W^H \right\|_F^2$

Consequently, the expected value in equation (3.64) is upper bounded as [5] –

$$E\{\min_{W\epsilon F}(\|HW_{opt}\|_F^2 - \|HW\|_F^2)\} \leq E\{\lambda_1^2\{H\}\min_{W\epsilon F}\frac{1}{2}\left\|\overline{V}\overline{V}^H - WW^H\right\|_F^2\} \tag{3.72}$$

Since $\lambda_1^2\{H\}$ is given, the codebook must be designed so as to minimize -

$E\{\min_{W\epsilon F}\frac{1}{2}\left\|\overline{V}\overline{V}^H - WW^H\right\|_F^2\}$ in equation (3.72).In order to minimize we have considered a suboptimal yet practical design method. One particular design method is to use DFT matrices given as [16].

$$F = \{W_{DFT}, \theta W_{DFT}, \ldots, \theta^{L-1}W_{DFT}\} \tag{3.73}$$

The first code word W_{DFT} is obtained by selecting M columns of $N_T \times N_T$ DFT matrix, of which The $(k,l)th$ entry is given as $\frac{e^{\frac{j2\pi u_1(k-1)(l-1)}{N_T}}}{\sqrt{N_T,}}$ where $k, l = 1,2, \ldots\ N_T$. Furthermore, θ is the diagonal matrix given as -

$$\theta = diag\left(\left[e^{j2\pi u_1/N_T}\ e^{j2\pi u_2/N_T} \ldots\ e^{j2\pi u_{NT}/N_T}\right]\right) \tag{3.74}$$

After obtaining the first code word W_{DFT} the remaining (L-1) codewords is obtained by multiplying W_{DFT} by θ^i,where *i=1,2.....L-1*.The free variables in (3.67) can be obtained such that the minimum chordal distance is maximized. That is-

$$u = \underset{\{u_1, u_2 \ldots u_{NT}\}}{\arg max}\ \underset{l=1,2,\ldots N-1}{min}\, d(W_{DFT,}\theta^l W_{DFT}) \tag{3.75}$$

Table 3.1 shows that the values of u=$[\ u_1, u_2 \ldots\ldots u_{N_T}\ ]^1$ that has been adapted in IEEE 802.16e for various values of M, N_T and L. For example N_T=4, M=3 and L=64, First precoding matrix W_1 is given as-

$$W_1 = \frac{1}{\sqrt{4}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{j2\pi.\frac{1.2}{4}} & e^{j2\pi.\frac{1.3}{4}} \\ 1 & e^{j2\pi.\frac{2.2}{4}} & e^{j2\pi.\frac{2.3}{4}} \\ 1 & e^{j2\pi.\frac{3.2}{4}} & e^{j2\pi.\frac{3.3}{4}} \end{bmatrix} \tag{3.76}$$

N_t Number of TX antennas	M Number of Data streams	L / F_B Codebook size (feedback bits)	**c** column indices	**u** rotation vector
2	1	8/(3)	[1]	[1,0]
3	1	32/(5)	[1]	[1,26,28]
4	2	32/(5)	[1,2]	[1,26,28]
4	1	64/(6)	[1]	[1,8,61,45]
4	2	64/(6)	[0,1]	[1,7,52,56]
4	3	64/(6)	[0,2,3]	[1,8,61,45]

Table 3.1: Codebook design parameters for OSTBC in IEEE 802.16e specification.

The remaining precoding matrix are obtained as given bellow-

$$W_i = diag\left(\left[e^{j2\pi.1/4} e^{j2\pi.8/4} e^{j2\pi.61/4} e^{j2\pi.45/4}\right]\right)^{i-l} W_1, i = 2,3, \ldots 64 \qquad (3.77)$$

3.7.3 Summarized Algorithm for Precoded OSTBC System with Unitary Precoding

1.Design a Codebook F for particular number of transmit antennas N_T, data stream M, column indices c, rotation vector u. Define number of feedback bits and finally determine codebook size L.

2. Assign the same code book both transmitter and receiver .Where each index of a codebook denotes a precoding matrix W_i where *i=1, 2….. L-1*

3. At Receiver calculate optimum precoding matrix $W_{opt} = \underset{W \epsilon F}{\arg max} \|HW\|_F^2$, find the index of W_{opt} within codebook F

4. Sends back the index to transmitter.

5. Transmitter uses the index to find best precoding matrix W_{opt} in its codebook F.

6. Perform the multiplication W_{opt} with Space Time Code word matrix C and transmit it over channel H.

7. Divide linearly combined signals at the receiver by $\left\|HW_{opt}\right\|_F^2$

8. Feed the output to the maximum likelihood decoder and extract information signal.

A simple flowchart of the algorithm is given as bellow-

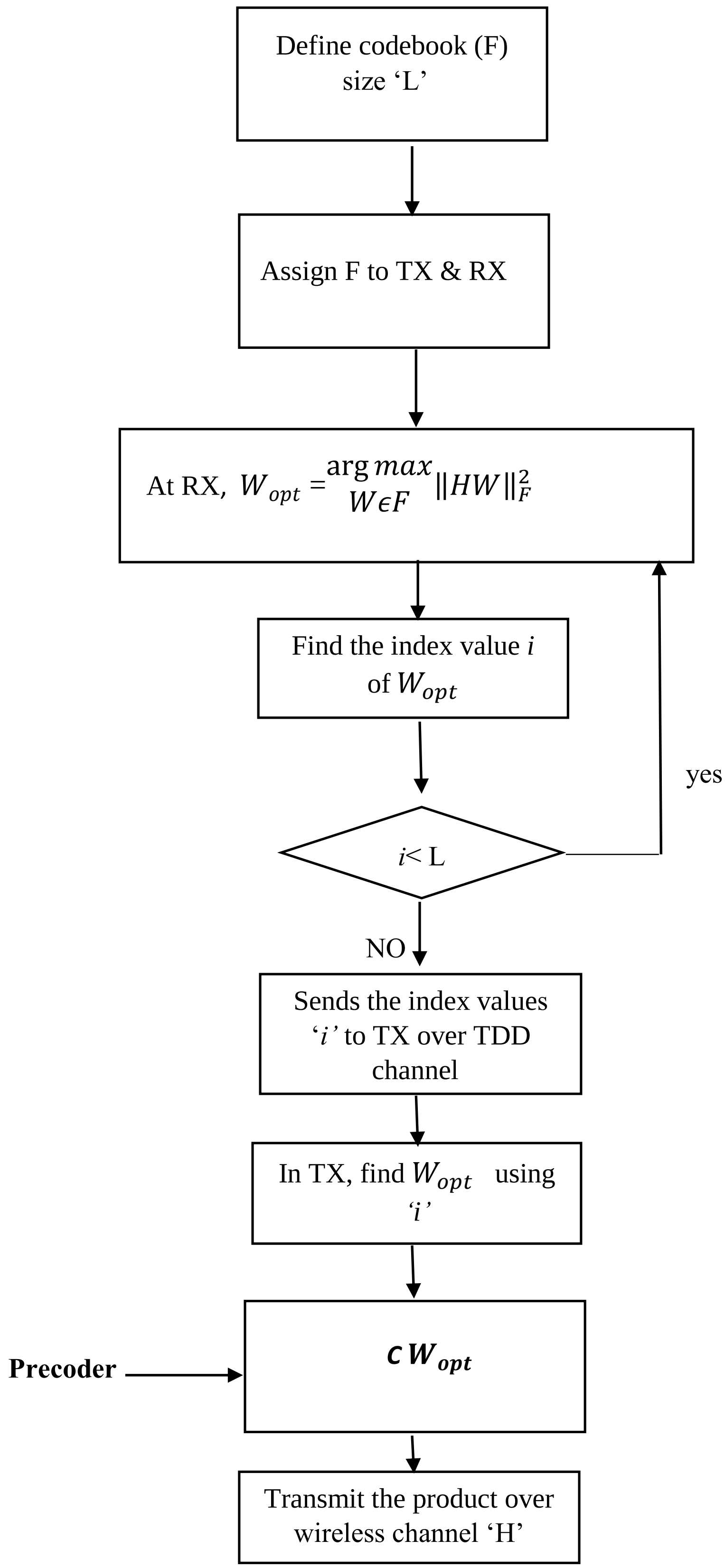


Fig 3.5: Flowchart of Precoded OSTBC System with Unitary Precoding

3.8 Precoded OSTBC System with Antenna Selection

Like precoding Antenna selection technique is used to exploit channel state information at transmitter side. In antenna selection system Q RF module are used to support N_T transmit antenna where Q<N_T.In antenna selection system Q RF modules are selectively mapped to Q of N_T transmit antennas.If $H_{\{p_1,p_2,\dots p_Q\}}$ is the corresponding effective channel matrix of Q transmit antennas.

