Comparing the BER Performance of SFBC-OFDM System with STBC-OFDM System in FADING MIMO Channel

A Thesis presented to the **Department of Electrical and Electronic Engineering** in partial fulfillment of the requirements for the Degree of **Bachelor of Science in Electrical and Electronic Engineering.**

Submitted by

Shaikh Abrar Kabir	**ID: 14-01-05-139**
Azhar Niaz Kakon	**ID: 14-01-05-146**
Md. Jahidul Islam	**ID: 14-01-05-153**
Rudaba Zaman	**ID: 14-01-05-023**
Shezan Hossain Mahmud	**ID: 14-01-05-027**

Under The Supervision Of

Mr. Md. Jakaria Rahimi

Assistant Professor, Department Of EEE, AUST, DHAKA

AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

Dhaka, Bangladesh

April 2018

DECLARATION

This is to declare that the works done in this thesis are the result of our study and experiments under the supervision of Mr. Md. Jakaria Rahimi, Assistant Professor of Department of Electrical and Electronic Engineering of Ahsanullah University of Science and Technology, Dhaka. It is farther declared that neither this thesis nor any part has been copied from any other thesis and submitted elsewhere for any degree or diploma.

Signature of Supervisor

Supervisor

Mr. Md. Jakaria Rahimi

Assistant Professor

Department of Electrical and Electronic Engineering

AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

Signature of Students

Shaikh Abrar Kabir **ID: 14-01-05-139**

Azhar Niaz Kakon **ID: 14-01-05-146**

Md. Jahidul Islam **ID: 14-01-05-153**

Rudaba Zaman **ID: 14-01-05-023**

Shezan Hossain Mahmud **ID: 14-01-05-027**

ACKNOWLEDGEMENTS

All praise, thanks and glory go to the most merciful almighty Allah for giving us the strength, patience, knowledge and capability to complete this work successfully.

We would like to express heartfelt gratitude to our instructor, Assistant Professor Mr.Muhammad Jakaria Rahimi for his valuable guidance, suggestions, encouragements and invaluable assistance in the process of completing this thesis.

We would like to acknowledge the contribution of the Department of Electrical and Electronic Engineering for the facilities provided to us for doing the research work.

Sincere thanks to our friends and well-wishers who helped us by giving their valuable time to complete the thesis.

ABSTRACT

Combining Space-Time Block Coding (STBC) with Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) which is STBC-MIMO-OFDM system is a promising system in modern ages for handling high data rate. This can be used even in 5G technology. This system provides satisfactory Bit Error Rate (BER) performance. But we have found that this performance gets better when we use Space Frequency Block Coding (SFBC)-Multiple Input Multiple Output-Orthogonal Frequency Division Multiplexing system instead of the STBC-MIMO-OFDM system. BER decreases to a particular value for a specific value of Signal to Noise Ratio (SNR) in SFBC-MIMO-OFDM which is less than the SNR value in the STBC-MIMO-OFDM system. In our research, firstly, we have observed the BER performance of both SFBC-MIMO-OFDM and STBC-MIMO-OFDM systems by varying the number of transmitting and receiving antennas using Rayleigh fading channel for perfect CSI. Then we have also observed the BER performance of the only SFBC-MIMO-OFDM system by varying the number of transmitting and receiving antennas using Rayleigh fading channel for imperfect CSI. As here we have used imperfect CSI, so we have varied variance of channel estimation error (σ_e^2) and have found out the effects. Lastly, we have discussed how to reduce cost by reducing the number of receiving antennas.

TABLE OF CONTENTS

List of Figures

Figure **Page No.**

List of Tables

Table **Page No.**

List of ABBREVIATIONS

8PSK	Eight Phase Shift Keying
AM	Amplitude Modulation
BER	Bit Error Rate
BPSK	Binary Phase-shift keying
CP	Cyclic Prefix
CSI	Channel State Information
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
ISI	Inter-Symbol Interference
LOS	Line of Sight
MIMO	Multiple Input Multiple Output
MIMO-OFDM	Multiple Input Multiple Output- Orthogonal Frequency Division Multiplexing
MISO	Multiple Input Single Output
NLOS	Non Line of Sight
OFDM	Orthogonal Frequency Division Multiplexing
PAM	Pulse Amplitude Modulation
P/S	Parallel to Serial
PSK	Phase Shift Keying

QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
SFBC	Space Frequency Block Coding
SIMO	Single Input Multiple Output
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
S/P	Serial to Parallel
STBC	Space Time Block Coding
STCs	Space-Time Codes
STFBC	Space-Time-Frequency Block Coding

CHAPTER 1

INTRODUCTION

In this thesis at first we got the concepts of Fading channel and its classifications, MIMO, MIMO-OFDM, STBC, STBC-OFDM, SFBC, SFBC-OFDM and main differences between STBC and SFBC. After that we utilized these concepts in simulating results. We used Rayleigh fading channels. We simulated results for both perfect CSI and imperfect CSI. In perfect case we used both SFBC and STBC and compared them. And then by getting the idea of which block coding is better, we simulated results using only one of the above two methods for imperfect CSI.

1.1 Ideas about Chapters

At first we discussed about fading channels in **CHAPTER 2** we also covered MIMO, OFDM and MIMO-OFDM in this chapter.

In **CHAPTER-3** we discussed about space time block coding and also STBC with OFDM. Lastly pros and cons of STBC are explained.

In **CHAPTER-4** we explained SFBC & SFBC-OFDM, the differences between SFBC & STBC and in which cases SFBC is better.

In **CHAPTER-5**_we discussed the concept of PSK and QAM. These are explained with examples. We also mentioned the fields where these modulation techniques are used.

In **CHAPTER-6** we simulated BER vs SNR curves for perfect channels for BPSK, QPSK & 8PSK or QAM 16 & QAM 64 by varying number of transmitters from 1 to 4 for a fixed number of receivers in each figure using SFBC or STBC.

We compared the effects for

1. Varying the number of transmitters.
2. Varying the number of receivers.
3. Varying phase shifting or quadrature amplitude modulation techniques.
4. SFBC & STBC.
5. Figured out the best and suitable techniques.

In **CHAPTER-7** we simulated BER vs SNR curves for imperfect channels for BPSK, QPSK & 8PSK or QAM 16 & QAM 64 by varying number of transmitters from 1 to 4 for a fixed number of receivers for a fixed σ_e^2 in each figure using SFBC only.

We compared the effects for

1. Varying the number of transmitters.
2. Varying the number of receivers.
3. Varying phase shifting or quadrature amplitude modulation techniques.
4. Varying the values of σ_e^2 (variance of variance of channel estimation error).
5. Figured out the best and suitable techniques.

Lastly we discussed about future works and preferred modifications in **CHAPTER-8.**

1.2 Topics Covered:

Fading Channel: Due to reflection, diffraction, scattering and shadowing difference in phase angles, amplitude and time intervals occurs. This is in a nutshell known as Fading Channel in wireless communication

Signal Fading: The amplitude fluctuation of the received signal is called signal fading.

LOS and NLOS (Line of Sight and Non Line of Sight): LOS - Directly transmitted from the transmitter to receiver; NLOS – Not directly transmitted from the transmitter to receiver.

Multiple-input and multiple-output: More than one antenna at both transmitter and Receiver end.

Spatial Diversity: Sending same data stream with different antenna to reduce error probability.

Spatial Multiplexing: Sending different data stream by different antenna to increase spatial efficiency and additional throughput.

Orthogonal Frequency Division Multiplexing (OFDM): Multiple carriers (called subcarriers) carry the information which are orthogonal to each other.

MIMO-OFDM: Combination of MIMO and OFDM where MIMO is used to increase the capacity and OFDM provides more reliable communication at high speed.

STBC: Space Time Block Coding (STBC) is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer.

STBC Alamouti's Code: It's a technique where one symbol is transmitted with two antennas by two adjacent time slots with same frequency.

STBC-OFDM: It's a combination of STBC and OFDM where symbols are transmitted with different OFDM symbols.

SFBC: Space–Frequency Block Coding(SFBC) is a technique used in wireless communications where the symbol of an orthogonal design are transmitted on neighboring subcarriers of the same OFDM rather than on the same subcarrier of subsequent OFDM symbols.

SFBC-OFDM: It is the combination of SFBC & OFDM

Phase-shift keying (**PSK**): It is a **digital modulation** process which conveys **data** by changing (modulating) the **phase** of a reference **signal**.

Quadrature amplitude modulation (QAM): It is both an analog and a digital modulation scheme. It conveys two analog message signals, or two digital bit streams, by changing (modulating) both the amplitudes and phases of carrier waves.

CHAPTER 2

MIMO and MIMO-OFDM

2.1 Fading Channel

In wireless mobile communications, surrounding objects like houses, buildings, trees and mountains provoke reflection, diffraction, scattering and shadowing of the transmitted signals and causes multipath propagation which results different phase angles, amplitude and time intervals. [1]

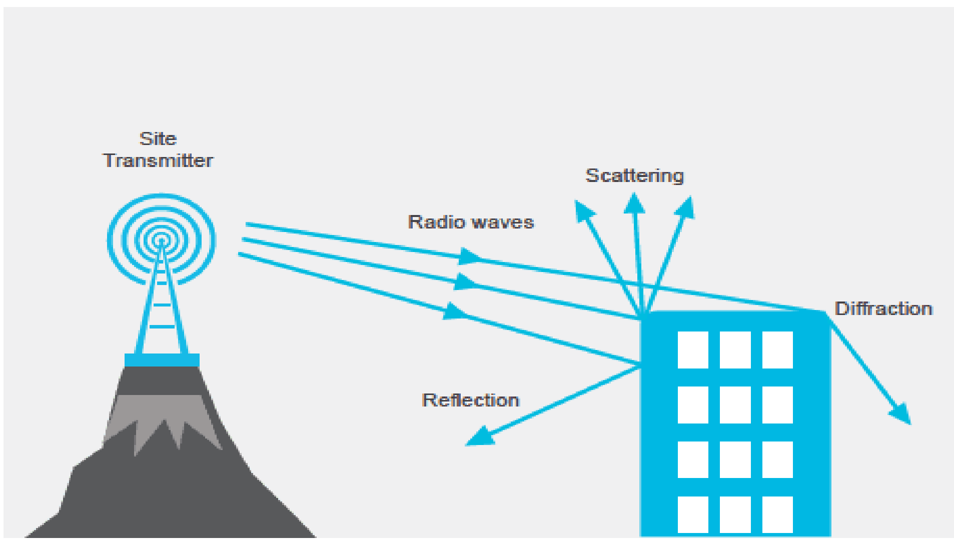

Figure 2.1: Fading Channel [5]

2.2 Signal Fading

- The amplitude fluctuation of the received signal is called signal fading.
- Caused by the frequency selective or time variant characteristics of the multipath channel. [1]

2.3 Line of Sight (LOS) and Non Line of Sight (NLOS)

- Components which are directly transmitted from the transmitter to receiver without any reflection referred as LOS.
- Components which are reflected are referred to a NLOS. [1]

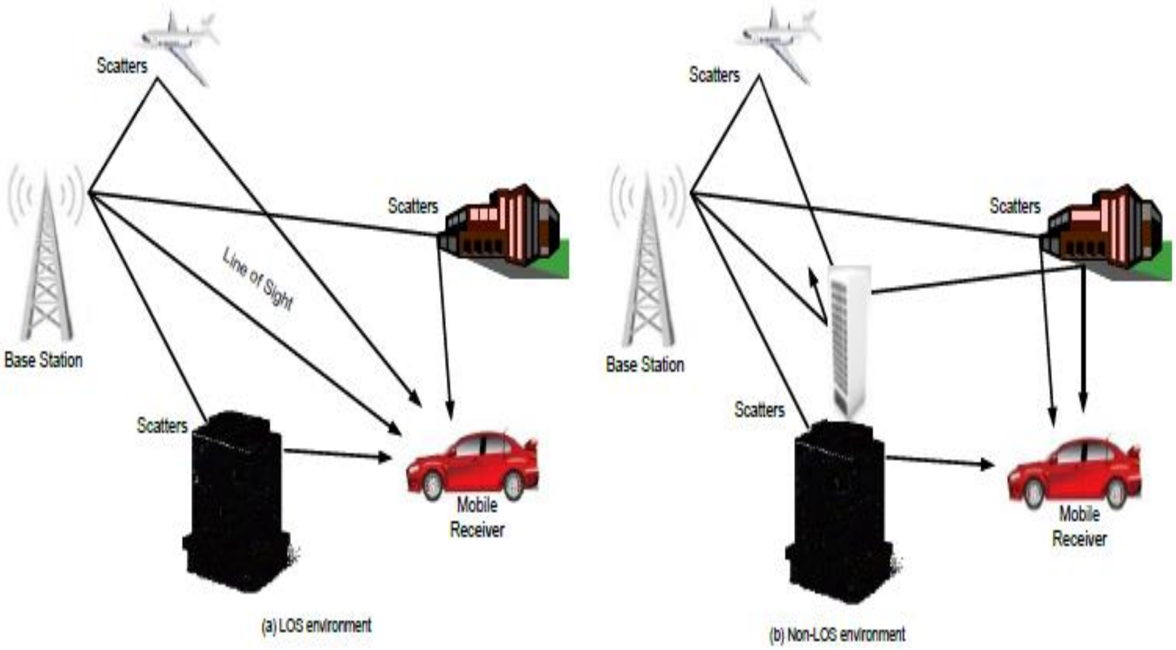

Figure 2.2: Signal Propagation in a Wireless Environment, with and without LOS [1]

2.4 Fading process Description

- LOS signals are described by Rician probability distribution.
- NLOS signals follows Rayleigh probability distribution. [1]

2.5 MIMO

Multiple-input and multiple-output or **MIMO** is a method for multiplying the capacity of a transmission link using multiple transmit and receive antennas to exploit multipath propagation.

Used to provide

- Improvement in channel throughput.
- Ameliorates channel robustness.
- Increase channel capacity.

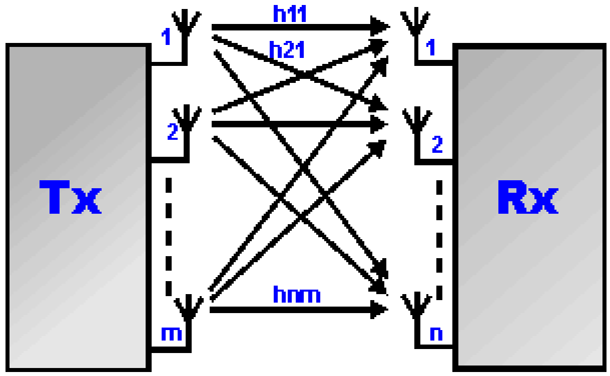

Figure 2.3: MIMO - Multiple Input Multiple Output [6]

MIMO

1. Multipath between the transmitter and receiver ends allows the signal to be received at different times
2. Hence reduced multipath fading with faster speed and increased capacity
3. Data rate increases directly in commensurate to the number of antennas used.
4. Important part of 4G network.

Between a transmitter and a receiver, the signal can take many paths. By using MIMO, these additional paths can be used to advantage.

2.5.1 Formats of MIMO

The two main formats for MIMO are

1. Spatial Diversity
2. Spatial Multiplexing

Spatial Diversity

- Transmitter sends multiple copies of the same data sequence and receiver combines them.
- Decreases error probability.

Spatial multiplexing

- Transmitter sends many data sequences simultaneously in different antenna in same frequency band and receiver detects them.
- Increase spectral efficiency as sending many data sequence in different antenna.
- Provides additional data throughput capacity.