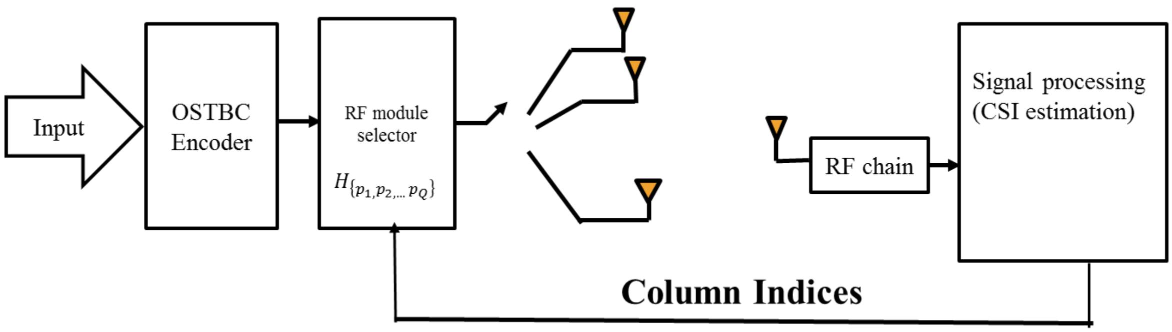


Fig 3.6: Feedback of CSI with Antenna selection technique.

Then received signal *r* is given by-

$$r = \sqrt{\frac{E_X}{Q}}\, H_{\{p_1,p_2,\dots p_Q\}} C + \mathcal{N} \tag{3.78}$$

C is the space time code word matrix and $\boldsymbol{\mathcal{N}}$ is the noise matrix.

3.8 .1 Antenna Selection Criterion

In antenna selection OSTBC error performance can also be used as design criterion. In other words, transmit antennas can be selected so as to minimize the error probability. $\Pr(C_i \to C_j \,|H_{\{p_1,p_2,\dots p_Q\}})$ denote the pairwise error probability when a space-time codewords C_i is transmitted but C_j is decoded for the given channel $H_{\{p_1,p_2,\dots p_Q\}}, j \neq i$. For an effective channel $H_{\{p_1,p_2,\dots p_Q\}}$ with Q columns of H chosen, an upper bound for the pairwise error probability for orthogonal STBC (OSTBC) is given as bellow-

$$\Pr\left(C_i \to C_j \,\middle|H_{\{p_1,p_2,\dots p_Q\}}\right) = Q\left(\sqrt{\frac{\rho \left\|H_{\{p_1,p_2,\dots p_Q\}}E_{ij}\right\|_F^2}{2N_T}}\right) \leq exp\left(-\frac{\rho \left\|H_{\{p_1,p_2,\dots p_Q\}}E_{ij}\right\|_F^2}{4N_T}\right) \tag{3.79}$$

The above upper bound follows from a similar way as in precoding section. The *q* transmit antennas can be selected to minimize the upper bound in Equation (3.79), or equivalently-

$$\{p_1^{opt}, p_2^{opt}, \dots, p_q^{opt}\} = \underset{p_1, p_2, \dots, p_q \epsilon A_q}{\arg max} \left\| H_{\{p_1, p_2, \dots p_Q\}} E_{ij} \right\|_F^2$$

$$= \underset{p_1, p_2, \dots, p_q \epsilon A_q}{\arg max} tr\left[H_{\{p_1, p_2, \dots p_Q\}} E_{ij} E_{ij}^H H_{\{p_1, p_2, \dots p_Q\}}^H\right] \quad (3.80)$$

$$= \underset{p_1, p_2, \dots, p_q \epsilon A_q}{\arg max} tr\left[H_{\{p_1, p_2, \dots p_Q\}} H_{\{p_1, p_2, \dots p_Q\}}^H\right]$$

$$= \underset{p_1, p_2, \dots, p_q \epsilon A_q}{\arg max} \left\| H_{\{p_1, p_2, \dots p_Q\}} \right\|_F^2$$

Where A_q represents a set of all possible antenna combinations with q selected antennas. In deriving Equation (3.79), we have used the fact that the error matrix E_{ij} has the property-

$E_{ij} E_{ij}^H = aI$ With constant a. From Equation (3.79), we can see that the antennas corresponding to high column norms are selected for minimizing the bit error rate.

3.8.2 Summarized Algorithm for implementing Precoded OSTBC with Antenna Selection Technique

1. Calculate $\underset{p_1, p_2, \dots, p_q \epsilon A_q}{\arg max} \left\| H_{\{p_1, p_2, \dots p_Q\}} \right\|_F^2$ at the receiver.

2. Organize the value in descending order.

3. Sends the corresponding index *i to* the transmitter.

4. According to index values *i* transmitter choose the antennas representing each column index of $H_{\{p_1, p_2, \dots p_Q\}}$

5. Take the Frobenous norm and its square of selected channels, $\left\| H_{\{i\}} \right\|_F^2$ for *i=1, 2….Q*.

6. Divide the linear combinations of received signals by $\left\| H_{\{i\}} \right\|_F^2$

7. Feed the output to the ML decoder.

A simple flowchart of the algorithm has been given bellow-

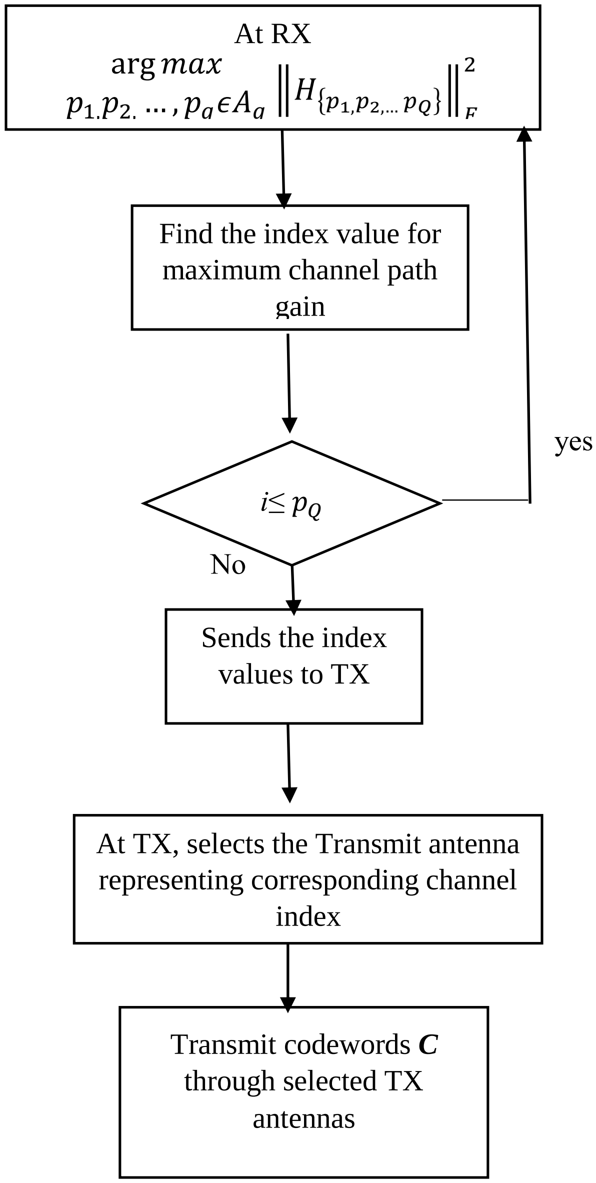


Fig 3.7: Flowchart of OSTBC with Antenna Selection Technique.

Conclusion

In OSTBC full rate can't be obtained for more than two transmitter antennas, however full diversity can be obtained for generalized OSTBC. Although Generalized OSTBC provide a code with a rate of three-by-four it creates higher decoding complexity at the receiver end. For better performance modern wireless communication adopt precoding and antenna selection techniques.

CHAPTER FOUR

Result and Discussion

CHAPTER 4

Result and Discussion

In this section, we provide simulation result for the Alamouti OSTBC and generalized OSTBC in open loop and close loop MIMO. Those codes have a definite code rate and use different modulation scheme depends on the transmission bit rate.so, we have used the suitable modulation scheme due to transmission bit rate for different STBCs.

4.1 Performance Analysis of OSTBC

In all simulation result we consider different numbers of transmit antenna and one receive antenna and a given transmission bit rate on the channel. Then using this result the performance of each Alamouti OSTBC is provided. For a fair comparison the modulation type and code size are varied with a view to maintaining a constant bit rate. As a result, proper combination of OSTBC and constellation are very essential.

Since only for real signal constellation a full-rate full-diversity code exists. For complex signal constellation full-rate OSTBCs exist only for two transmit antenna and this code is provided by Alamouti. This code has a great advantage that, one can transmit the desire transmission bit rate while only depends on the modulation techniques. If we want to transmit 1 bit/(s Hz) he may use BPSK, the 2 bits/(s Hz) use QPSK and continues for higher modulation technique. But code rate less than one need higher modulation technique for same transmission bit rate that obtained by Alamouti code. For half code needs QPSK where the Alamouti codes need BPSK modulation. In case of full-rate code one can transmit more bits than lower code rate by using same modulation scheme. This is why full-rate code is more efficient than lower rate code.

At the end of each simulation the average bit error ratio (BER) for the current SNR value is Calculated by dividing the number of incorrectly detected bits by the total number of transmitted bits:

$$BER = \frac{1}{N_b L_b} \sum_{k=1}^{N_b} b_{err,k} \tag{4.1}$$

With N_b being the number of simulated blocks (equaling the number of simulated channel instances). Hence, during each block k, the same number of bits L_b are transmitted, with $b_{err,k}$ bits being erroneous.

4.1.1 Transmission bit rate of 1 bit/(s/Hz)

The Figure 4.1 ,4.2 give the graph plotted against Bit Error Rate (BER) versus SNR(dB) of transmission bit rate of 1bit/(s/HZ) for Alamouti OSTBC, generalized OSTBC, and uncoded MIMO using equation (4.1). For QPSK (2bits/symbol) generalized OSTBC with half rate uses four constellation point so its bit rate will be 2×(1/2) =1bits/(s/ HZ). Similarly, Alamouti OSTBC uses BPSK for having bit rate of 1bit/(s/HZ).

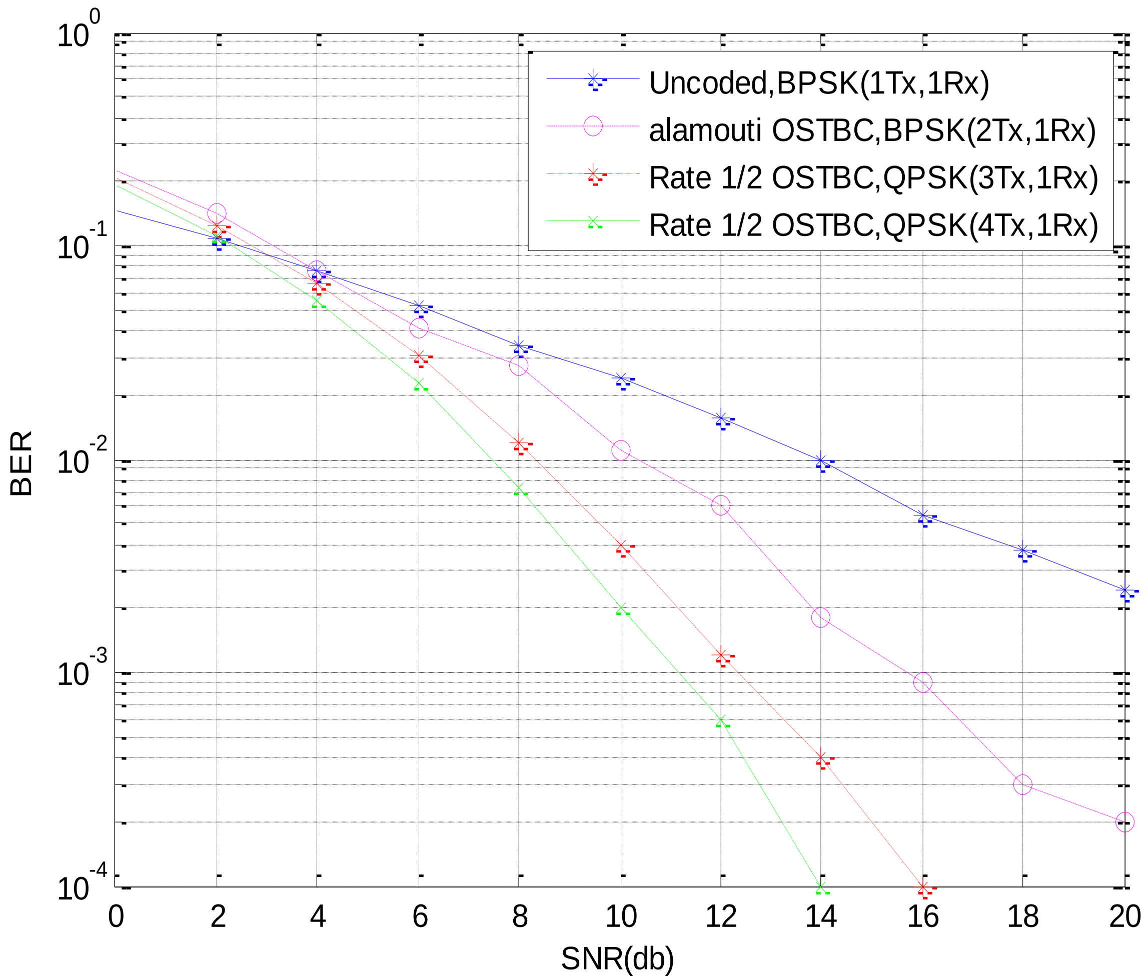


Fig 4.1: Bit Error Rate plotted against SNR for OSTBC's for one receive antennas

In 4.1 figure for one transmit antenna, a BPSK modulation scheme is used with no additional coding. The transmission using two transmit antennas employs the BPSK constellation and the Alamouti code The QPSK constellation and the code are utilized for four transmit antennas. It shows that For same receive antennas $\mathcal{G}_{448}$ outperform over $\mathcal{G}_{348}$, $\mathcal{G}_{222}$ and uncoded mimo .At BER 10^{-4} it provides a gain about 1dB over $\mathcal{G}_{348}$, more than 4 dB gain over $\mathcal{G}_{222}$ and more than 6dB gain over uncoded MIMO . It also shows that at lower transmission bit rate and spectral efficiency OSTBC perform better with the increase of number of transmit antenna *N* with constant receive antennas. As expected, a higher-order diversity is obtained with a larger number of transmit antennas, that is, steepening the slope of BER curves as the number of transmit antenna increases.

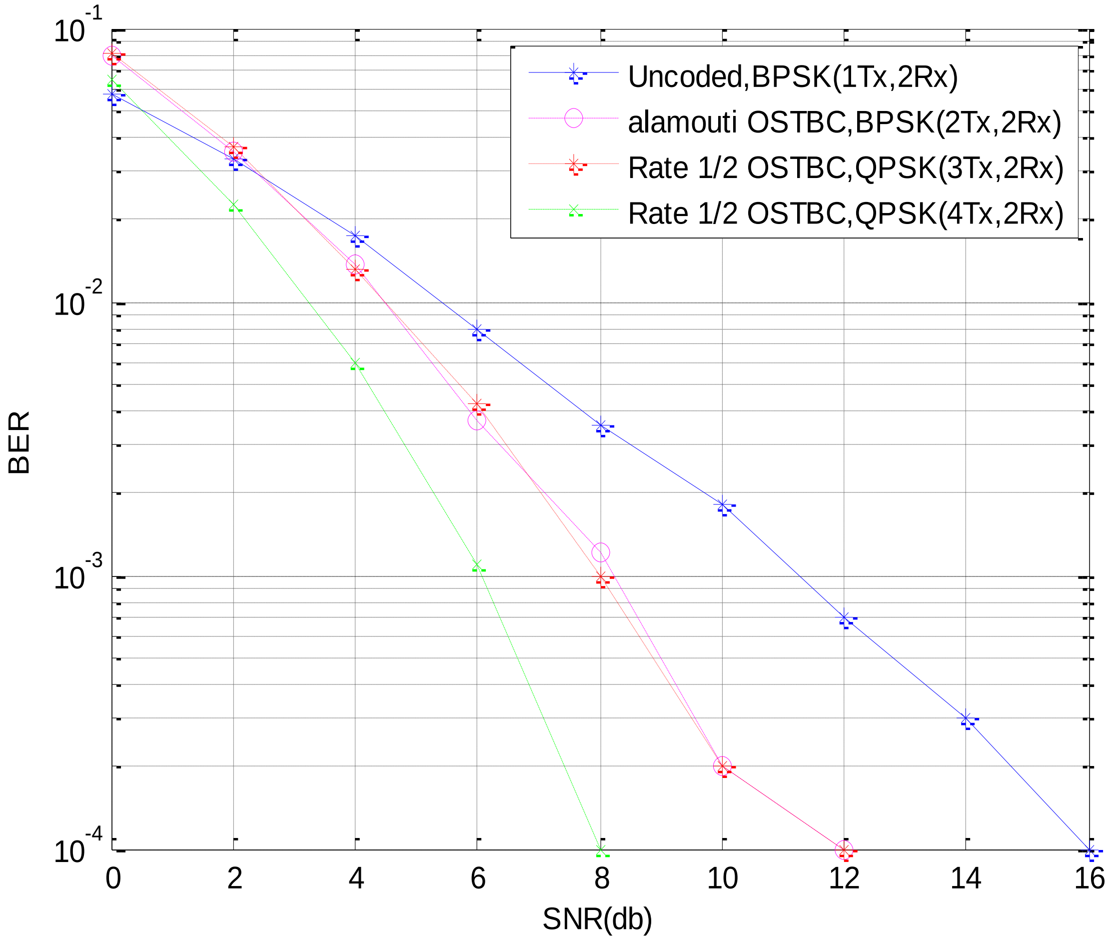


Fig 4.2: Bit Error Rate plotted against SNR for OSTBC's for two receive antennas

The simulation figure 4.2 shows that performance of$\mathcal{G}_{448}$, $\mathcal{G}_{348}$, $\mathcal{G}_{222}$, and uncoded MIMO is significantly improved with the increase of number of receive antenna N_r due to increase in diversity gain. The more we increase the receive diversity from equation (3.27), (3.28) and (3.48) to (3.51) we can see that more accurately we can combine the received symbol at the receiver end .It is seen that BER performance $\mathcal{G}_{348}$ almost identical to that of $\mathcal{G}_{222}$ .In that case. $\mathcal{G}_{448}$ Provide 4dB gain over $\mathcal{G}_{348}$, $\mathcal{G}_{222}$ and 8dB gain over uncoded MIMO. However, since the diversity gain of the codes for three and four transmit antenna is higher, the slop of their curve is downward. As a result, the codes for three and four transmit antennas outperforms the code for two transmit antennas at high SNR.