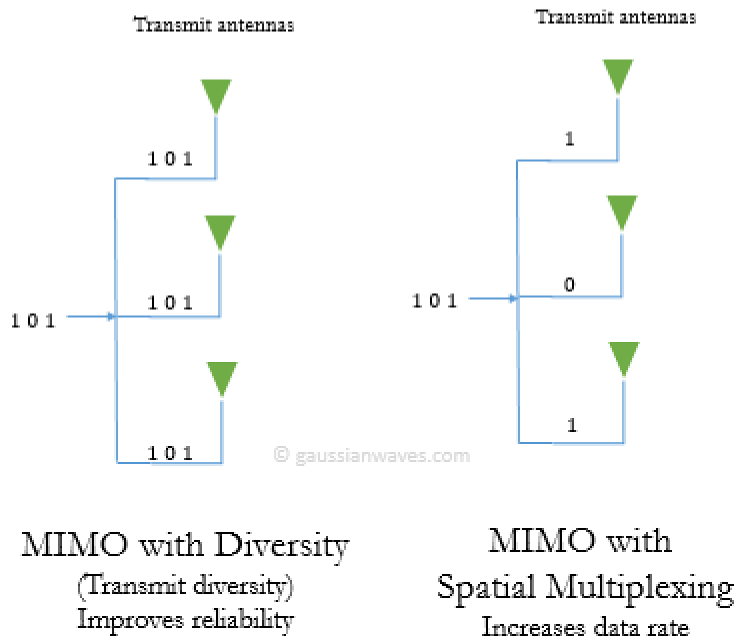

Figure 2.4: Spatial Diversity vs Spatial Multiplexing [7]

To take advantage a matrix mathematical approach is taken in Spatial Multiplexing.

Data streams t1, t2,... ,tn can be transmitted from antennas 1, 2,…, n.

Variety of paths, each having different channel properties and 3 transmit, 3 receive antenna system a matrix can be set up:

$$\mathbf{r1 = h11\ t1 + h21\ t2 + h31\ t3}$$

$$\mathbf{r2 = h12\ t1 + h22\ t2 + h32\ t3}$$

$$\mathbf{r3 = h13\ t1 + h23\ t2 + h33\ t3}$$

Where,

r1 = signal received at antenna 1,

r2 = the signal received at antenna 2 and so on.

In matrix format this can be represented as:

$$[R] = [H] \times [T]$$

Decoder must estimate individual channel transfer characteristic hij to determine the channel transfer matrix. Then the matrix [H] has been produced thus the transmitted data streams can be reconstructed by

$$[T] = [H]^{-1} \times [R]$$

Caution:

In any case for MIMO spatial multiplexing the number of receive antennas must be equal to or greater than the number of transmit antennas otherwise information can be lost. [1], [2], [3]

2.5.2 Comparison between different Antenna Configurations

Different types of Antenna Configuration and their advantages and disadvantages are given in the table below.

Table 2.1: Comparison between different Antenna Configurations [10]

Antenna Configuration	Advantage	Disadvantage
SISO (Tx → Rx)	Simplicity, No additional Processing	Limited in performance, More interference and fading
SIMO Receive Diversity (Tx → Rx)	Easy to Implement	Additional Processing required at receiver, can not used in cell phone
MISO Transmit Diversity (Tx → Rx)	Used in cell phone due to less processing required at receiving end	Additional Processing required at Transmitter
MIMO (Tx → Rx)	Link robustness & Throughput Enhancement	Additional processing, Cost, Size

2.5.3 Advantages and Disadvantages of MIMO

Advantages of MIMO

➡The higher data rate can be achieved.

➡Reducing BER (Bit Error Rate)

➡The techniques such as STBC (Space Time Block Coding) and BF (Beam-forming) employed in MIMO helps in achieving extension of cell coverage.

➡ Minimizes fading effects seen by the information traveling from transmit to receive end.

➡ High QoS (Quality of Service) with increased spectral efficiency.

➡ Supports large number of subscribers per cell.

Disadvantages of MIMO

➡ Resource requirements and hardware complexity is higher

➡ Resources needs more power requirements. Battery gets drain faster.

➡MIMO based systems cost higher compare to single antenna based system due to increased hardware and advanced software requirements. [2], [3]

2.6 Orthogonal Frequency Division Multiplexing (OFDM)

1. Orthogonal frequency division multiplexing is the method of encoding digital data on multiple carrier frequency.
2. It is a vital part of current generation wireless technology.
3. Closely spaced sub-carrier are used to carry data on several parallel data streams or channels.
4. Minimal signal fading.
5. Provides enhanced data rates. [8]

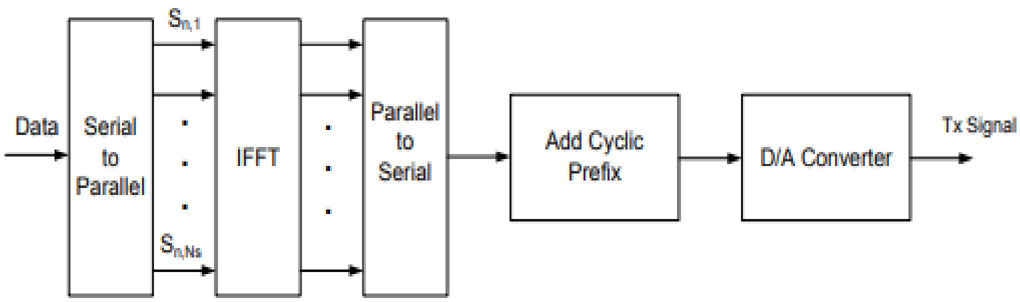

Figure 2.5: Block Diagram of OFDM [1]

Illustration of Block Diagram

1. First Data Stream is converted to serial to parallel
2. Then converted data is done IFFT
3. Again data is converted parallel to serial
4. Cyclic prefix is added
5. Before transmission D/A converter is used

2.7 Difference between FDM and OFDM

The OFDM scheme differs from traditional FDM in the following interrelated ways:

- Multiple carriers (called subcarriers) carry the information
- The subcarriers are orthogonal to each other
- Inter-symbol Interference is reduced
- A guard interval is added to each symbol to minimize the channel delay spread and inter symbol interference. [4]

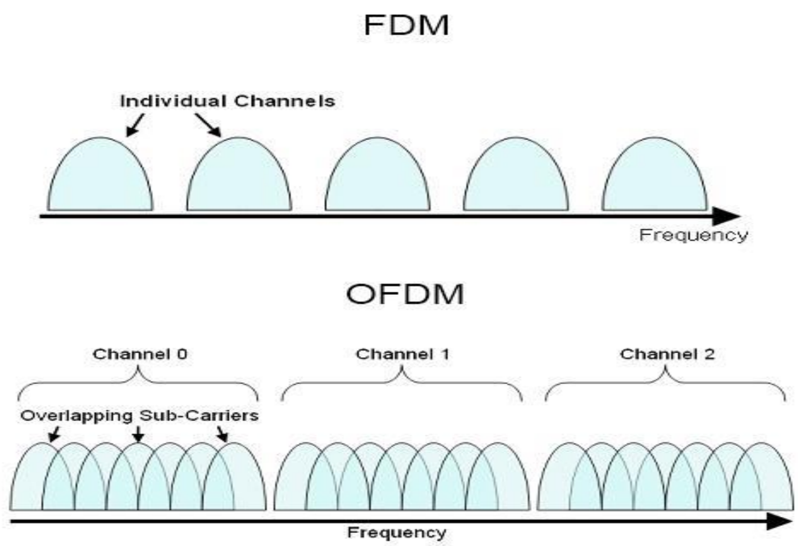

Figure 2.6: Difference between FDM and OFDM [8]

2.8 MIMO-OFDM

MIMO multiplies capacity by transmitting different signals over multiple antennas and OFDM provides more reliable communications at high speeds.

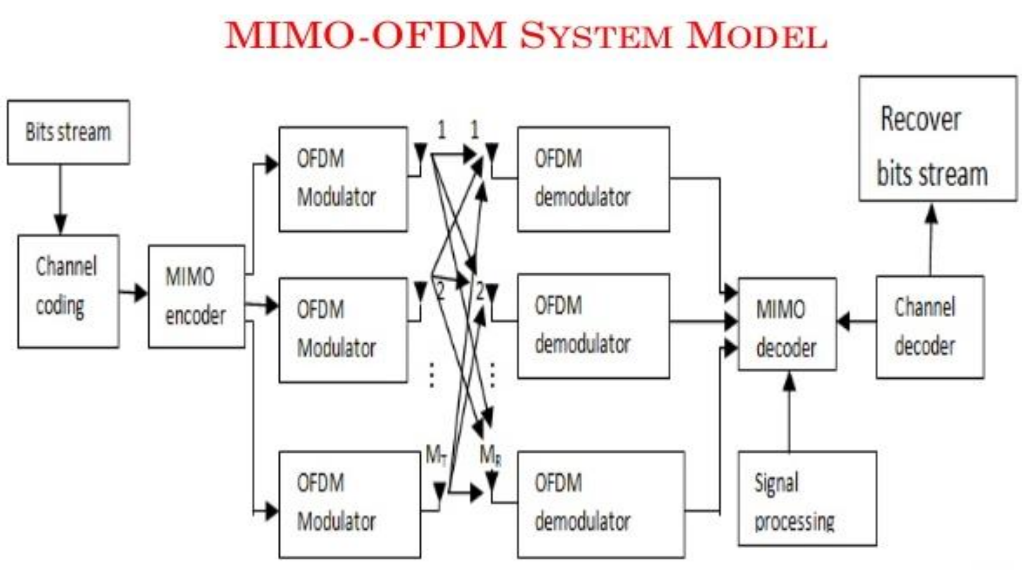

Figure 2.7 : MIMO-OFDM block representation [9]

OFDM-MIMO

1. Backbone of current generation wireless system such as LAN,LTE-A
2. OFDM system when used with multiple antennas at the transmitter and receiver ends leads to OFDM-MIMO system.
3. Excessive increased in performance gains and spectral efficiency when these are used together.
4. The Numbers of antenna are directly proportional to interference caused.
5. Higher order MIMO-OFDM system has problems of reliability and signal fading. [1]

2.8.1 STBC with MIMO-OFDM

1. Increased orthogonal process.
2. Removes multiples access interference and hence reduces the coupling effect.
3. Uses various received version of data streams at transmitter end to improve the overall reliability
4. Data streams are encoded as blocks.
5. These space time block codes are represented in the form of matrix
6. Best known MIMO coding scheme is ALAMOUTI scheme. [1]

CHAPTER 3

STBC and STBC-OFDM

3.1 Introduction

Space-Time Codes (STCs) have been implemented in cellular communications as well as in wireless local area networks. Space time coding is performed in both spatial and temporal domain introducing redundancy between signals transmitted from various antennas at various time periods. It can achieve transmit diversity and antenna gain over spatially uncoded systems without sacrificing bandwidth. The research on STC focuses on improving the system performance by employing extra transmit antennas. In general, the design of STC amounts to finding transmit matrices that satisfy certain optimality criteria. [11]

In STBC we can use Alamouti code. The main function of alamouti code is to transmit four symbols instead of two symbols .It improves transmission diversity and develop reliability.

STBC-OFDM is the combination of STBC and OFDM. When we use STBC-OFDM instead of STBC, the performance of the system reliability improves. Here we send data using different OFDM symbols.

3.2 Space-Time Block Codes

Space Time Block Coding (STBC) is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. [16]

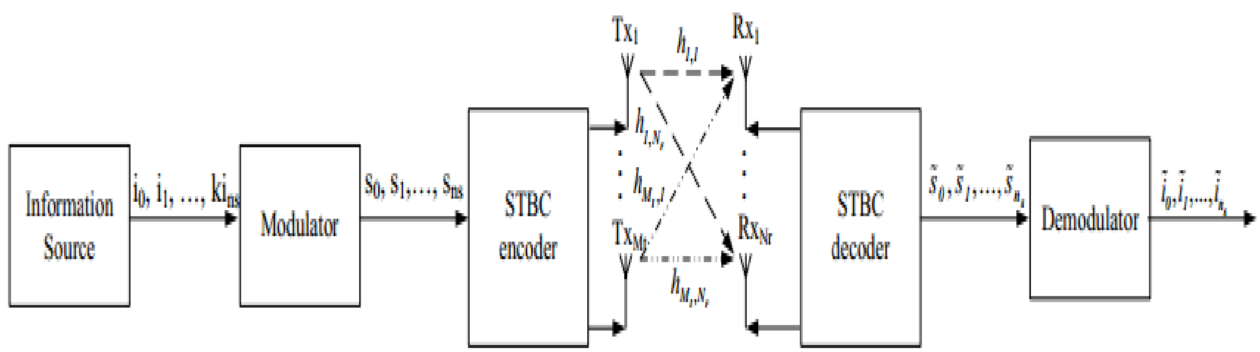

Figure 3.1: A Block Diagram of STBC Communications [1]

Space-time block codes (STBC) are a generalized version of Alamouti scheme. These codes have the same key features. That is, they are orthogonal and can achieve full transmit diversity specified by the number of transmit antennas.

In other words, space-time block codes are a complex version of Alamouti's space-time code, where the encoding and decoding schemes are the same as in both the transmitter and receiver sides. The data are constructed as a matrix which has its rows equal to the number of the transmit antennas and its columns equal to the number of the time slots required to transmit the data. At the receiver side, when signals are received, they are first combined and then sent to the maximum likelihood detector where the decision rules are applied.

Space-time block code was designed to achieve the maximum diversity order for the given number of transmit and receive antennas subject to the constraint of having a simple decoding algorithm. Additionally, space-time block coding provides full diversity advantage but is not optimized for coding gain. In the following, different implementations of space-time block codes are explained in details. This includes the encoding, decoding and system performance for the two and four transmit antennas and two and four receive antennas for both real and complex signal constellations. [12]

3.2.1 STBC Code Representation [17]

An STBC is usually represented by a matrix. Each row represents a time slot and each column represents one antenna's transmissions over time.

$$\begin{array}{cc} & \xrightarrow{\text{transmit antennas}} \\ \text{time-slots} \Big\downarrow & \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n_T} \\ s_{21} & s_{22} & \cdots & s_{2n_T} \\ \vdots & \vdots & & \vdots \\ s_{T1} & s_{T2} & \cdots & s_{Tn_T} \end{bmatrix} \end{array}$$

Here **S**ij is the modulated symbol to be transmitted in time slot i from j antenna.

3.2.2 Advantage and disadvantage of STBC [16]

Advantages:

- STBC utilizes multiple antennas to create special diversity, this allows a system to have better performance in a fading environment.
- No feedback from receiver to transmitter is required for CSI to obtain full transmit diversity.
- Good performance with minimum decoding complexity.
- Can achieve maximum diversity gain.
- Receivers that use only linear processing.
- It maintains orthogonality.

Disadvantages:

- Does not have much coding gain.
- Cannot always achieve maximum data rate.
- The technique is sensitive to delay.