4.1.2 Transmission bit rate of 2 bit/ (s/Hz)

The Figure 4.3, 4.4 give the graph plotted against Bit error probability versus SNR(dB) of transmission bit rate of 2bit/(s/HZ) for Alamouti OSTBC, generalized OSTBC, and uncoded MIMO. For 16QAM (4bits/symbol) generalized OSTBC with half rate uses 16 constellation point so its bit rate will be $\frac{1}{2}\times 4$ =2bits/(s/HZ). Similarly, Alamouti OSTBC uses QPSK for having bit rate of 2bit/ (s/HZ). Equation (4.1) are utilized to determine BER for alamouti and generalized OSTBC.

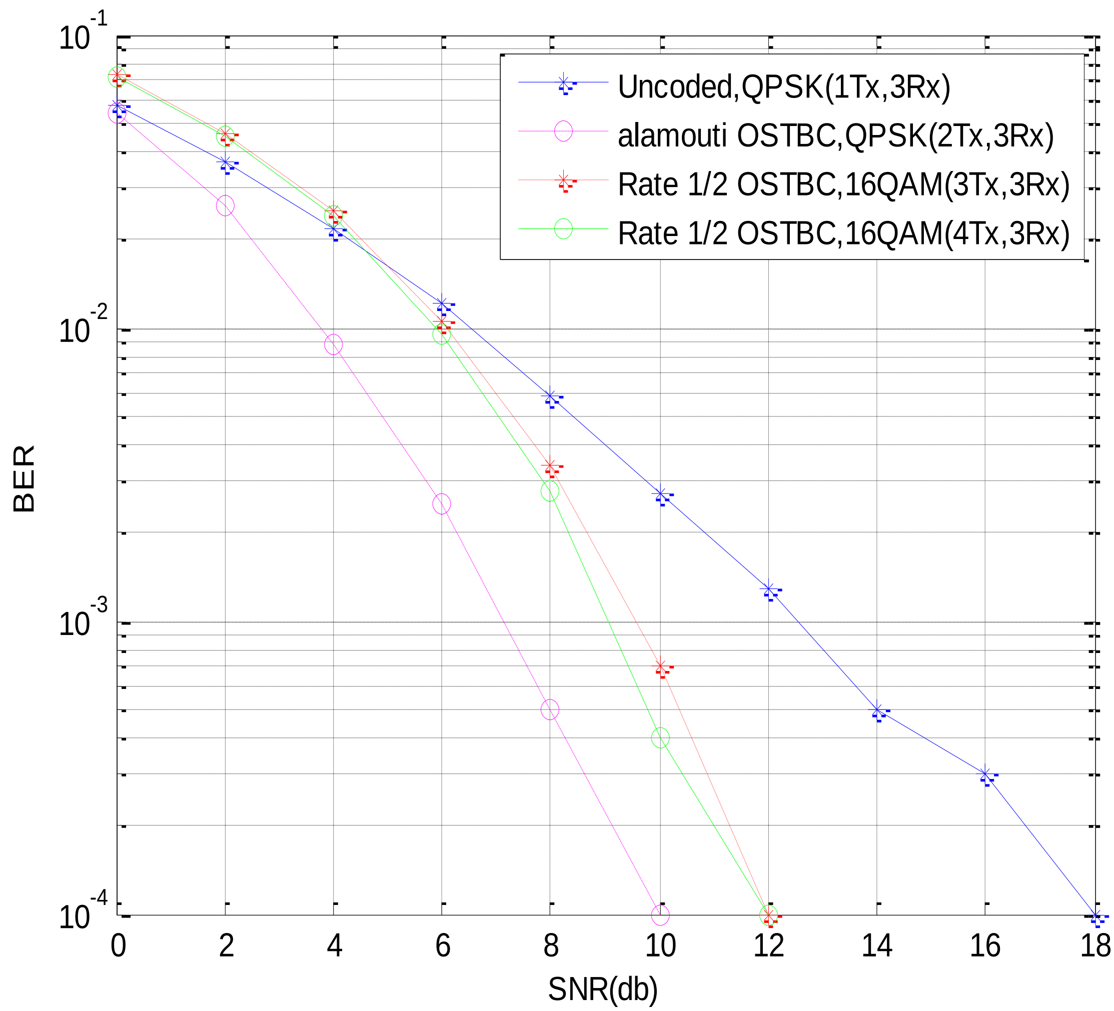


Fig 4.3: Bit Error Rate plotted against SNR for OSTBC's for three receive antennas

The simulation figure 4.3 shows that for 2bit/sHZ with three receive antennas, $\mathcal{G}_{222}$ outperform over $\mathcal{G}_{448}$, $\mathcal{G}_{348}$,and uncoded MIMO.Increasing receiver antennas to three provide more gain incase of full rate almouti code .Due to full coderate at BER 10^{-4} it provides 2 dB gain over $\mathcal{G}_{448}$

and $\mathcal{G}_{348}$, 8dB gain over uncoded MIMO .At 2bit/s/HZ $\mathcal{G}_{448}$, doesn't provide significant gain over $\mathcal{G}_{348}$ .Rate one OSTBC like $\mathcal{G}_{222}$, provide significant gain over other OSTBC's of code rate less than one at higher receive antennas .

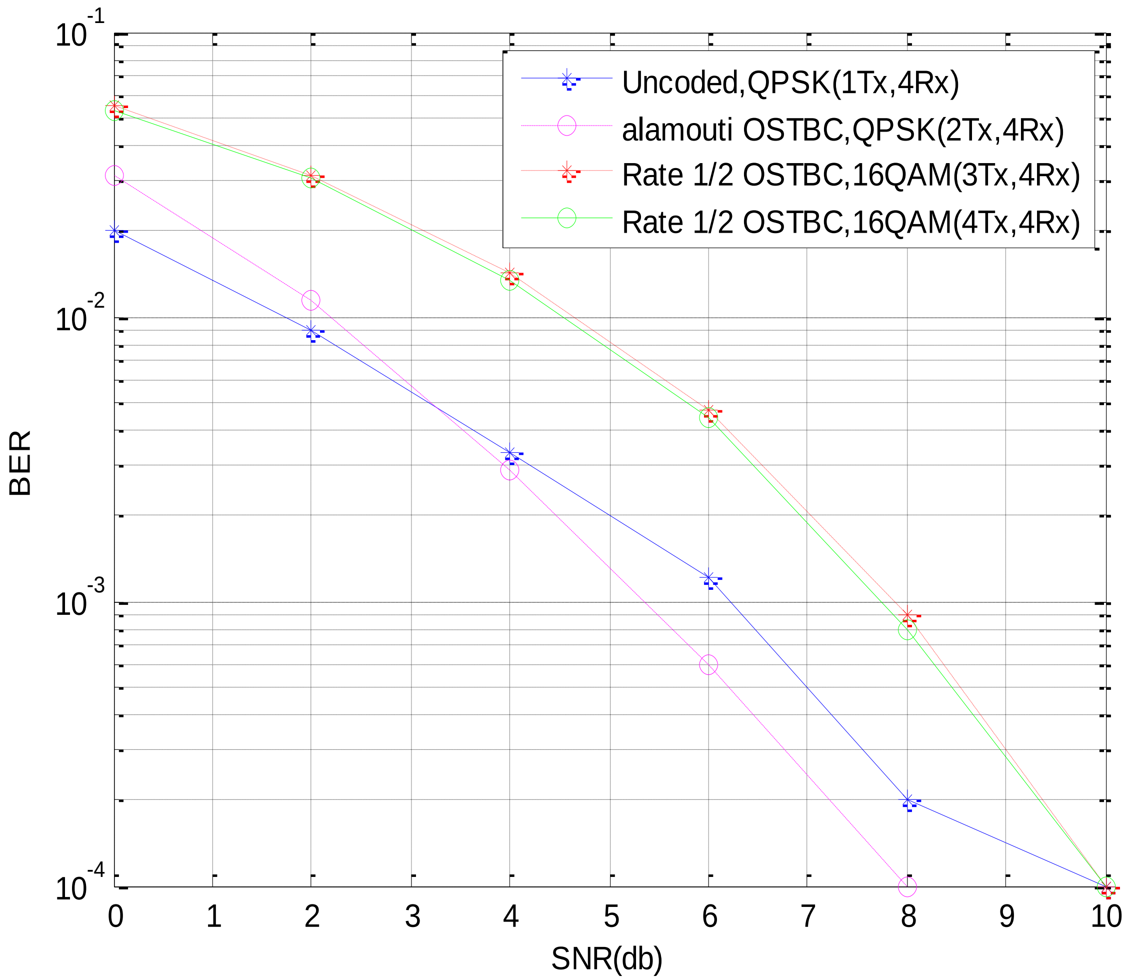


Fig 4.4: Bit Error Rate plotted against SNR for OSTBC's for four receive antennas

Like previous simulation figure 4.4 shows that full rate Alamouti OSTBC outperform over half rate OSTBC with receive antenna four. With the increase of transmission bit rate performance of generalized OSTBC with three and four transmit antennas are almost identical to each other .At BER 10^{-4} Alamouti OSTBC $\mathcal{G}_{222}$ provide a gain of 2 dB over $\mathcal{G}_{448}$, $\mathcal{G}_{438}$. At higher modulation increasing number of transmit antennas of Generalized OSTBC can not amiliorate their performnace too much.

4.1.3 Transmission bit rate of 3 bit/ (s/Hz)

For 16QAM (4bits/symbol) generalized OSTBC with 3/4 rate uses 16 constellation point so its bit rate will be $\frac{3}{4}\times 4$ =3bits/ (s/HZ). Similarly, Alamouti OSTBC uses 8PSK for having bit rate of 2bit/ (s/HZ).

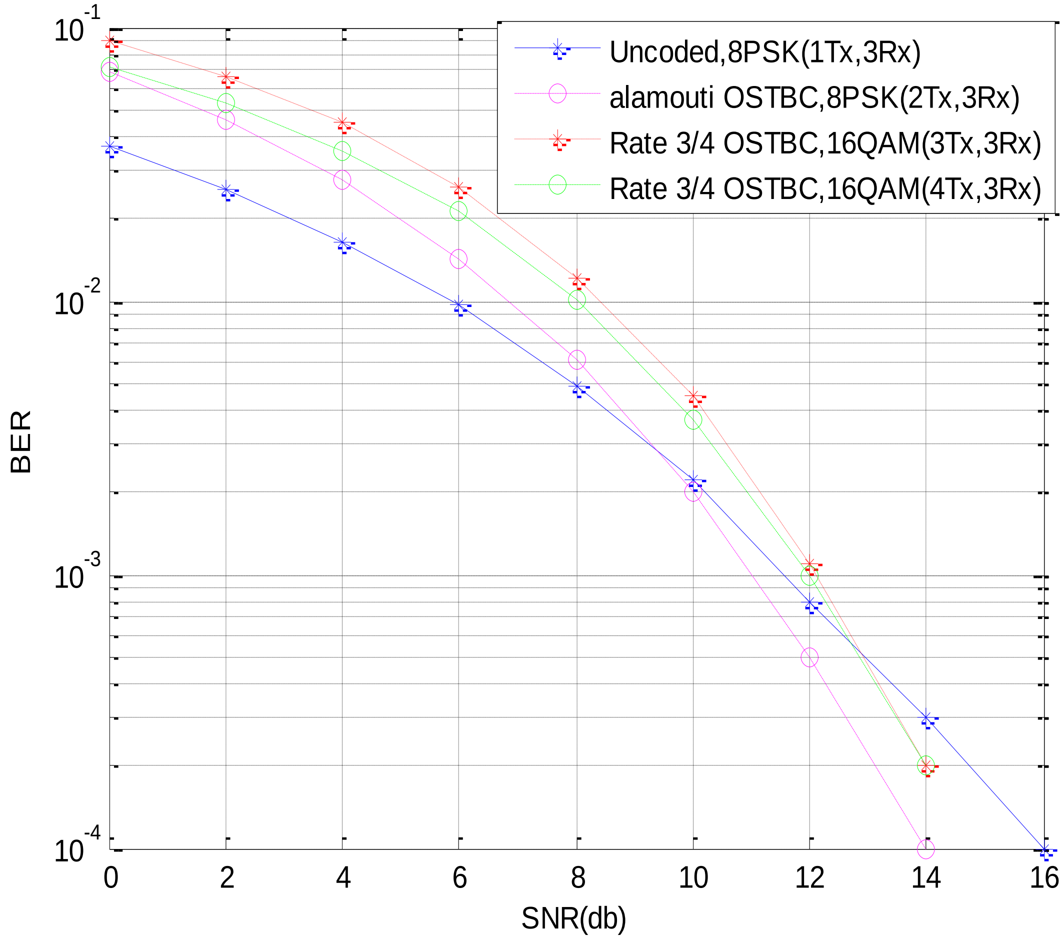


Fig 4.5: Bit Error Rate plotted against SNR for OSTBC's for three receive antennas

From the simulation figure 4.5 it can be seen that uncoded MIMO perform better at low SNR at 3bit/ (s/Hz).It can be observed that for higher bit rate Alamouti OSTBC outperform over Generalized OSTBC $\mathcal{G}_{434}$ of code rate 3/4. At BER 10^{-4}Alamouti provides 1.5dB gain over $\mathcal{G}_{434}$, and $\mathcal{G}_{334}$ .At higher SNR $\mathcal{G}_{434}$, and $\mathcal{G}_{334}$ perform identically at higher modulation scheme and data bit rate. At 3bit/ (s/Hz) for same number of receive antennas increasing of transmit antenna of Space Time Coded system doesn't provide significant diversity performance than each other.

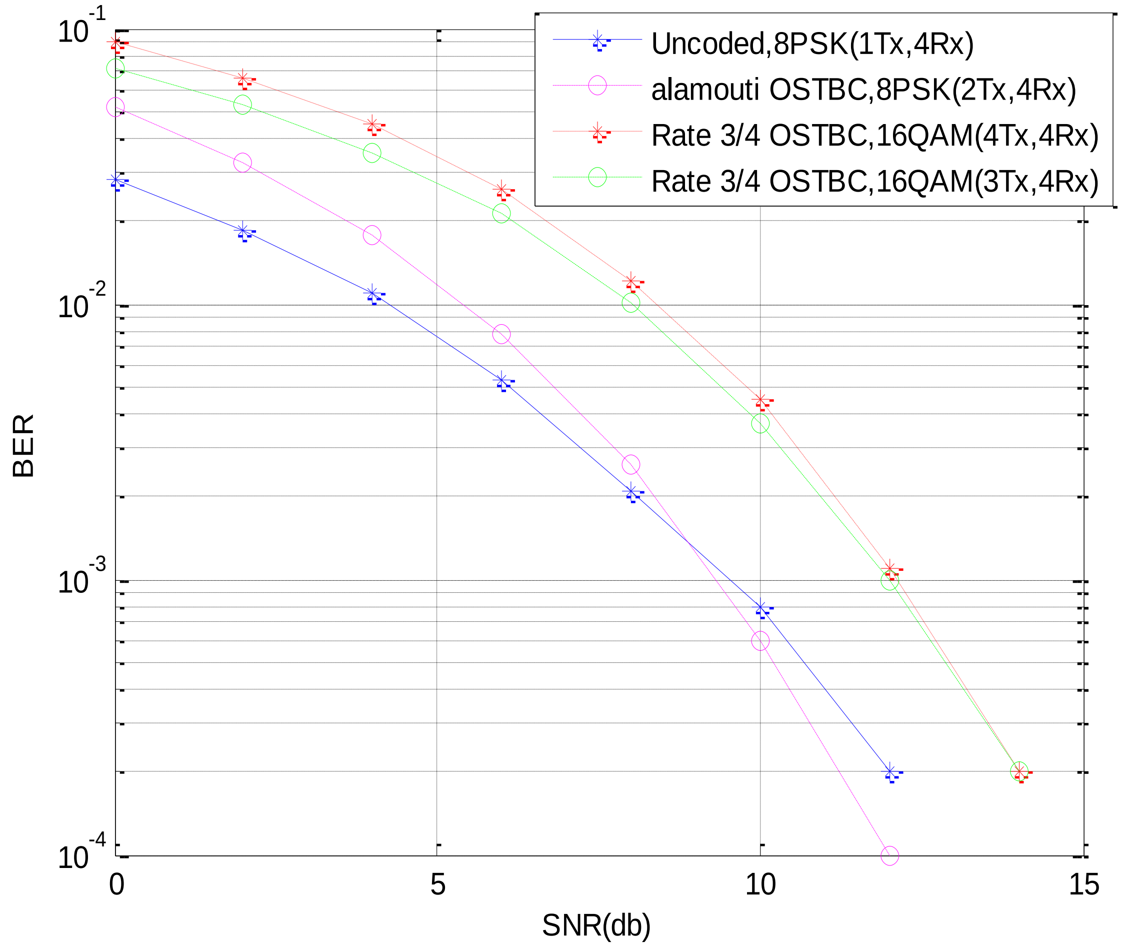


Fig 4.6: Bit Error Rate plotted against SNR for OSTBC's for four receive antennas

This simulation figure 4.6 shows that alamouti OSTBC perform better from previous simulation as we have increased number of receive antenna from three to four. At 10^{-4}Alamouti OSTBC $\mathcal{G}_{222}$ provide more gain 3dB over $\mathcal{G}_{434}$, and $\mathcal{G}_{334}$ .At lower SNR uncoded MIMO system outperforms over alamouti space time coded system. It can be easily conclude that increasing number of receive antennas result in better diversity performance than increasing of transmit antennas.