3.3 Alamouti Scheme

Alamouti block code. It is a complex space-time diversity technique that can be used in 2x1 MISO mode or in a 2x2 MIMO mode. The Alamouti block code technique is the only complex block code that has a data rate of 1 while achieving maximum diversity gain. This performance has been achieved using the following space-time block code:

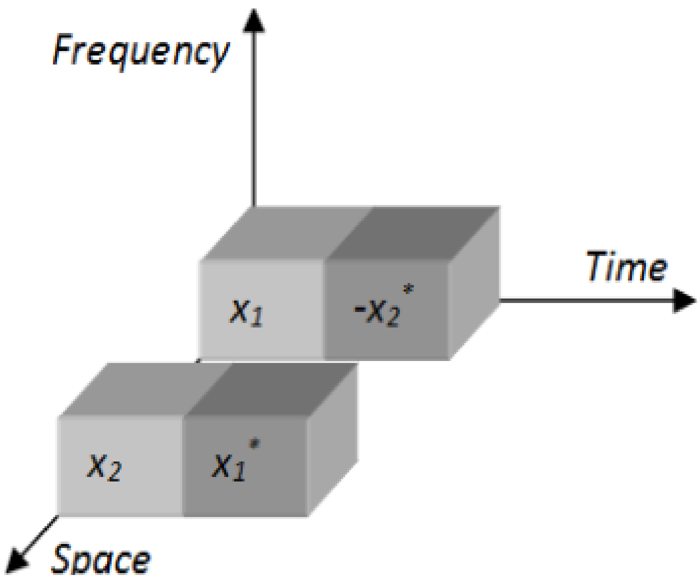

Figure 3.2: Alamouti space-time diversity technique [12]

Here one symbol is transmitted with two different antenna with different time slots but with same frequency. [13]

At the transmitter side, a block of two symbols is taken from the source data and sent to the modulator. After that, Alamouti space-time encoder takes the two modulated symbols, in this case called s1 and s2 creates encoding matrix S where the symbols s1 and s2 are mapped to two transmit antennas in two transmit time slots. The encoding matrix is given by:

$$S = \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix}$$

. . . . (3.1)

The fading coefficients denoted by h1(t) and h2(t) are assumed constant across the two consecutive symbol transmission periods and they can be defined as:

$$h_1(t) = h_1(t+T) = h_1 = |h_1|e^{j\theta 1}$$

$$h_2(t) = h_2(t+T) = h_2 = |h_2|e^{j\theta 2}$$

. . . . (3.2)

The receiver receives r1 and r2 denoting the two received signals over the two consecutive symbol periods for time t and t+T. The received signals can be expressed by:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} = \begin{bmatrix} h_1 s_1 + h_2 s_2 + n_1 \\ -h_1 s_2^* + h_2 s_1^* + n_2 \end{bmatrix}$$

. . . . (3.3)

The maximum likelihood (ML) decoder chooses a pair of signals (ŝ1, ŝ2) from the signal constellation to minimize the distance metric over all possible values of ŝ1 and ŝ2.

$$d^2(r_1, h_1\hat{s}_1+h_2\hat{s}_2) + d^2(r_2, -h_1\hat{s}_2^* + h_2\hat{s}_1^*)$$
$$= |r_1-h_1\hat{s}_1-h_2\hat{s}_2|^2 + |r_2+h_1\hat{s}_2^*-h_2\hat{s}_1^*|^2$$

. . . . (3.4)

For phase-shift keying (PSK) signals, the decision rule can be expressed by:

$$d^2\,(\hat{s}_1, s_i) \leq d^2\,(\hat{s}_1, s_k)\ \forall\ i \neq k$$
$$d^2\,(\hat{s}_2, s_i) \leq d^2\,(s2, s_k)\ \forall\ i \neq k$$

. . . . (3.5)

The combiner shown in Figure 3 builds the following two combined signals that are sent to the maximum likelihood detector.

$$\begin{bmatrix} \tilde{s}_1 \\ \tilde{s}_2 \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = \begin{bmatrix} h_1^* r_1 + h_2 r_2^* \\ h_2^* r_1 - h_1 r_2^* \end{bmatrix}$$

. . . . (3.6)

The encoder and decoder of the Alamouti scheme system is shown in Figure 3 and Figure 4. Here the information to be transmitted is modulated and fed to the space time encoder. The space time encoder consists of two transmit antennas as part of the multiple input multiple output technology. So here the information is transmitted through two separate antennas. Each transmitting and the receiving antenna pair has a channel, represented by different channel coefficients. These channel coefficients play a major role in the design of the system. As the number of antennas increases at both the ends of the channel, the complexity of the system also increases.

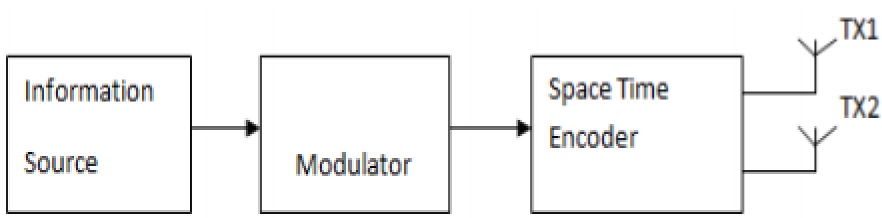

Figure 3.3: Alamouti space-time encoder [13]

In the decoder, the received signal is fed to the channel estimator. The estimated coefficients of the channel together with the combiner are given as the input to the maximum likelihood detector. The detected signal is then fed to the demodulator. The demodulator gives the original information which is transmitted.

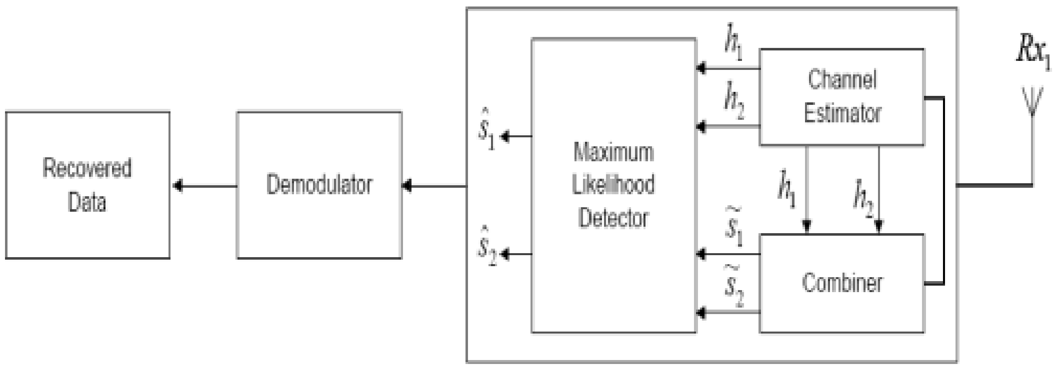

Figure 3.4: Alamouti space-time decoder [13]

The space-time block codes are the higher version of the Alamouti scheme. i.e., increment of the number of antennas of the Alamouti scheme, the space-time block codes will result. As an example of the STBC's, a case of 4 transmitted antennas and one receive antenna is explained here. [14]

3.4 STBC-OFDM [14]

Figure 3.5 describes the block diagram of the STBC-OFDM system considered in this paper. Binary input data are first mapped to one of modulation symbols. An N x M data matrix is formed through serial-to-parallel conversion of N successive modulation symbols, where N and M represent the FFT size and the number of OFDM symbols in each slot, respectively. OFDM symbols are then space-time encoded for each row using two successive symbols for Alamouti's scheme and four successive symbols for quasi-orthogonal scheme (or eight symbols for Tarokh's scheme). A preamble is inserted at the beginning of each slot for channel estimation. The size of the preamble should be as small as possible to avoid the serious reduction of transmission efficiency.

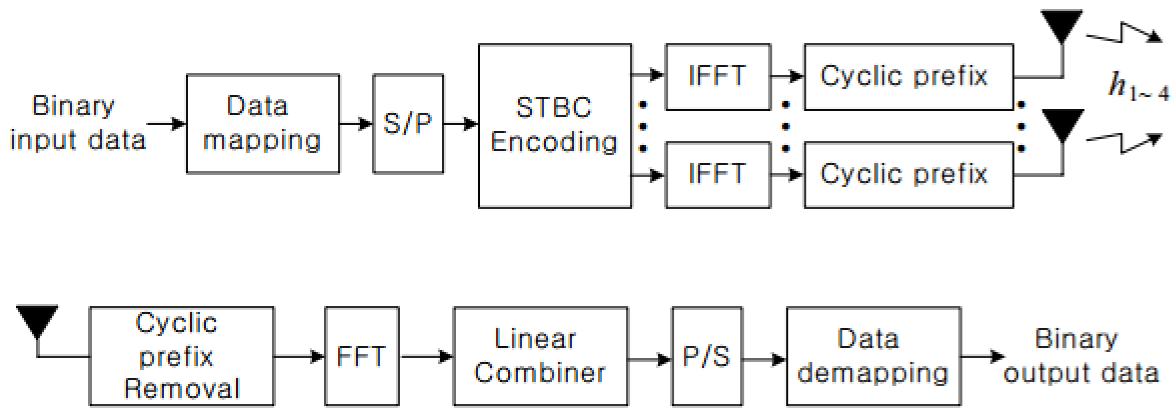

Figure 3.5: Block diagram of STBC-OFDM systems [14]

3.4.1 STBC-OFDM for 2 Transmit Antennas [1]

In this Section, data transmission is considered using *Ns* subcarriers over two transmit and Nr receive antennas. The channel parameters are assumed known at the receiver. We know, data is encoded through space, time and frequency with the help of the space time encoder and OFDM modulation. Two time slots are required to transmit the matrix G 2, c. Therefore, each antenna of the STBC-OFDM system is fed with a data stream of length 2*Ns* transmitted over *nt=2* OFDM symbols.

For a two transmit antenna STBC-OFDM, vectors *S1*(*n*) and *S1*(*n+1*) are transmitted alternatively form antenna 1. Simultaneously, *S2*(*n*) and *S2*(*n+1*) are similarly transmitted from antenna 2. Each vector is composed of symbols coded according to STBC rules.

Figure 3.6, shows the organization of the data through space, time and frequency. Assuming h (n) i, j, k = h (n 1) i, j, k the received equation at the output of the FFT, for the case of two transmit and *Nr* receive antenna can be expressed as:

$$R_j(n)=\sum_{j=1}^{Nr} H_{1,j}(n)S_1(n)+H_{2,j}(n)S_2(n)+N_j(n)$$

$$R_j(n+1)=\sum_{j=1}^{Nr} H_{1,j}(n+1)S_1(n+1)+H_{2,j}(n+1)S_2(n+1)+N_j(n+1)$$

$$=\sum_{j=1}^{Nr} -H_{1,j}(n)S_2^*(n)+H_{2,j}(n)S_1^*(n)+N_j(n+1)$$

…. (3.7)

where R j (n) , S i(n) and N j (n)are the received symbols, transmitted vector symbols and the Gaussian noise sample respectively; n refers to the n-th OFDM symbol and j to the j-th receive antenna.

In addition, S 1(n) and S 2(n) are the vectors given after the serial to parallel operation at transmit antennas 1 and 2 respectively, and given for the OFDM symbol n and n+1 by the following equations:

$$S_1(n)= s_0, s_2, \dots, s_{2k},\dots, s_{2Ns-4}, s_{2Ns-2}\ ^T$$

$$S_2(n)= s_1, s_3, \dots, s_{2k+1},\dots, s_{2Ns-3}, s_{2Ns-1}\ ^T$$

$$S_1(n+1)=\left[-s_1^*, -s_3^*, \dots, -s_{2k+1}^*,\dots, -s_{2Ns-3}^*, s_{2Ns-1}^*\right]^T=-S_2^*(n)$$

$$S_2(n+1)=\left[s_0^*, s_2^*, \dots, s_{2k}^*, \dots, s_{2Ns-4}^*, s_{2Ns-2}^*\right]^T=S_1^*(n)$$

….(3.8)

With k=0, 1, …, Ns-1 and n represent the n-th OFDM symbols.

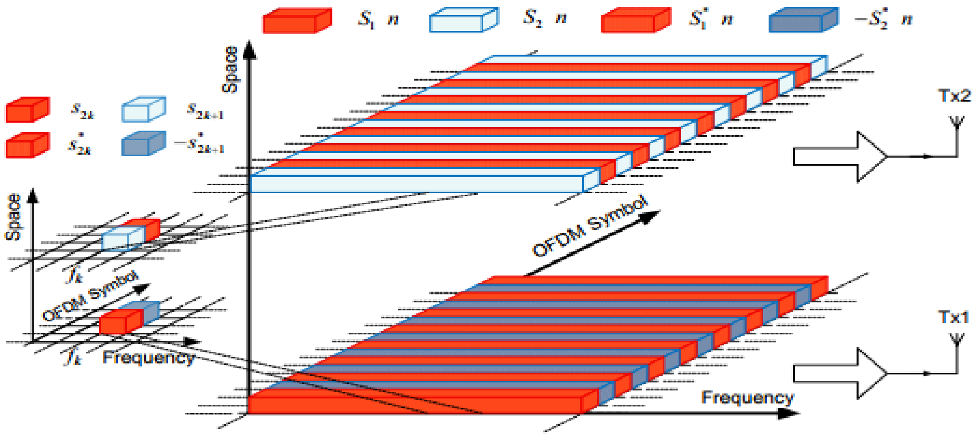

Figure 3.6: Symbols Organization of a STBC-OFDM [1]

With the help of Figure 3.6 and equation (3.11), it can be seen that at OFDM symbol n, **s2k** and **s**2k+1 are transmitted simultaneously at subcarrier k from antenna 1 and 2 respectively and in the second OFDM symbol n+1 at the same subcarrier k, **-s**2k+1 * is transmitted from antenna 1 while simultaneously, **s2k** * is transmitted from antenna 2.

At the receiver, the signal is first demodulated by an FFT demodulator and data is recovered by the space time decoder. For an ideal transmission where the channel is known at the receiver and according to the equations given in for single carrier system, the following can be derived for multicarrier systems:

$$\tilde{S}_{1,k}(n) = \sum_{j=1}^{N_r} (H_{1,j,k}(n) R_{j,k}(n) + H_{2,j,k}(n) R_{j,k}(n+1))$$

$$= \tilde{s}_{2k} = \sum_{j=1}^{N_r} (h^*_{1,j,k} r_{j,2k} + h_{2,j,k} r^*_{j,2k+1})$$

$$\tilde{S}_{2,k}(n) = \sum_{j=1}^{N_r} (H^*_{2,j,k}(n) R_{j,k}(n) + H_{1,j,k}(n) R^*_{j,k}(n+1))$$

$$= \tilde{s}_{2k+1} = \sum_{j=1}^{N_r} (h^*_{2,j,k} r_{j,2k} - h_{1,j,k} r^*_{j,2k+1})$$

…. (3.9)

With k=1, 2, ...,Ns, representing the symbol number, j represent the j-th receive antenna and ~**Si, k** , and, ~**s2k** and ~**s**2k+1 and are the decoded signal and symbols respectively.

CHAPTER 4

SFBC, SFBC-OFDM and Comparison between SFBC and STBC

4.1 SFBC

Space–Frequency Block Coding(SFBC) is a technique used in wireless communications where the symbol of an orthogonal design are transmitted on neighboring subcarriers of the same OFDM rather than on the same subcarrier of subsequent OFDM symbols.

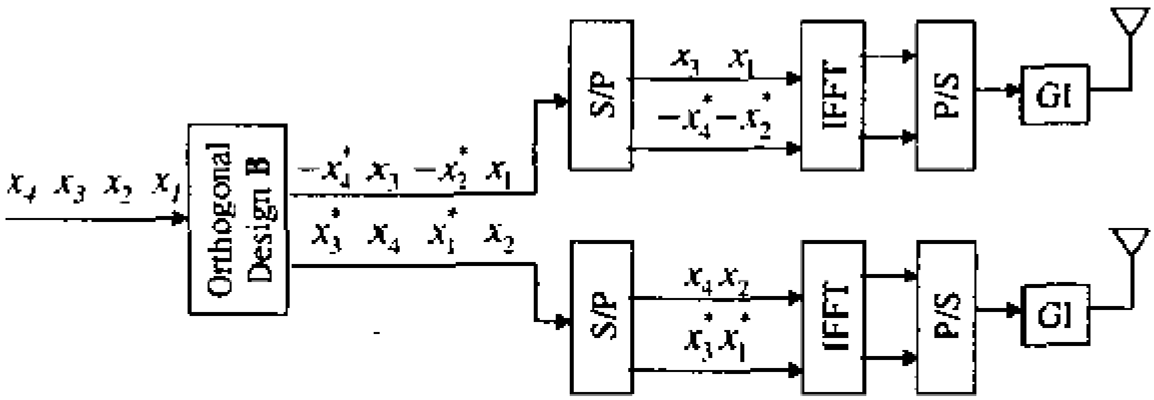

Figure 4.1: Space-Frequency Block Code in OFDM [17]

- To avoid the problem of fast channel variations in time we can use SFBC system.
- In SFBC system the symbol of an orthogonal design can be transmitted on neighboring subcarriers of the same OFDM.
- This reduces the transmission delay.
- The channel needs to be about constant over *P* neighboring subcarriers.
- This is true in channels with low frequency-selectivity.
- It can be accomplished by using a large number of subcarriers in order to make the subcarrier spacing very narrow.
- The performance will degrade in heavily frequency-selective channels if the assumption of constant channel coefficients over a space-frequency block code matrix is not justified.
- Particularly, this is a problem for more than $nT = 2$ transmit antennas, where $P >= 4$ subcarriers are needed per space frequency block code matrix. [17]

4.1.1 SFBC for 2 Symbols

SFBC is a kind of coding scheme for TX diversity.