4.1.4 Transmit Antenna Three

In fig 4.7 BER performance of different code rate OSTBC are shown with three transmit antenna and multiple receive antennas. For modulation each OSBC uses QPSK modulation technique. In this simulation rate Three-by-four and rate Half OSTBC are simulated with same modulation scheme and for arbitrary number of receive antennas .It shows in which OSTBC perform better with the increase of receive diversity at the receiver .We have taken the SNR value up-to 20 and see BER response with respect to SNR.

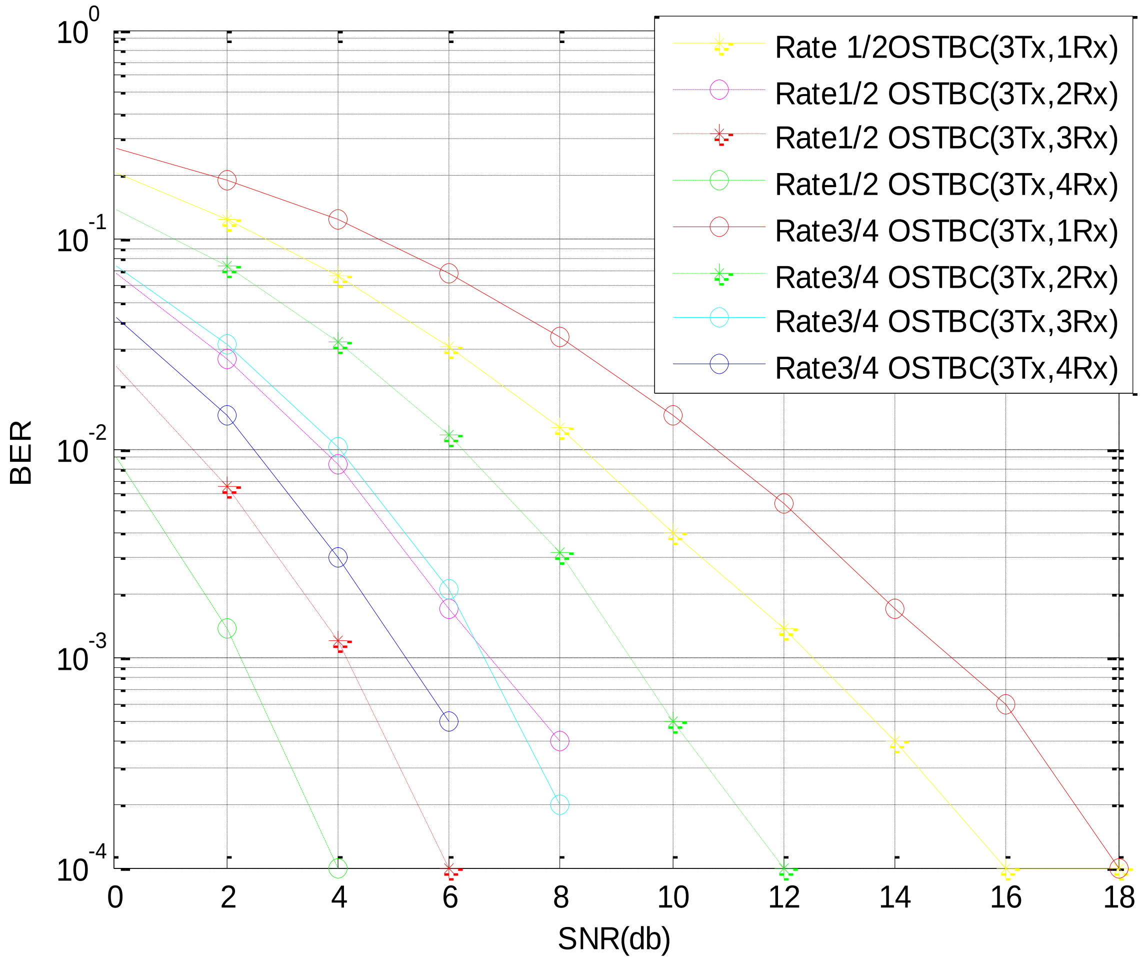


Fig 4.7: BER plotted against SNR for Transmit antenna three

From the above simulation figure 4.7 it can be seen that rate half OSTBC $\mathcal{G}_{348}$ outperform over $\mathcal{G}_{334}$ for three transmitters and four receivers , three transmitters and two receivers , three transmitter and one receiver and so on .With three transmitters and four receivers $\mathcal{G}_{348}$ provides 3.5 dB gain over $\mathcal{G}_{334}$. With three transmitters and three receivers $\mathcal{G}_{348}$ provides 2.5 dB gain over $\mathcal{G}_{334}$.At low SNR value $\mathcal{G}_{348}$ with three transmitter and two receiver are identical in performance with $\mathcal{G}_{334}$ with three transmitter and three receiver. At rate half OSTBC in same time slot symbols rarely interfere with each other’s .At rate three-by-four same type of symbol are transmitted at same time slots as a result it create more interference and therefore rate half OSTBC always performs better than rate three-by-four OSTBC. According to (3.48)-(3.51) as we increase the receive antennas that ensures more accuracy in symbol formation, which decreases the BER.

4.1.5 Performance on Spatial Diversity of Twelve

Figure 4.8 displays a BER curve for the case of equal diversity gain .To obtain the spatial gain 12 with QPSK modulation technique we simulate $\mathcal{G}_{348}$ with 4 receive antennas , $\mathcal{G}_{448}$ with 3 receive antennas , $\mathcal{G}_{222}$ with six receive antennas , $\mathcal{G}_{334}$ with four receive antennas, $\mathcal{G}_{434}$ with three receive antennas .

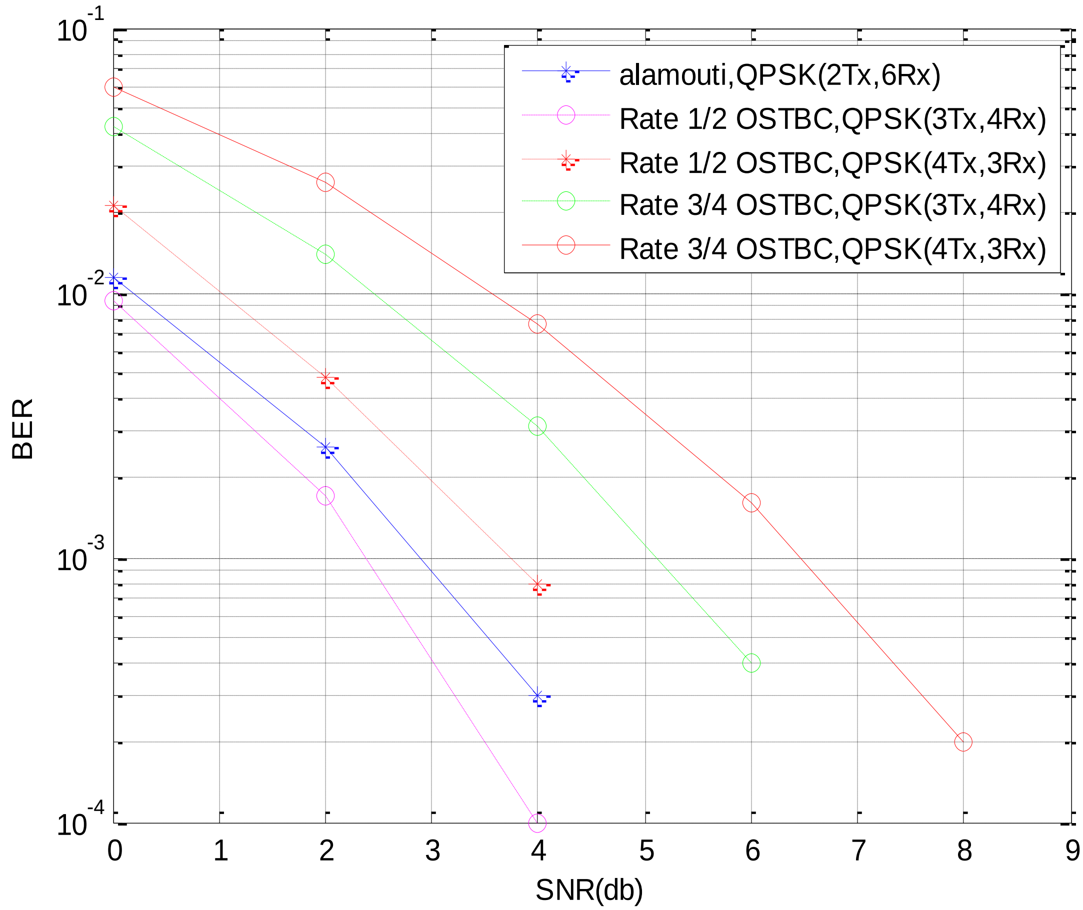


Fig 4.8: BER different OSTBC's plotted against SNR for spatial diversity 12

From the figure 4.8 it can be seen that $\mathcal{G}_{348}$ with three transmitter and four receiver outperforms over $\mathcal{G}_{448}$ with four transmitter and three receiver and provides gain about 2dB.Similarly $\mathcal{G}_{334}$ with four receive antennas provides almost 1.4 dB gain over $\mathcal{G}_{434}$with three receive antennas. It can be notable that alamouti OSTBC $\mathcal{G}_{222}$ with six receive antennas outperform over $\mathcal{G}_{448}$ and provide almost 1.2dB gain over $\mathcal{G}_{448}$ .As increase of number of transmit antennas decrease the energy per transmit antennas. From these simulations it can be summarized that with less number of transmit antennas and more number of receive antennas results in better performance in wireless communication.

4.1.6 Transmission bit rate 1bit/ (s/HZ) with Precoding

Figure 4.9 shows the BER performance of Alamouti OSTBC, Rate ½ OSTBC with precoding and without precoding.

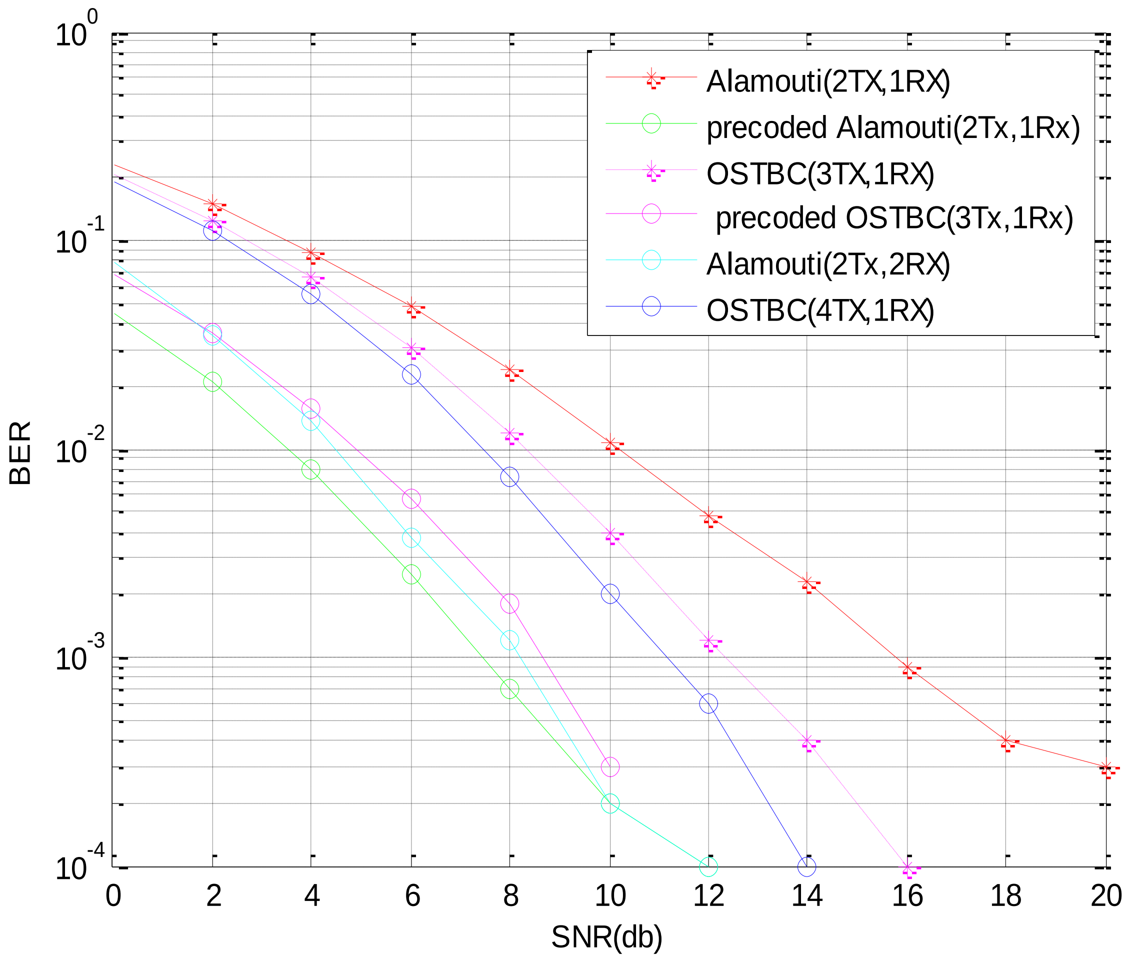


Fig 4.9**:** BER performance analysis again SNR for Alamouti & rate ½ OSTBC

In the figure it can be shown that precoded alamouti for two transmit antenna, one receives antenna outperform over without precoded Alamouti 2×1 system. Most significantly precoded 2 ×1 alamouti provide 1 dB gain over without precoded alamouti 2×2 MIMO system. In other scenario precoded OSTBC with ½ rate in 3×1 system provide 4dB gain over without precoded OSTBC with ½ rate in 3×1 system. It also provides 2dB gain over 4×1 system. So from above simulation it can be easily summarized that unitary precoding method decreases the number of required receive antenna to ensure good wireless link.