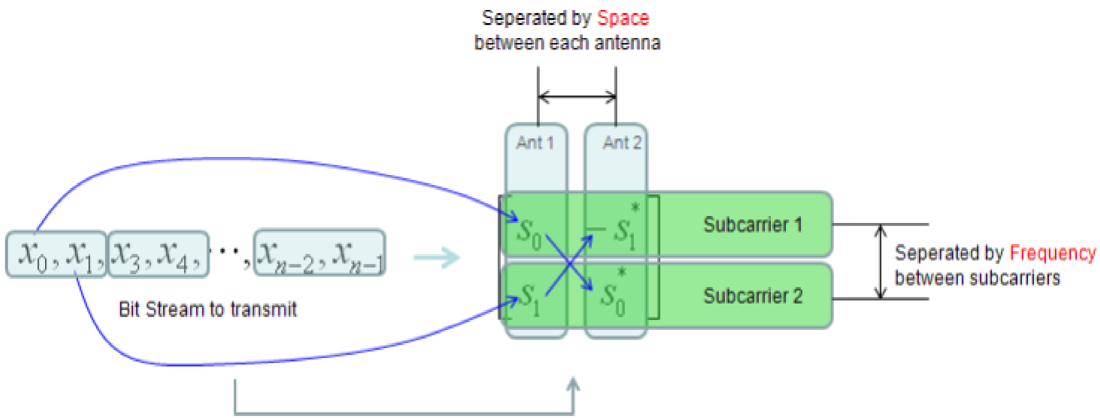

Figure 4.2: SFBC for 2 symbols per block [19]

This conversion (Coding) is performed in 'Block'(In this example, there are two data in a block), not one bit by one bit. So this process is called "Block Coding"

- First symbol at antenna 1 and negative conjugate of second symbol at antenna 2 at a time at same subcarrier.
- Then second symbol at antenna 1 and conjugate of first symbol at antenna 2 at a time at another subcarrier. [19]

4.1.2 SFBC for 4 Symbols

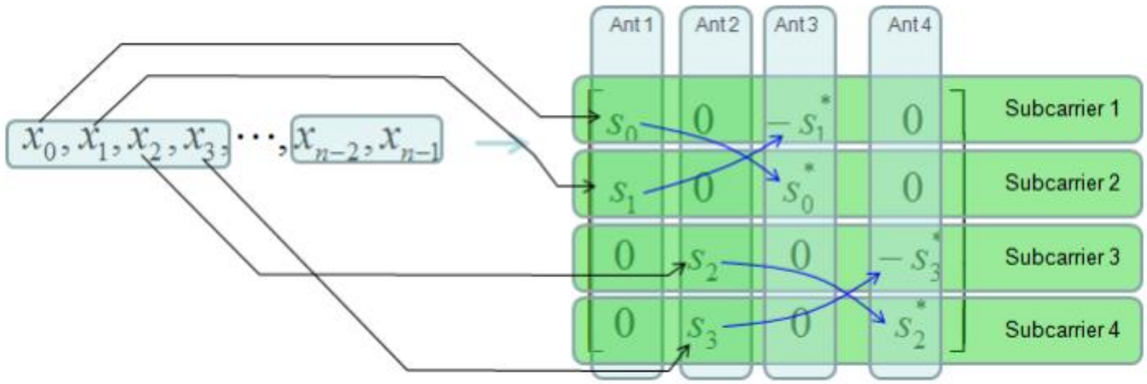

Figure 4.3: SFBC for 4 symbols per block [19]

4.1.3 SFBC using 2 transmitters and 1 receiver

For simplicity, let's look into the case with two transmitter antenna and one receiver antenna to perform the transmission in diversity. It can be illustrated as shown below.

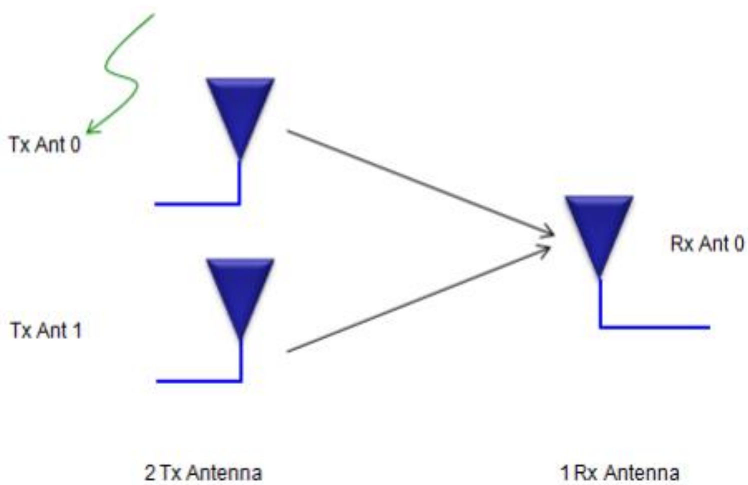

Figure 4.4: SFBC using 2transmitters and 1 receiver [19]

Now let's suppose channel coefficient of each diversity path is shown as below and two symbols x0, x1 is being transmitted at the sub carrier 0. [19]

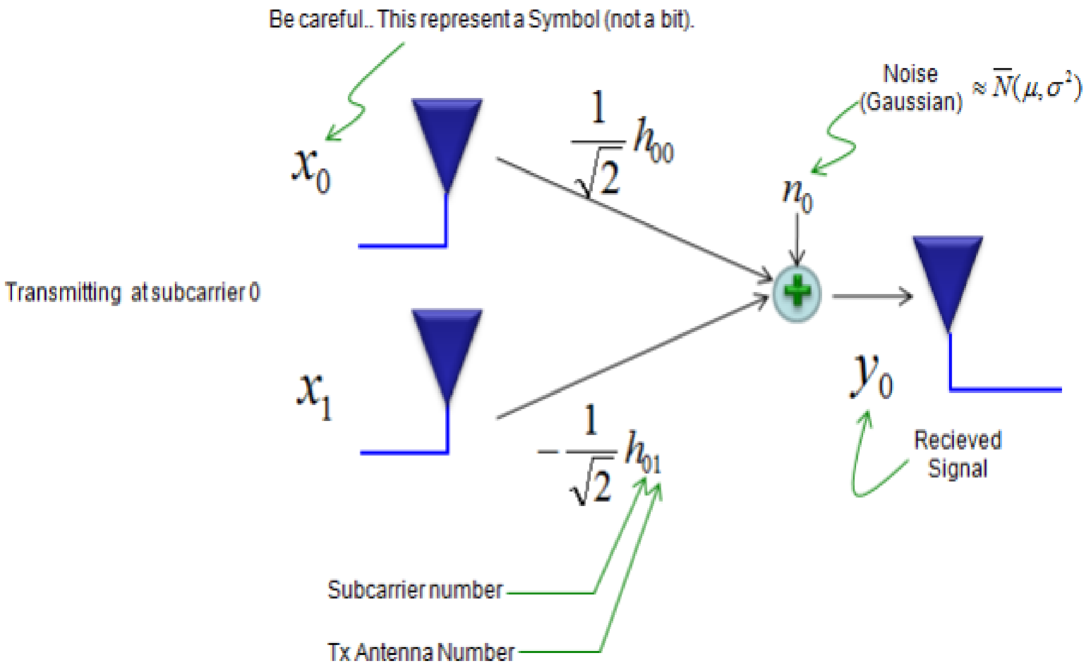

Figure 4.5 : symbols x0, x1 is transmitted at the sub carrier 0 [19]

We can represent the received signal y0 as shown below:

$$y_0 = \frac{1}{\sqrt{2}} h_{00} x_0 - \frac{1}{\sqrt{2}} h_{01} x_1 + n$$

Now let's suppose channel coefficient of each diversity path is shown as below and two symbols x0, x1 is being transmitted at the sub carrier 1. [19]

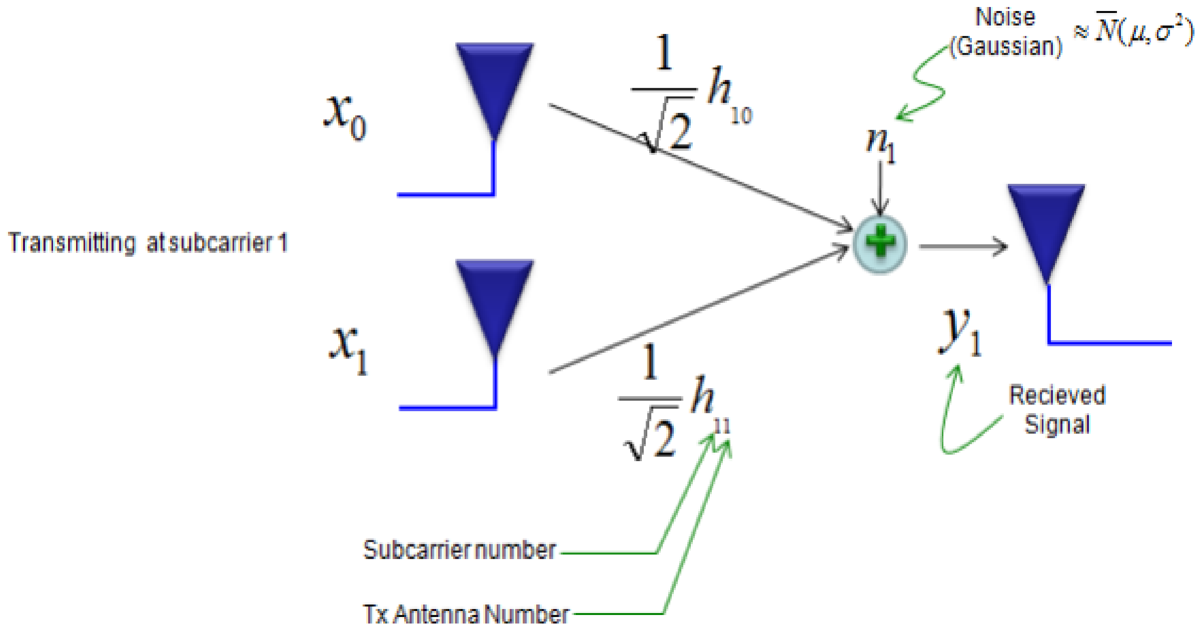

Figure 4.6: symbols x0, x1 is transmitted at the sub carrier 1 [19]

We can represent the received signal y1 as shown below:

$$y_1 = \frac{1}{\sqrt{2}}h_{10}x_0 + \frac{1}{\sqrt{2}}h_{11}x_1 + n$$

Now we have two equations representing y0, y1. We can combine the two equations into one matrix equation as shown below.

$$\underbrace{\begin{bmatrix} y_0 \\ y_1^* \end{bmatrix}}_{\mathbf{y}} = \frac{1}{\sqrt{2}}\underbrace{\begin{bmatrix} h_{00} & -h_{01} \\ h_{11}^* & h_{10}^* \end{bmatrix}}_{\mathbf{H}}\underbrace{\begin{bmatrix} x_0 \\ x_1^* \end{bmatrix}}_{\mathbf{x}} + \underbrace{\begin{bmatrix} n_0 \\ n_1^* \end{bmatrix}}_{\mathbf{n}}$$

4.2 SFBC-OFDM

It is the combination of SFBC & OFDM.

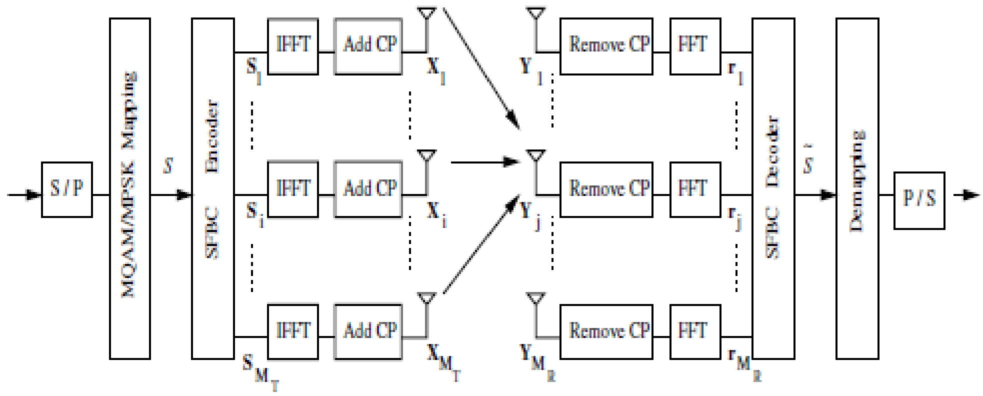

Figure 4.7: SFBC-OFDM block diagram [18]

- MT transmit and *M*R are receive antennas.
- Information is first converted from serial to parallel.
- Ns = *N/q; N*s be the number of sub bands, *N* subcarriers (or sub channels) and *q* is the symbol period of the SFBC system.
- Sub bands are modulated using MQAM or MPSK signal vector S = {s [0], s [1], … , s [Nt − 1]} is the input to the SFBC encoder.
- SFBC code rate, *Rc*.
- Here IFFT and CP (Cyclic Prefix) are part of OFDM.
- Cyclic Prefix acts as a buffer region or guard interval to protect the OFDM signals from inter symbol interference.
- It repeats the end of the symbol so the linear convolution of a frequency-selective multipath channel can be modeled as circular convolution.
- It improves the robustness to multipath propagation.
- Higher gains are achieved by using higher order SFBC with more antennas at the transmitter.
- SFBC-OFDM is sensitive to channel gain variation over frequency. [18]

A space-time block code is defined by a $q \times M$T transmission matrix **G** given by [18]:

$$\mathbf{G} = \begin{pmatrix} g_{1,1} & g_{1,2} & \cdots & g_{1,M_\mathrm{T}} \\ g_{2,1} & g_{2,2} & \cdots & g_{2,M_\mathrm{T}} \\ \vdots & \vdots & \cdots & \vdots \\ g_{q,1} & g_{q,2} & \cdots & g_{q,M_\mathrm{T}} \end{pmatrix}$$

Where each element *gi, j* is a linear combination of a subset of elements of *S* and their conjugates. The $q \times M$ transmission matrix **G** is based on a complex generalized orthogonal design. In order to utilize the space frequency diversity, the input blocks for OFDM at each transmit antenna should be of length *N*. SFBC provides *M* blocks, **S**1, **S**2*,…* , **S***M*T, each of length *N* and consisting of *Nq* sub-blocks, i.e., **S***i* = (**s***i*[0] **s***i*[1] ... **s***i*[*Nq*
− 1]) *T* for *i* = 1, 2*,…* ,*M*T, where the superscript (.)*T* denotes the transpose operator. Then, OFDM modulators generate blocks **X**1, **X**2, ... ,**X***M*T to be transmitted by the first, second, ...,and *M*T-th transmit antenna simultaneously. [20]

4.2.1 SFBC-OFDM with 3 Transmit Antennas

Consider an SFBC-OFDM scheme with three transmit antennas (*M*T = 3) and code **G**3 [2], and define the following Sub blocks:

s1 [*k*] = (*s* [4*k*] − *s* [4*k* + 1] − *s* [4*k* + 2] − *s* [4*k* + 3]
s∗ [4*k*] − *s*∗ [4*k* + 1] − *s*∗ [4*k* + 2] − *s*∗ [4*k* + 3]),
s2 [*k*] = (*s* [4*k* + 1] *s* [4*k*] *s* [4*k* + 3] − *s* [4*k* + 2]
s∗ [4*k* + 1] *s*∗ [4*k*] *s*∗ [4*k* + 3] − *s*∗ [4*k* + 2]),
s3 [*k*] = (+*s* [4*k* + 2] − *s* [4*k* + 3] *s* [4*k*] *s* [4*k* + 1]
s∗ [4*k* + 2] − *s*∗ [4*k* + 3] *s*∗ [4*k*] *s*∗ [4*k* + 1]).

Therefore, the code **G**3 for SFBC can be written as

$$\mathbf{G}_3 = \left[(\mathbf{s}_1[k])^T \quad (\mathbf{s}_2[k])^T \quad (\mathbf{s}_3[k])^T \right],\ k = 0, \cdots, \frac{N}{8} - 1.$$

The SFBC encoder provides three blocks **S**1, **S**2 and **S**3 with length *N* as follows

$$\mathbf{S}_i = [\mathbf{s}_i[0] \quad \mathbf{s}_i[1] \ \cdots \ \mathbf{s}_i[N/8-1]]^T, \ i = 1,2,3.$$

Then, OFDM modulators generate blocks **X**1, **X**2 and **X**3 that are transmitted by the first, second and third transmit antenna, respectively. At the receiver side, the signal after OFDM demodulation can be written as:

r*j* = **H***j*, 1 **S**1 +**H***j*, 2 **S**2 +**H***j*, 3 **S**3 +**W***j*

Where **r***j* , **H***j*, 1, **H***j*, 2, **H***j*, 3 and **W***j* are as defined in Using ML detection for decoding the received signal, the detection scheme can be written as:

$$\begin{aligned}
\widetilde{s}[4k] = \textstyle\sum_j \big(& +H^*_{j,1}[8k]\, r_j[8k] + H^*_{j,2}[8k]\, r_j[8k+1] \\
& +H^*_{j,3}[8k]\, r_j[8k+2] + H_{j,1}[8k]\, r^*_j[8k+4] \\
& +H_{j,2}[8k]\, r^*_j[8k+5] + H_{j,3}[8k]\, r^*_j[8k+6] \big), \\
\widetilde{s}[4k+1] = \textstyle\sum_j \big(& +H^*_{j,2}[8k]\, r_j[8k] - H^*_{j,1}[8k]\, r_j[8k+1] \\
& +H^*_{j,3}[8k]\, r_j[8k+3] + H_{j,2}[8k]\, r^*_j[8k+4] \\
& -H_{j,1}[8k]\, r^*_j[8k+5] + H_{j,3}[8k]\, r^*_j[8k+7] \big), \\
\widetilde{s}[4k+2] = \textstyle\sum_j \big(& +H^*_{j,3}[8k]\, r_j[8k] - H^*_{j,1}[8k]\, r_j[8k+2] \\
& -H^*_{j,2}[8k]\, r_j[8k+3] + H_{j,3}[8k]\, r^*_j[8k+4] \\
& -H_{j,1}[8k]\, r^*_j[8k+6] - H_{j,2}[8k]\, r^*_j[8k+7] \big), \\
\widetilde{s}[4k+3] = \textstyle\sum_j \big(& -H^*_{j,3}[8k]\, r_j[8k+1] + H^*_{j,2}[8k]\, r_j[8k+2] \\
& -H^*_{j,1}[8k]\, r_j[8k+3] - H_{j,3}[8k]\, r^*_j[8k+5] \\
& +H_{j,2}[8k]\, r^*_j[8k+6] - H_{j,1}[8k]\, r^*_j[8k+7] \big).
\end{aligned}$$

And we assume that the CSI is known at the receiver and that the channel gains of eight adjacent sub channels are approximately equal, i.e., *Hj,* 1[8*k* + *m*] = *Hj,* 1[8*k*], *Hj,* 2[8*k* + *m*] = *Hj,* 2[8*k*], *Hj,* 3[8*k* + *m*] = *Hj,* 3[8*k*], for *m* = 0,… 7. Note that the channel gain variation in SFBC-OFDM, over frequency selective fading channels, depends on the channel delay, the number of paths and the block size. When the block size is large enough, the channel gain between the eight subcarriers is almost constant. Hence, substituting (1) into (2), the decoded signal can be expressed as in (13). Finally, *{s* [*m*]*} Nt*−1 *m*=0 is sent to the decision part. [18]

4.3 Comparison between STBC & SFBC

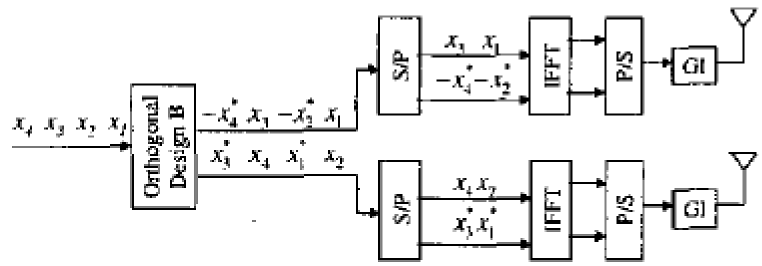

Figure 4.8: Space-Frequency Block Code in OFDM [17]

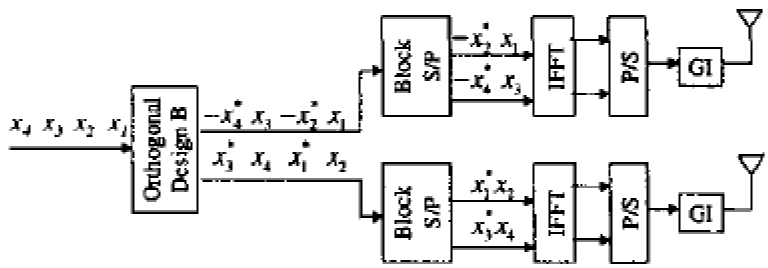

Figure 4.9: Space-Time Block Code in OFDM [17]

- In STBC data signal is transmitted through same sub carriers but in SFBC data signal is transmitted through neighboring sub carriers.
- In SFBC transmission delay reduces.
- SFBC-OFDM is sensitive to channel gain variation over frequency but STBC-OFDM is sensitive to channel gain variation over time. [17]

CHAPTER 5

M-PSK and M-QAM

5.1 M-PSK

Phase Shift Keying (PSK) is the digital modulation technique in which the phase of the carrier signal is changed by varying the sine and cosine according to the change of input at a particular time. [20]

This can be BPSK, QPSK, 8PSK etc. In general they are called M-PSK.

PSK technique is widely used for wireless LANs, bio-metric, contactless operations along with RFID and Bluetooth communications. [20]

5.1.1 Example of BPSK

For input 1001

For BPSK it will be:

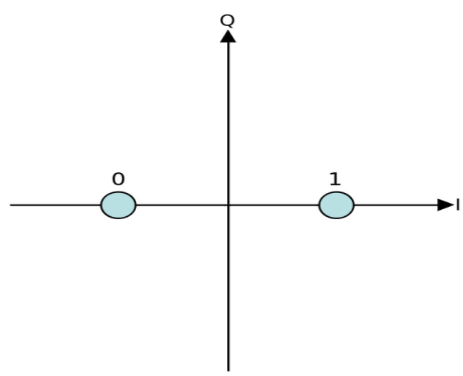

Figure 5.1a: BPSK constellation diagram [21]

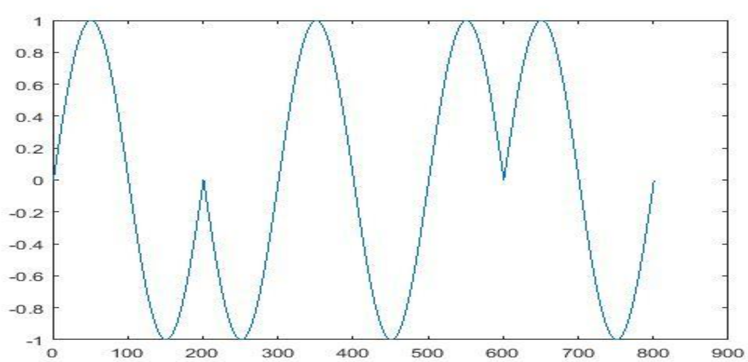

Figure 5.1b: BPSK time diagram

5.1.2 Example of QPSK

For input 1001

For QPSK it will be:

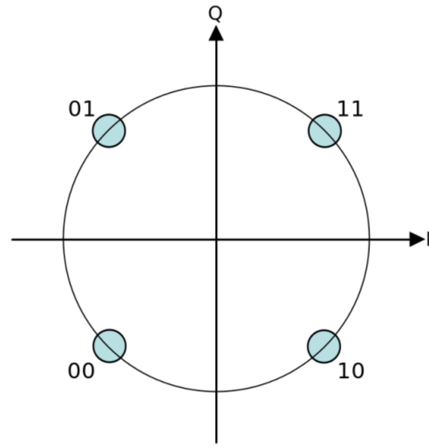

Figure 5.2a: QPSK constellation diagram [21]

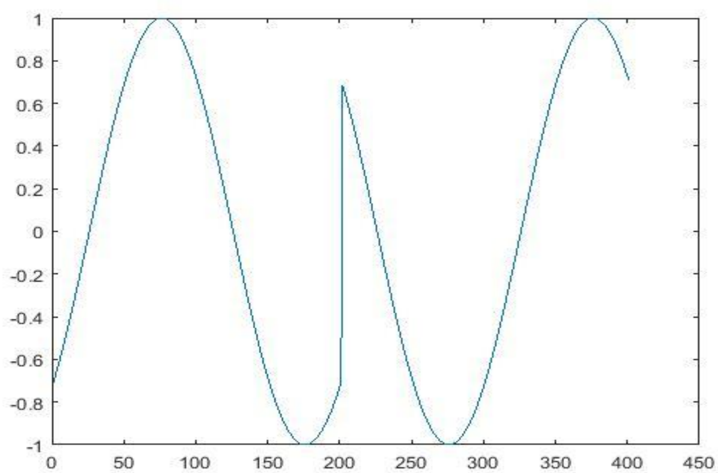

Figure 5.2b: QPSK time diagram

5.2 M-QAM

Quadrature Amplitude Modulation (QAM) is both analog and digital modulation technique in which both phase and magnitude of the carrier signal is changed by varying the sine and cosine according to the change of input at a particular time.

This can be QAM 8, QAM 16, and QAM 64 etc. In general they are called M-QAM.
QAM is being used in optical fiber systems.

5.2.1 Example of QAM 8

For input 100010

For QAM 8 it will be:

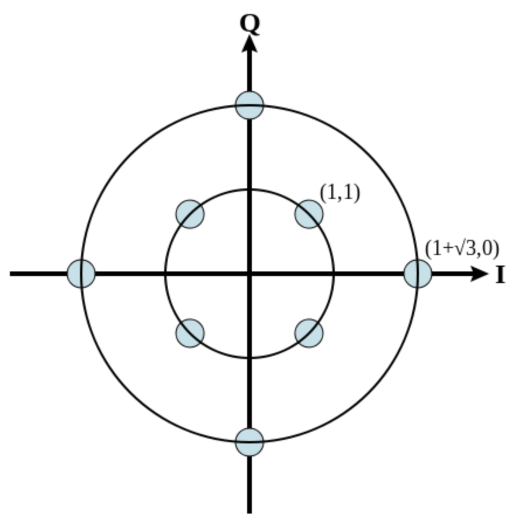

Figure 5.3a: QAM8 constellation diagram [22]

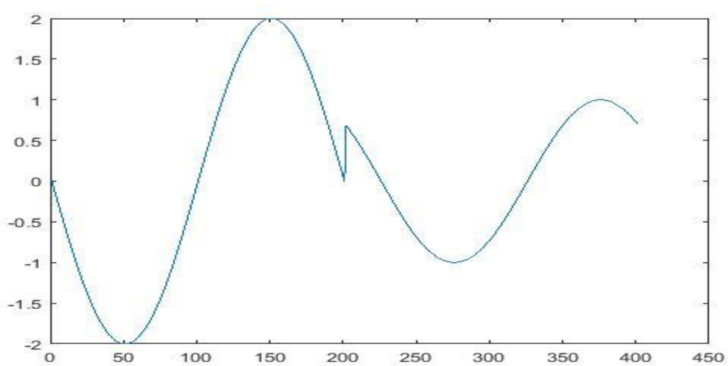

Figure 5.3b: QAM8 time diagram

5.2.2 Example of QAM 16

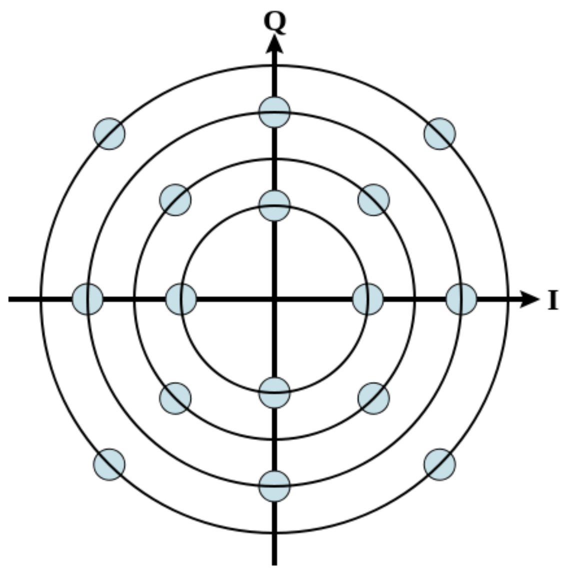

Figure 5.4: QAM16 constellation diagram [22]

CHAPTER 6

Results and Analysis for Perfect CSI

For perfect CSI using Rayleigh Fading channels we analyzed results for both SFBC and STBC. The following Table shows the parameters which we have varied.

Table 6.1 : SFBC and STBC for perfect CSI using Rayleigh Fading channels

Varied Parameters	Varied Numbers/Modulation Techniques
Transmitter	1,2,3,4
Receiver	1,2,3,4
M-PSK	BPSK,QPSK,8PSK
M-QAM	QAM16,QAM64

6.1 BER vs SNR curves for M-QAM using SFBC

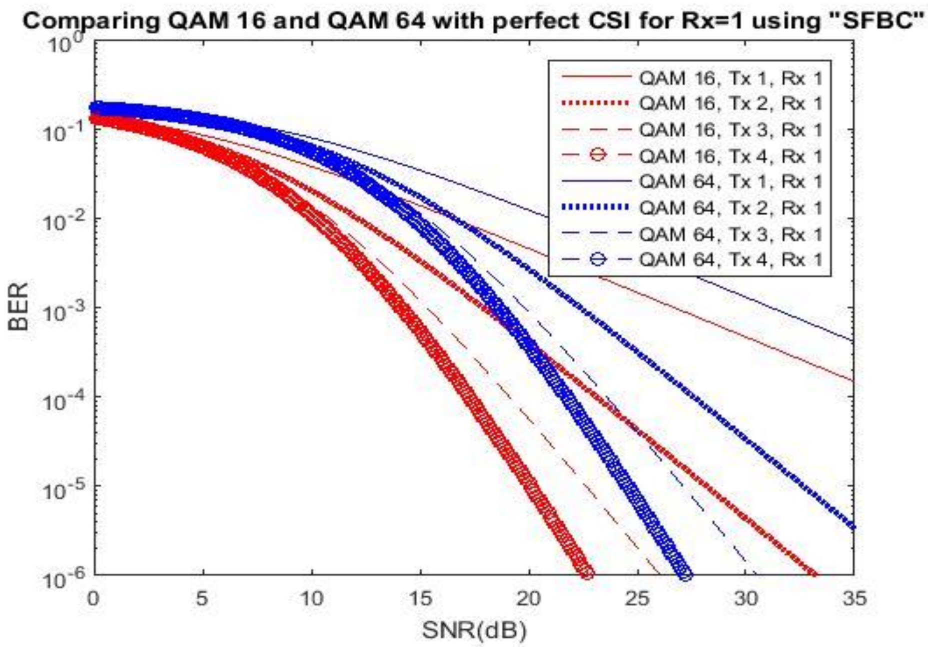

Figure 6.1: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

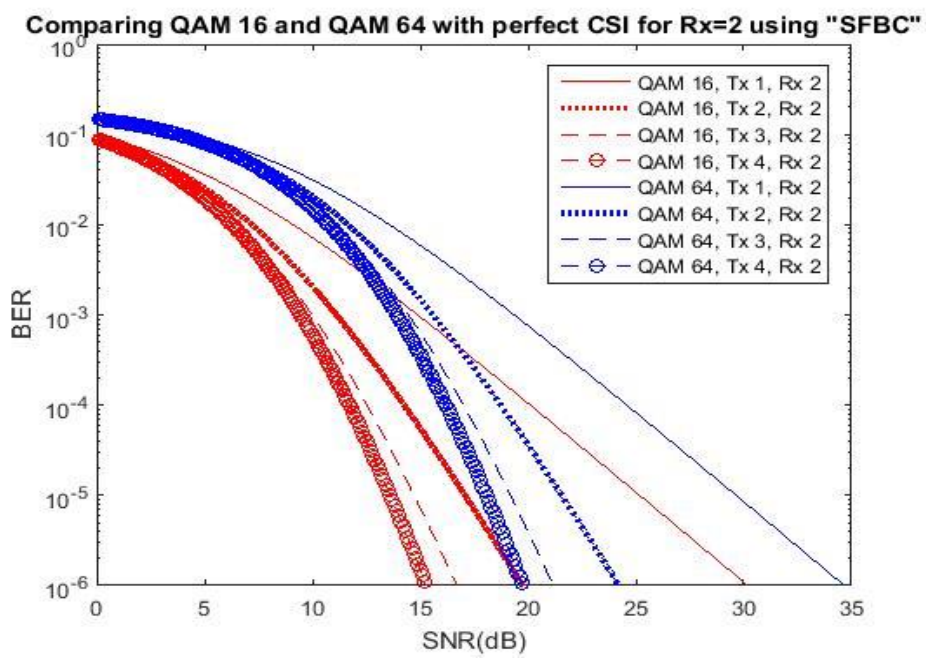

Figure 6.2: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

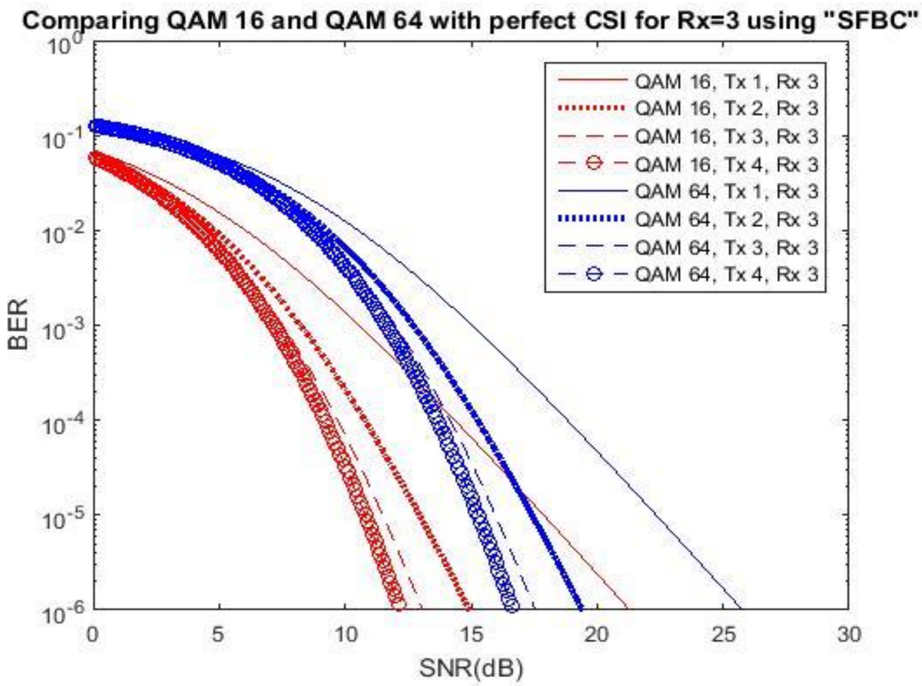

Figure 6.3: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=3 using “SFBC”