4.1.7 Transmission bit rate 1bit/ (s/HZ) with Antenna subset selection

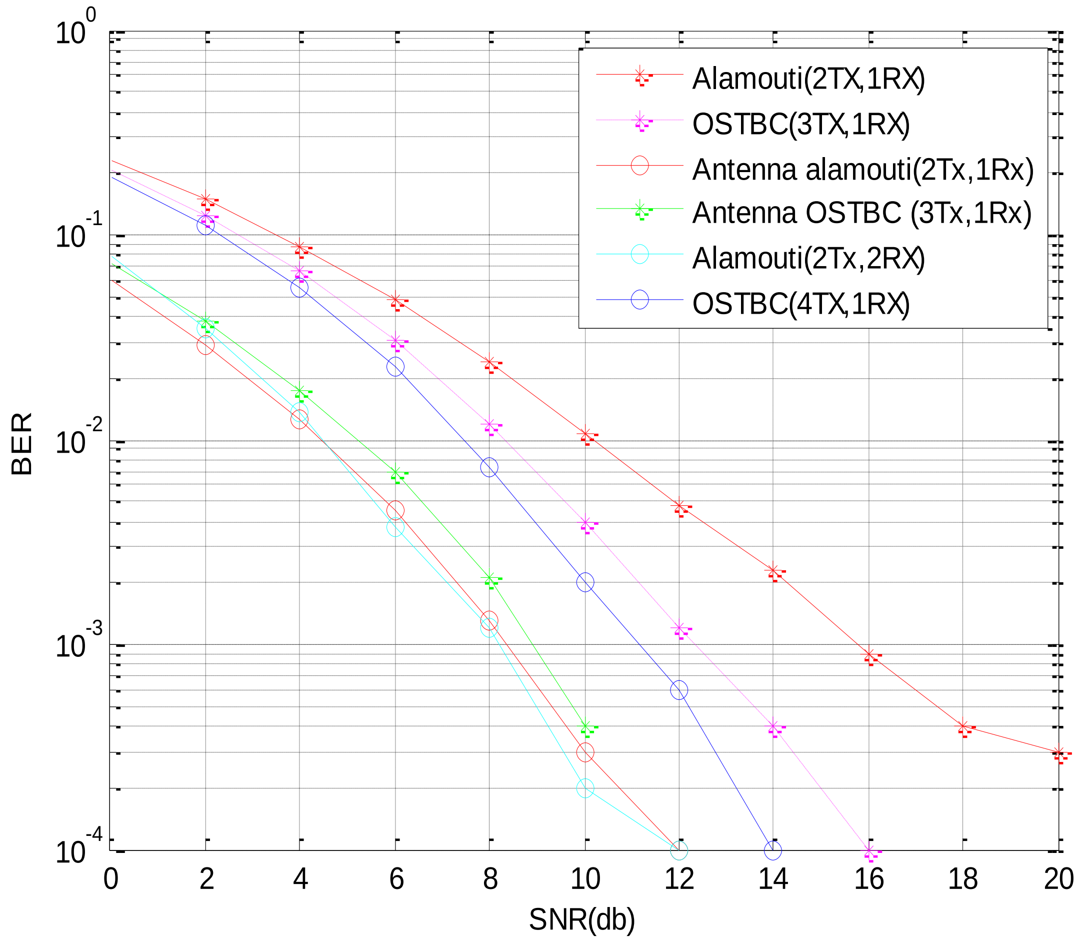


Fig 4.10**:** BER performance analysis again SNR for Alamouti & rate ½ OSTBC

In the figure 4.10 it can be shown that alamouti with antenna selection for two transmit antenna, one receives antenna outperform over without antenna selection Alamouti 2×1 system. Using antenna selection Alamouti 2×1 system almost identical to without antenna selection alamouti 2×2.So we can achieve same performance with Alamouti 2 ×1 with antenna selection as general 2×2 alamouti system performed without antenna selection. That reduces number of antennas at the receiver for achieving same performance. In other scenario antenna selection OSTBC with rate half OSTBC in 3×1 system provide 4dB gain over without antenna selection OSTBC with rate half OSTBC in 3×1 system. It also provides 2dB gain over 4×1 system. So from above simulation it can be easily summarized that like unitary precoding, antenna selection method decreases the number of receive antenna to ensure better wireless link and consequently reduce receiver circuit complexities.

4.1.8 Comparison between Antenna Selection and Unitary Precoding Technique in Data Communication

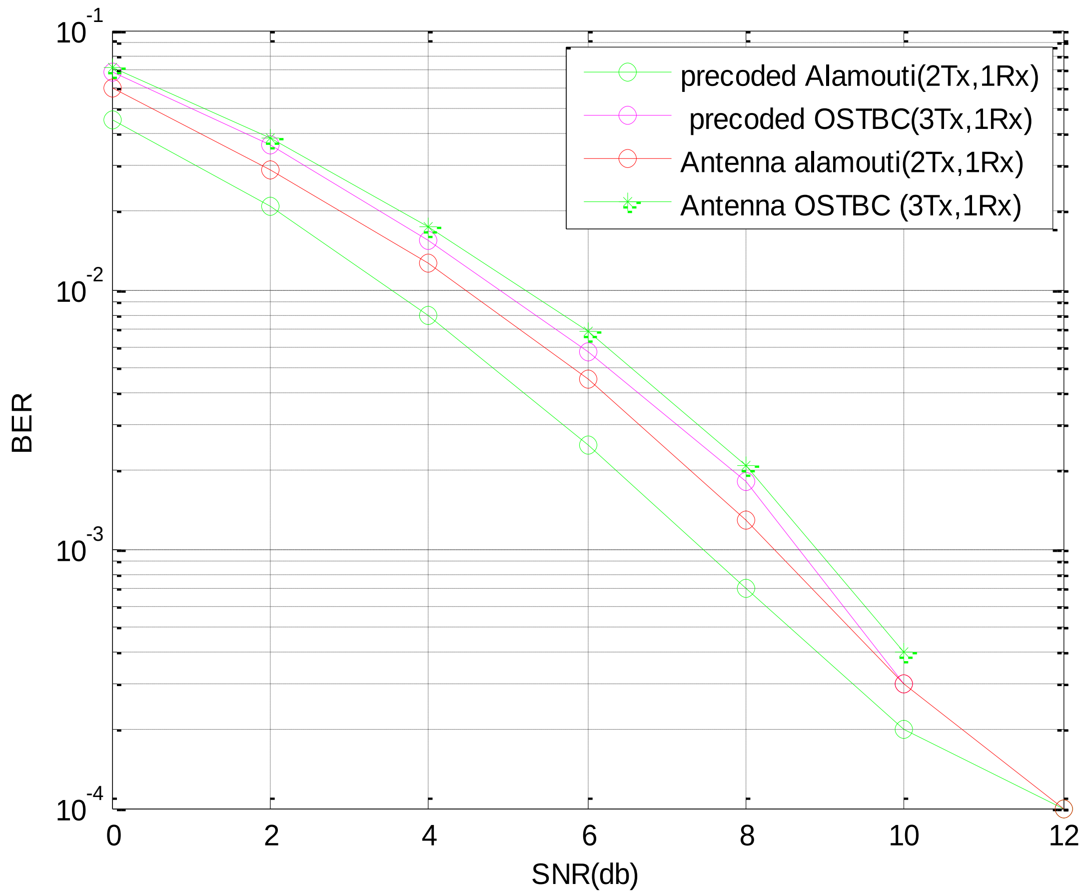


Fig 4.11**:** Performance analysis between precoding with limited feedback and Antenna subset selection

From fig 4.11 it can be shown that precoding method for alamouti scheme& Generalized OSTBC scheme outperform over antenna subset selection method and provide almost 1 dB gain over antenna selection method. As it is possible to adjust the size of codebook it can easily be possible to improve array gain and achieving more flexibility than a scheme based antenna selection method. So in my thesis it is preferred to use limited feedback with unitary precoding method for reducing the number of receive antenna and for reducing mobile station hardware complexity and finally improving OSTBC performance over wireless communication link.

4.2 Simulation Findings

- In higher transmission bit rate and spectral efficiency Alamouti OSTBC performs better with more than two receive antennas.
- Rate ½ OSTBC always outperforms over rate ¾ OSTBC.

- For certain OSTBC with constant receive antenna the more we increase transmit antenna the better will the performance.
- For same spatial diversity less transmit antennas with more receive antennas outperform over more transmit antenna with less receive antennas.
- CSI at transmitter reduce the necessity of extra radio equipment's at transmitter and receiver for attaining better performance.
- Precoding using codebook is efficient than antenna selection

4.3 Conclusion

This observation shows that there is an upper limit within which performance less transmit antenna with more receive antenna is identical with the use of more transmit antenna with less receive antenna. But if we increase the number of receive antenna at mobile station it will not be economical rather it will increase hardware complexity. For better performance with less receive antenna we are approaching channel adaptive transmission of OSTBC in which channel state information is exploited at the transmitter using some methods like quantized precoding and antenna selection which make the transmission more reliable and reduces the bit error rate.

CHAPTER FIVE

Conclusion and Future Work

Chapter 5

Conclusion and Future Work

5.1 Conclusion

This paper provides a basic overview of MIMO systems. A basic over view of Space Time (ST) coding including their design criterion and how they are implementing in coded MIMO system is presented. Orthogonal Space Time Block Codes use Space Time Coding that provides better reliability of data link.ST coding provides better performance against fading using Multiple –Input Multiple Output (MIMO) system. Multiple receive antennas are beneficial to both ST and block transmission, because ST coding relies on two-dimensional transmission system. Orthogonal Space Time Block code is a type of ST coding that allows various antenna diversity at MIMO system. Increasing number of radio equipment to increase the diversity gains but it ultimately creates receiver circuit complexity. For this reason, we think of channel adaptive transmission of OSTBC over MIMO channel.

A basic introduction with OSTBC is presented using Alamouti scheme. We then discuss the block code scheme with different code rate. Maximum code rate available for generalized OSTBC is three by four. For higher bit rates and modulation scheme rate one OSTBC performs much better. Performance mainly varies for different transmit and receive antennas. If we increase receive diversity OSTBC performs much better but it is not an economical procedure. Performance of OSTBC can be developed by exploiting Channel State Information (CSI) at the transmitter. It is difficult to sends CSI at the transmitter. Precoding techniques are used to sends CSI by generating codebook.

From simulation result it can be said that higher diversity gain does not always imply better performance. This was observed when $\mathcal{G}_{348}$ with three receive antennas outperformed $\mathcal{G}_{334}$ with four receive antennas for same number of transmit antennas three. It was also observed that equal diversity gain does not imply equal performance. This was observed when $\mathcal{G}_{348}$ outperforms over all OSTBC .When CSI is feedback to transmitter from receiver it is seen that at lower diversity gain show better performance .Feedback is send using unitary precoding matrix and antenna selection .Finally it has been shown that limited feedback from unitary precoding matrix performs better than antenna selection both for alamouti and generalized OSTBCs.

5.2 Future work

We believe that the studies we initiated here, only scratch the tip of the iceberg and many important questions remain to be answered. Research on the interactions and combinations of the Orthogonal Space Time Block code technology with other techniques are now being created. This thesis focuses some future works those are given bellow-

1. We uses Alamouti OSTBC as a rate one OSTBC and apply it to precoded system. In future we apply Quasi Orthogonal Space Time Block codes in precoded system and analysis the performance in Multi –User MIMO.

2. In the thesis we have used ML decoding. In future we will focus on Sphere Decoding for OSTBC and compare the performance with ML decoding

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