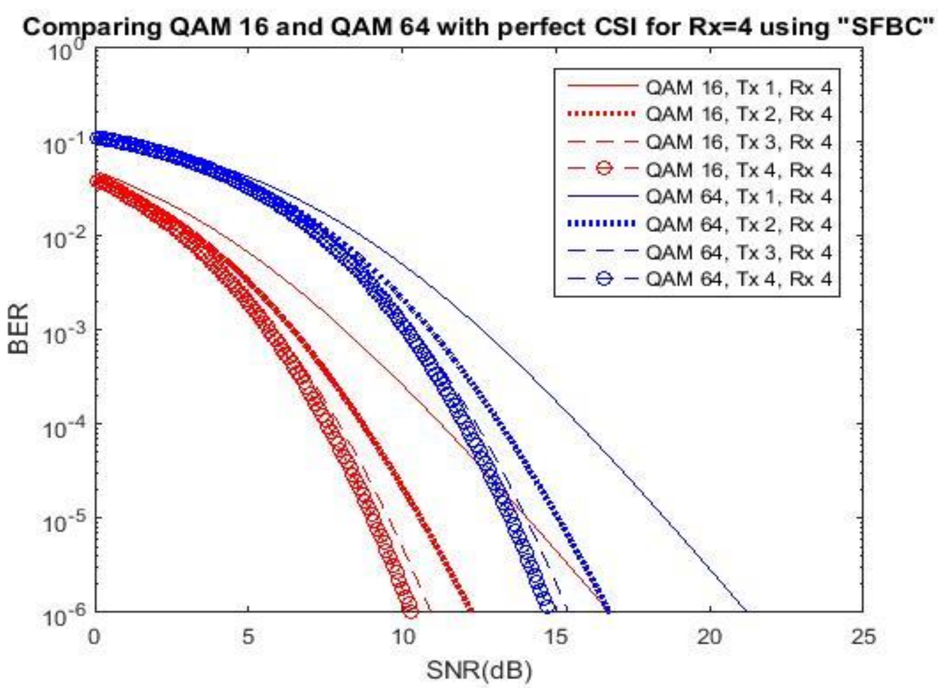

Figure 6.4: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=4 using “SFBC”

6.2 Comparison between QAM 16 and QAM 64 with perfect CSI using SFBC

1. Whatever the number of receivers is, BER becomes 10^{-6} for lowest SNR when we use QAM 16 with 4 transmitters.
2. As we increase SNR, values of BER decrease faster for QAM 16 than QAM 64.
3. For lower values of SNR, BER is less for QAM 16 than for QAM 64.
4. For a fixed number of receivers, as the number of transmitters is increased, slope becomes more and more negative. That means BER decreases faster when we increase SNR.
5. For a fixed number of transmitters, as the number of receivers is increased, BER decreases faster when we increase SNR.
6. We achieved best performance when we used QAM 16 technique with 4 transmitters and 4 receivers. That means higher the number of transmitters and receivers, better the performance becomes.
7. For reducing cost, we try to reduce the number of receivers but better performance will always be our topmost priority. Here we achieved best performance for QAM 16 with 4 transmitters and 4 receivers. But we got almost similar performance for QAM 16 with 4 transmitters and 3 receivers. So we would prefer QAM 16 with 4 transmitters and 3 receivers.

6.3 BER vs SNR curves for M-QAM using STBC

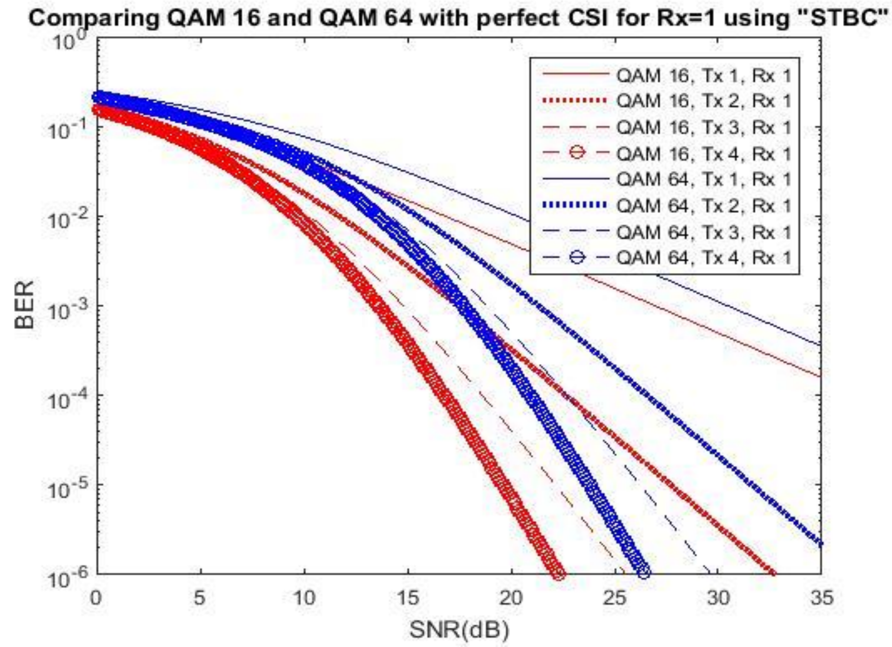

Figure 6.5: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=1 using "STBC"

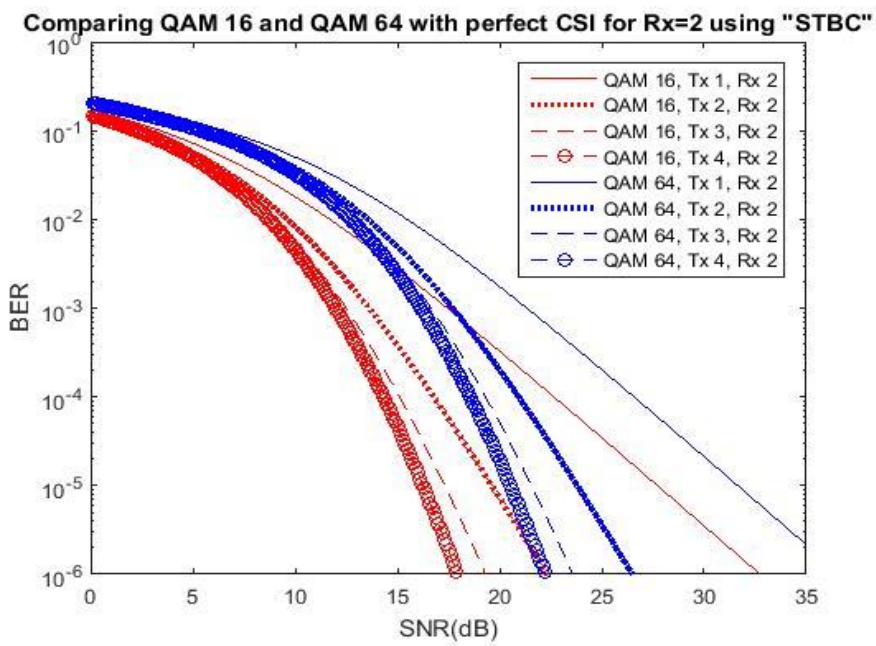

Figure 6.6: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=2 using "STBC"

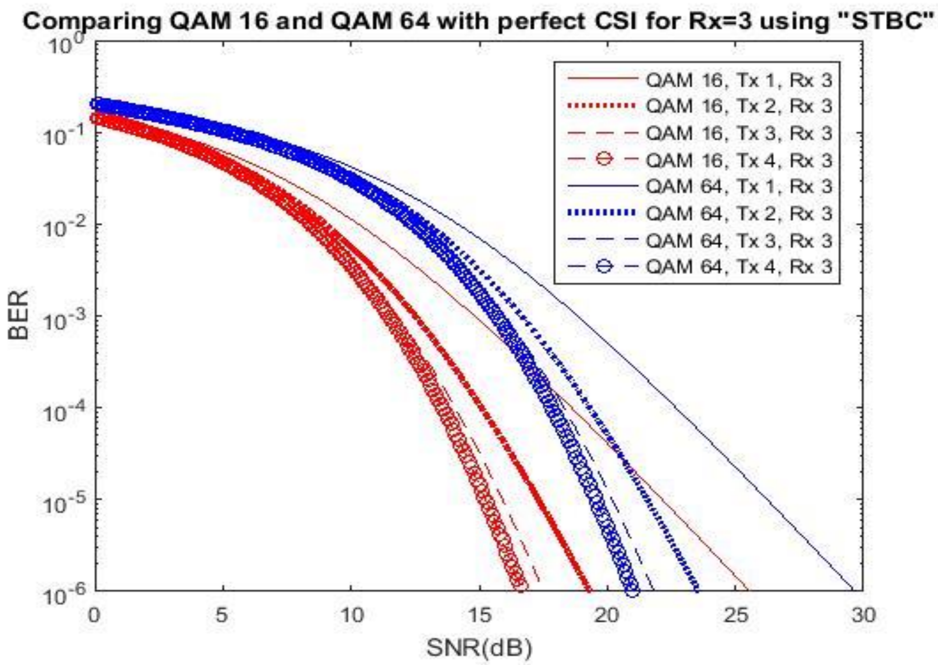

Figure 6.7: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=3 using "STBC"

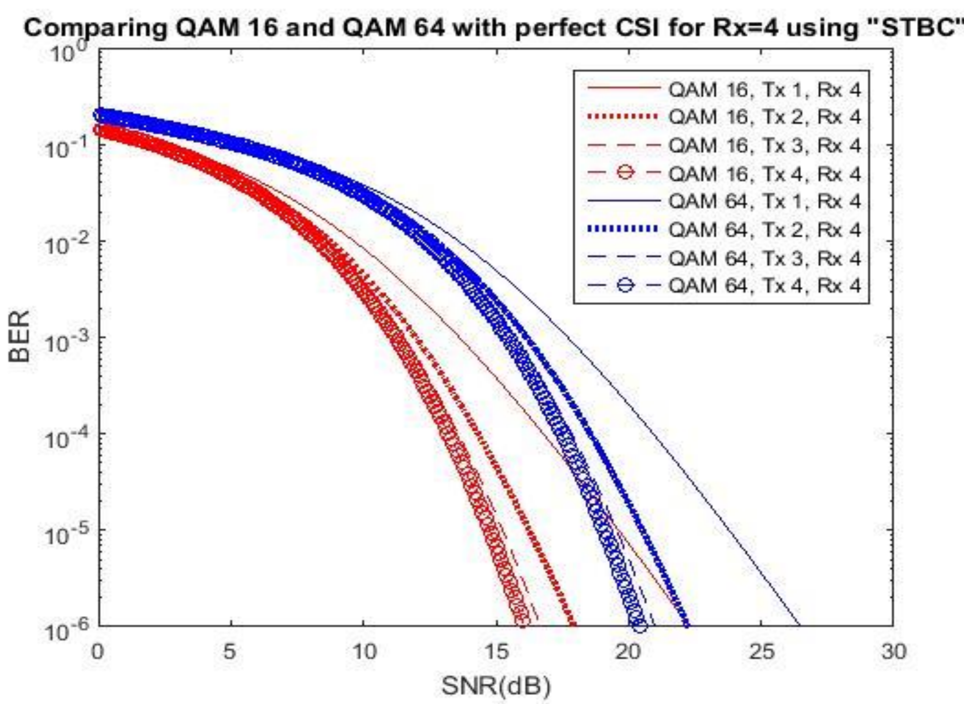

Figure 6.8: Comparing QAM 16 and QAM 64 with perfect CSI for Tx=1, 2, 3 & 4 and Rx=4 using "STBC"

6.4 Comparison between QAM 16 and QAM 64 with perfect CSI using STBC

1. Whatever the number of receivers is, BER becomes 10^{-6} for lowest SNR when we use QAM 16 with 4 transmitters.
2. As we increase SNR, values of BER decrease faster for QAM 16 than QAM 64.
3. For lower values of SNR, BER is less for QAM 16 than for QAM 64.
4. For a fixed number of receivers, as the number of transmitters is increased, slope becomes more and more negative. That means BER decreases faster when we increase SNR.
5. For a fixed number of transmitters, as the number of receivers is increased, BER decreases faster when we increase SNR. Variation of performance is very little among 2, 3 or 4 receiver cases.
6. We achieved best performance when we used QAM 16 technique with 4 transmitters and 4 receivers. That means higher the number of transmitters and receivers, better the performance becomes.
7. For reducing cost, we try to reduce the number of receivers but better performance will always be our topmost priority. Here we achieved best performance for QAM 16 with 4 transmitters and 4 receivers. As mentioned earlier we got almost similar performance for QAM 16 with 4 transmitters and 2 or 3 receivers. So we would prefer 4 transmitters and 2 receivers with QAM 16 technique.

6.5 Comparison between QAM 16 and QAM 64 with perfect CSI using SFBC and STBC

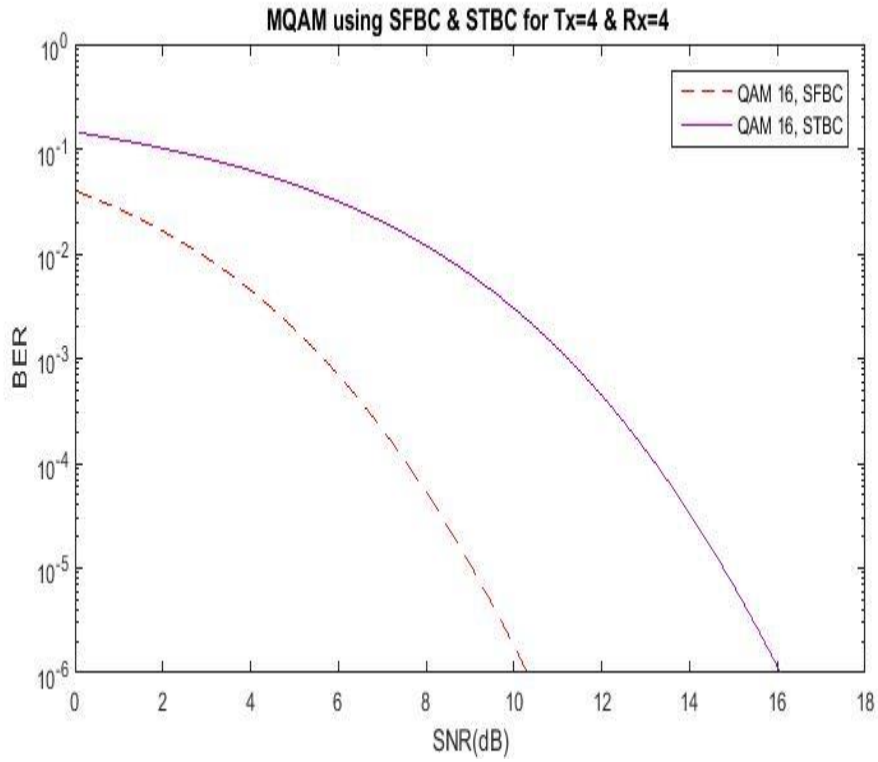

Figure 6.9: Comparing SFBC and STBC using QAM 16 with perfect CSI for Tx=4 and Rx=4

1. We got better performance for SFBC.
2. As we increase SNR, values of BER decrease faster for QAM 16 in both cases.
3. For lower values of SNR, BER is less for SFBC.
4. In both cases the higher the number of transmitters and receivers, the better the performance becomes.
5. For both SFBC and STBC we got best performance for QAM 16 and out of these cases SFBC gives the best performance.
6. We prefer QAM 16 with 4 transmitters and 3 receivers for SFBC and 4 transmitters and 2 receivers with QAM 16 technique for STBC. Out of these two we'll pick the SFBC case because performance is better.

6.6 BER vs SNR curves for M-PSK using SFBC

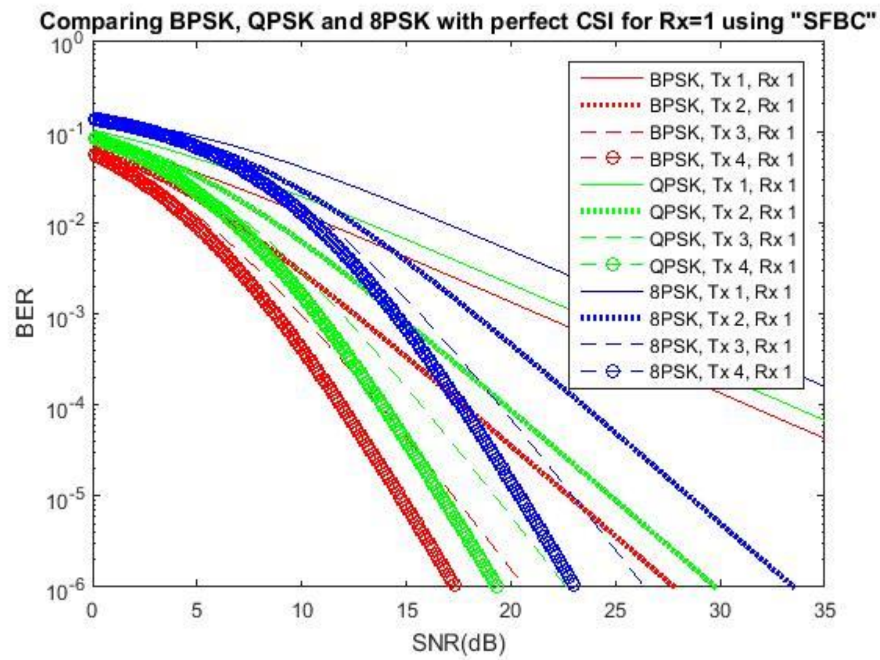

Figure 6.10: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

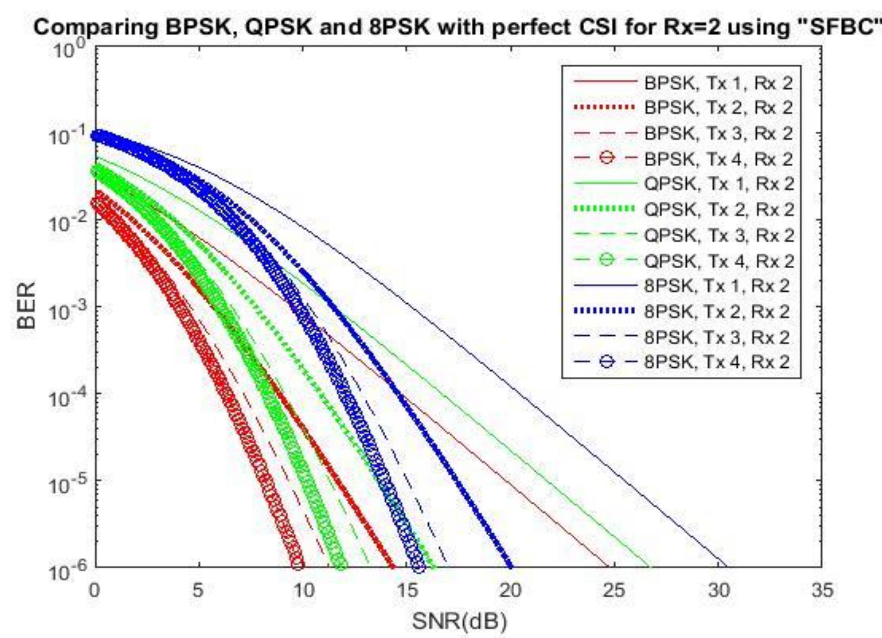

Figure 6.11: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

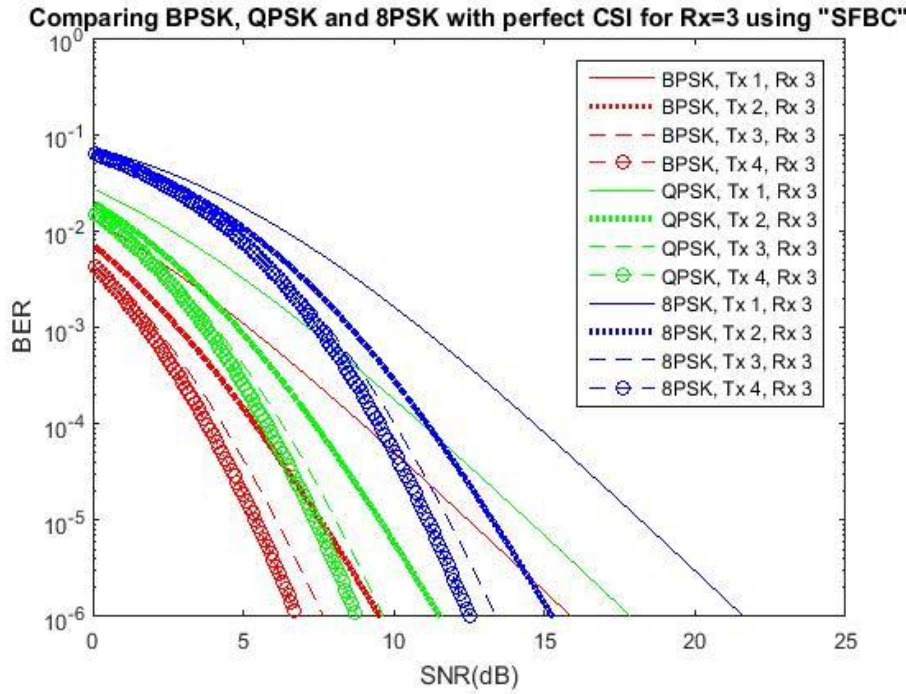

Figure 6.12: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

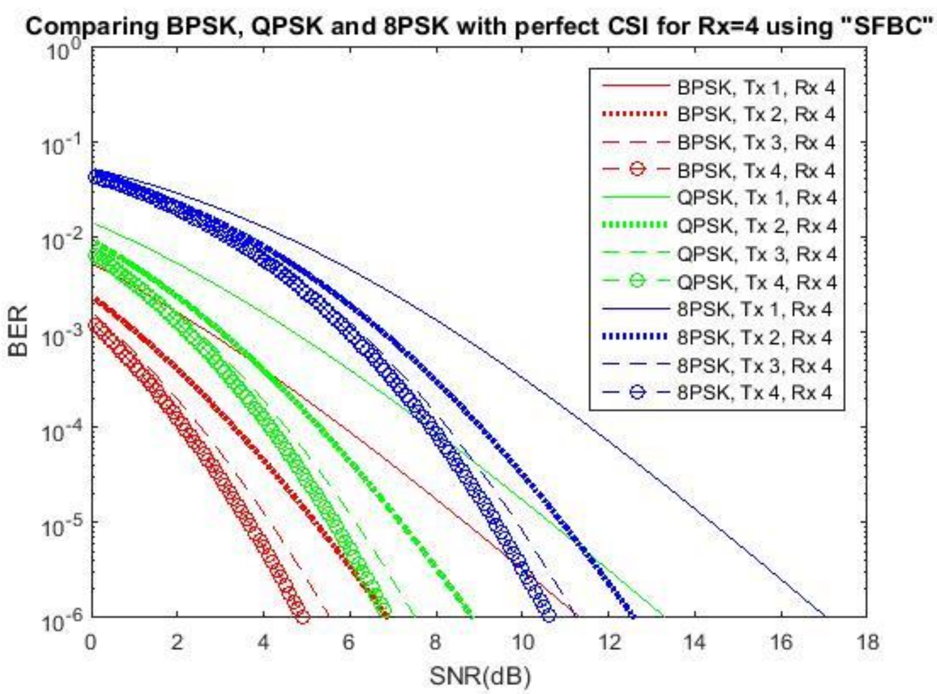

Figure 6.13: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

6.7 Comparison among BPSK, QPSK and 8PSK with perfect CSI using SFBC

1. BER becomes 10^{-6} for lowest SNR when we use BPSK with 4 transmitters.
2. As we increase SNR, the decreasing rate of BER is fastest for BPSK and BER decreases faster for QPSK than 8PSK.
3. For lower values of SNR, BER is less for BPSK, higher for 8PSK and QPSK is in between those. Variation becomes higher among them for lower SNR as number of receivers
4. For a fixed number of receivers, as the number of transmitters is increased, slope becomes more and more negative. That means BER decreases faster when we increase SNR.
5. For a fixed number of transmitters, as the number of receivers is increased, BER decreases faster when we increase SNR.
6. We achieved best performance when we used BPSK technique with 4 transmitters and 4 receivers. That means higher the number of transmitters and receivers, better the performance becomes.
7. For reducing cost, we try to reduce the number of receivers but better performance will always be our topmost priority. Here we achieved best performance for BPSK with 4 transmitters and 4 receivers. If we use 4 transmitters and 3 receivers for BPSK, performance becomes slightly worse but still this can meet our demand.

6.8 BER vs SNR curves for M-PSK using STBC

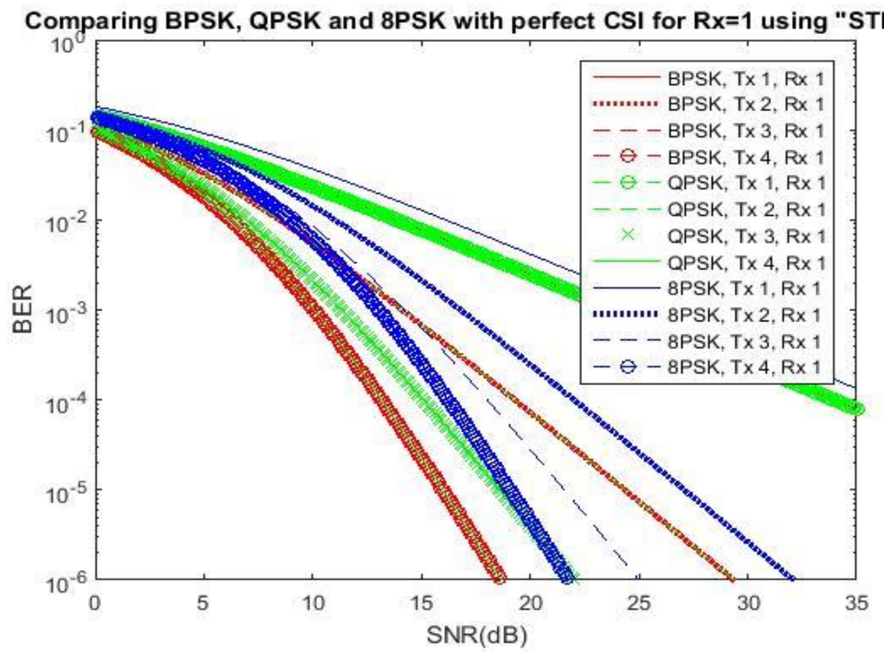

Figure 6.14: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=1 using "STBC"

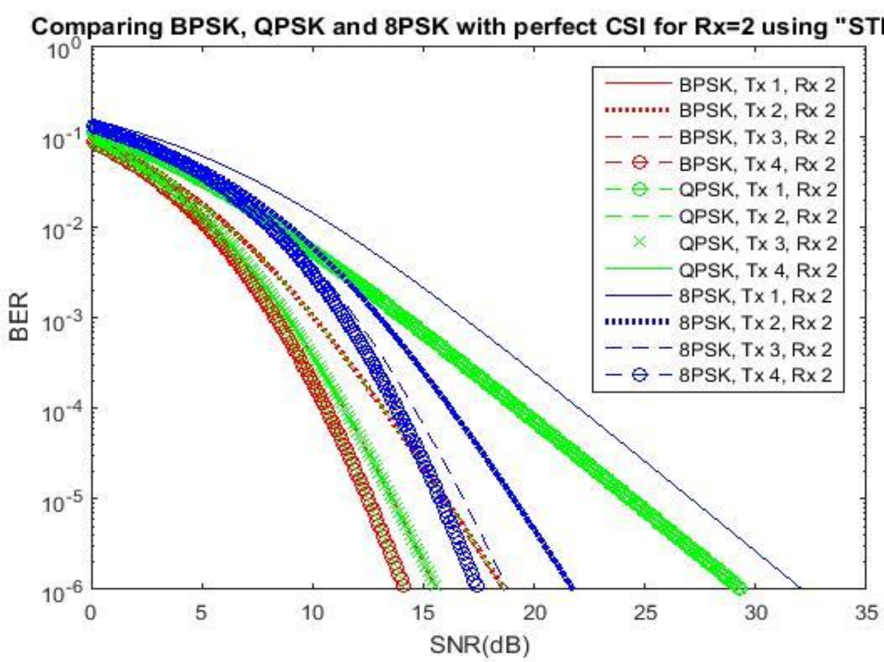

Figure 6.15: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=2 using "STBC"

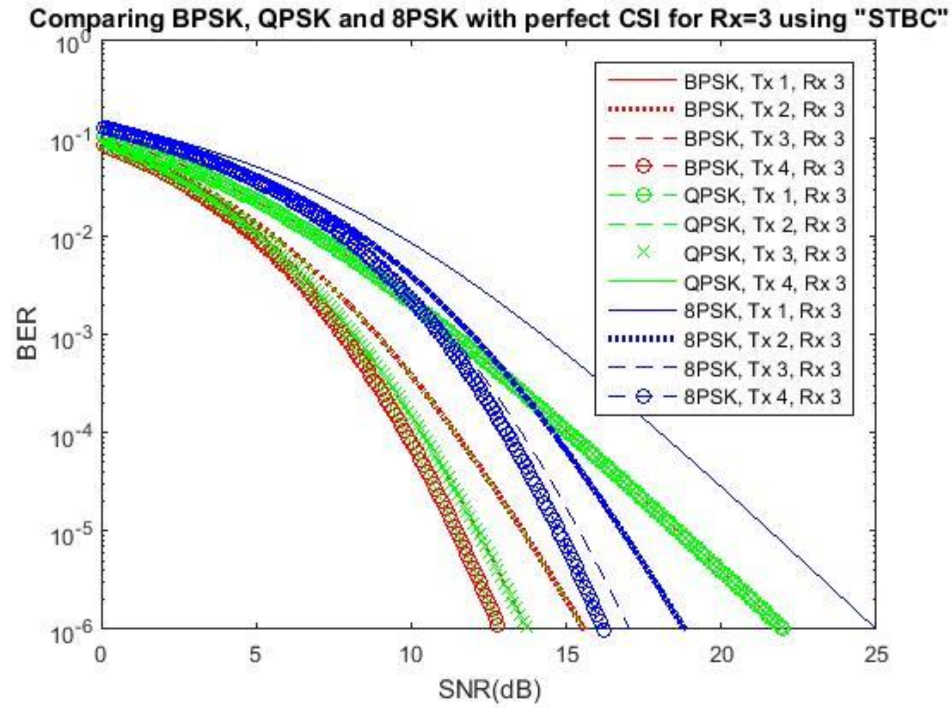

Figure 6.16: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=3 using "STBC"

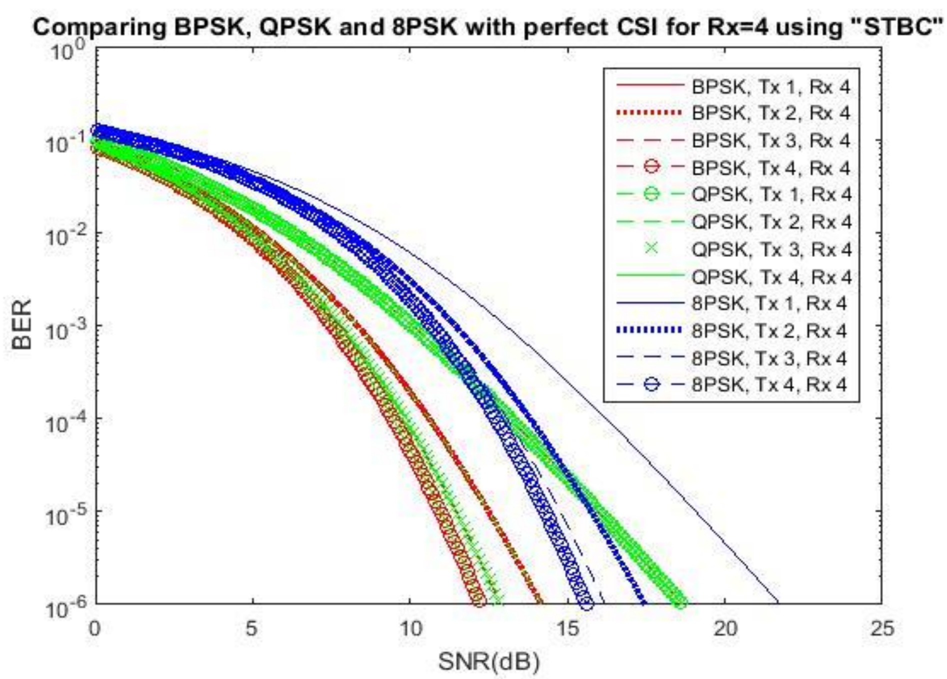

Figure 6.17: Comparing BPSK, QPSK and 8PSK with perfect CSI for Tx=1, 2, 3 & 4 and Rx=4 using "STBC"

6.9 Comparison among BPSK, QPSK and 8PSK with perfect CSI using STBC

1. Whatever the number of receivers is, BER becomes 10^{-6} for lowest SNR when we use BPSK or QPSK with 4 transmitters.
2. As we increase SNR, values of BER decrease faster for BPSK and QPSK than 8PSK.
3. For lower values of SNR, BER is less for BPSK and QPSK than for 8PSK.
4. For a fixed number of receivers, as the number of transmitters is increased, slope becomes more and more negative. That means BER decreases faster when we increase SNR.
5. For a fixed number of transmitters, as the number of receivers is increased, BER decreases faster when we increase SNR. Variation of performance is very little among 2, 3 or 4 receiver cases.
6. We achieved best performance when we used BPSK and QPSK techniques with 4 transmitters and 4 receivers. That means higher the number of transmitters and receivers, better the performance becomes.
7. For reducing cost, we try to reduce the number of receivers but better performance will always be our topmost priority. Here we achieved best performance for BPSK and QPSK techniques with 4 transmitters and 4 receivers. As mentioned earlier we got almost similar performance for BPSK and QPSK with 4 transmitters and 2 or 3 receivers. So we would prefer 4 transmitters and 2 receivers with QPSK technique because we get better throughput.

6.10 Comparison among BPSK, QPSK and 8PSK with perfect CSI using SFBC & STBC

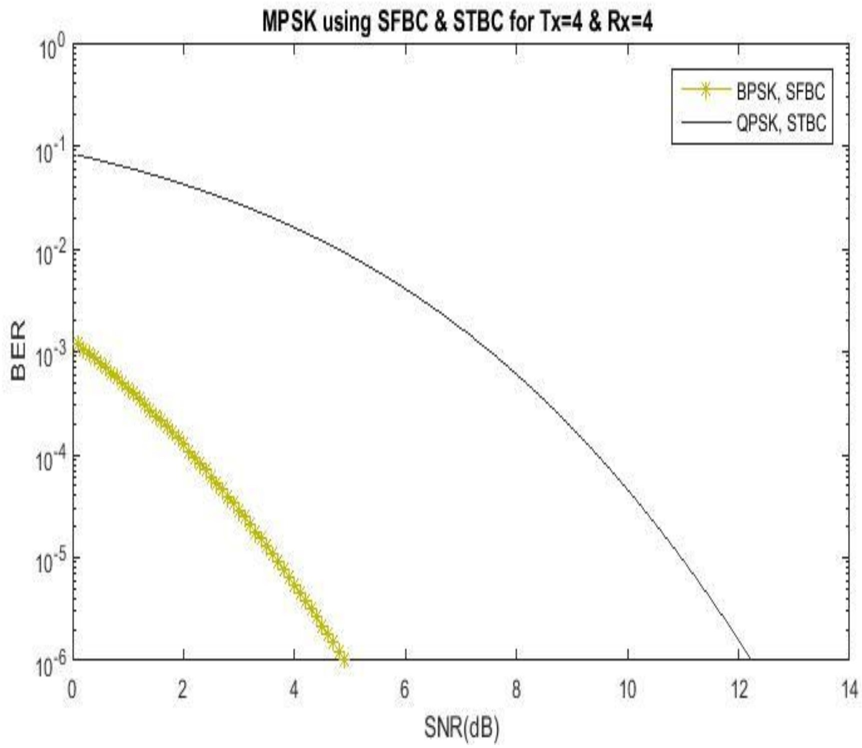

Figure 6.18: Comparing QPSK using STBC and BPSK using SFBC with perfect CSI for Tx=4 and Rx=4

1. We got better performance for SFBC.
2. As we increase SNR, values of BER decrease to 10^{-6} faster for BPSK in both cases.
3. For lower values of SNR, BER is less for SFBC.
4. No curve matches with each other in SFBC, but in STBC curves for BPSK and QPSK are exactly the same.
5. In both cases the higher the number of transmitters and receivers, the better the performance becomes.
6. For SFBC we got best performance for BPSK and for STBC it's both BPSK and QPSK. 4 transmitters and 4 receivers are used in both cases. But out of these cases SFBC gives the best performance.
7. We prefer BPSK with 4 transmitters and 3 receivers for SFBC and 4 transmitters and 2 receivers with BPSK technique for STBC. Out of these two we'll pick the SFBC case because performance is better though the number of receivers required is more.

6.11 Comparison **between MPSK and MQAM using SFBC**

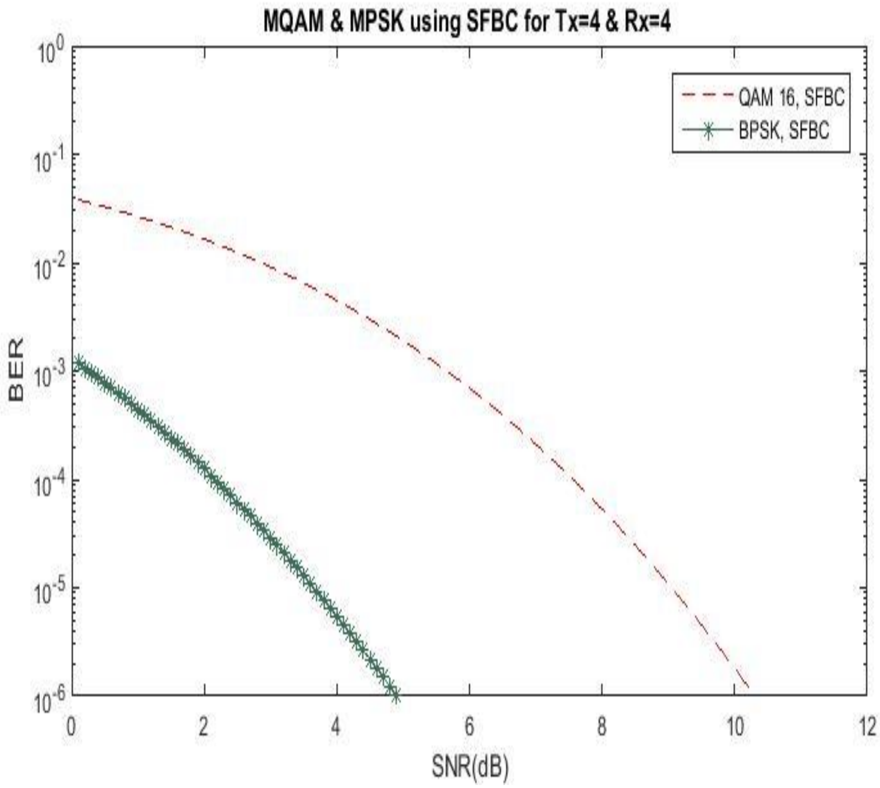

Figure 6.19: Comparing QAM 16 and BPSK using SFBC for Tx=4 and Rx=4

1. Between QAM 16 and QAM 64, QAM 16 always gives better performance. Among BPSK, QPSK and 8PSK, BPSK gives the best performance.
2. BER is less for QAM 16 in MQAM and for BPSK in MPSK for lower values of SNR. So, lower the number of bits, lower BER in lower values of SNR.
3. We got best performance for QAM 16 with 4 transmitters and 4 receivers in MQAM and for BPSK with 4 transmitters and 4 receivers in MPSK.
4. We prefer QAM 16 with 4 transmitters and 3 receivers in MQAM and BPSK 4 transmitters and 3 receivers. So we will choose BPSK with 3 receivers for better performance.

6.12 Comparison between MPSK and MQAM using STBC

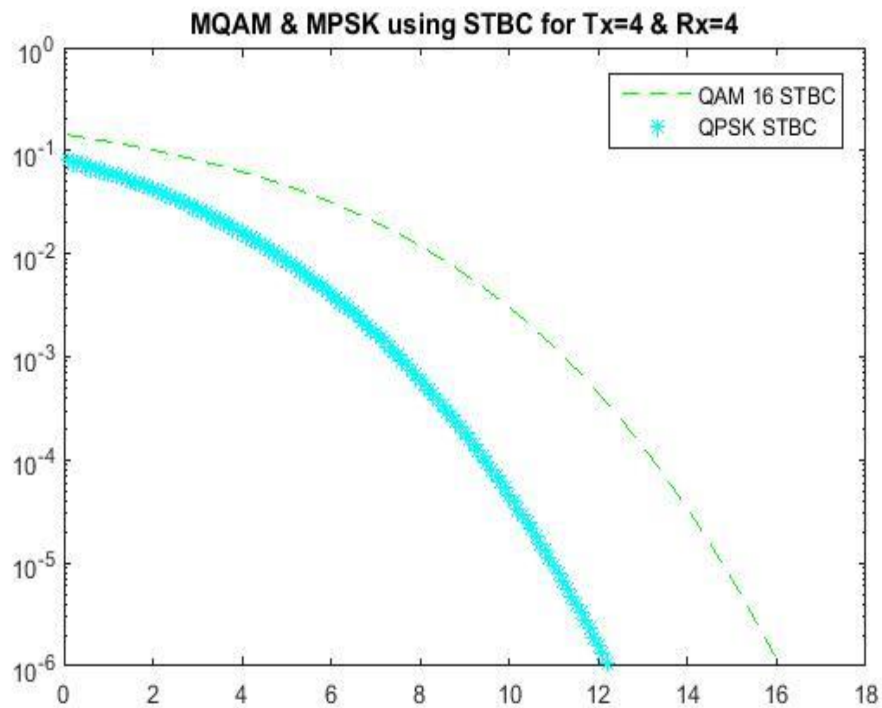

Figure 6.20: Comparing QAM 16 and QPSK using STBC for Tx=4 and Rx=4

1. Between QAM 16 and QAM 64, QAM 16 always gives better performance. Among BPSK, QPSK and 8PSK; BPSK and QPSK give better performance.
2. BER is less for QAM 16 in MQAM and for BPSK and QPSK in MPSK for lower values of SNR. So, lower the number of bits, lower BER in lower values of SNR.
3. Decreasing rate of BER for QAM 64 is less than QAM 16 for lower SNR and then becomes almost same in MQAM. Decreasing rate of BER for 8PSK is less than the other two for lower SNR then becomes almost same in MPSK.
4. In both cases increasing the number of transmitters and receivers will result in better performance.
5. We got best performance for QAM 16 with 4 transmitters and 4 receivers in MQAM and for BPSK and QPSK with 4 transmitters and 4 receivers in MPSK.
6. We prefer QAM 16 with 4 transmitters and 2 receivers in MQAM and QPSK with 4 transmitters and 2 receivers. We prefer QPSK for better performance and throughput.

6.13 Comparison between SFBC and STBC for both MQAM and MPSK

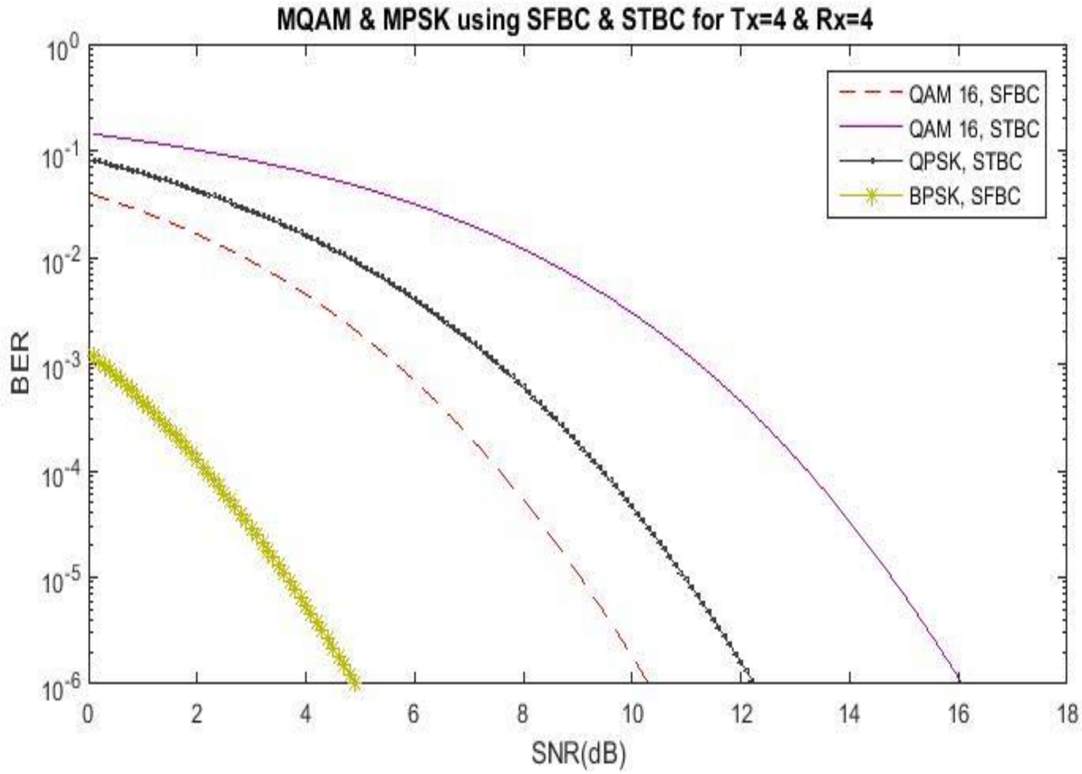

Figure 6.21: Comparing QAM 16 & BPSK using SFBC and QAM 16 & QPSK using STBC for Tx=4 and Rx=4

1. BEST PERFORMANCES

SFBC-MIMO-OFDM with M-QAM:

QAM 16 with 4 transmitters and 4 receivers. BER reaches 10^{-6} for almost SNR=10.3 dB.

STBC-MIMO-OFDM with M-QAM:

QAM 16 with 4 transmitters and 4 receivers. BER reaches 10^{-6} for almost SNR=16 dB.

SFBC-MIMO-OFDM with M-PSK:

BPSK with 4 transmitters and 4 receivers. BER reaches 10^{-6} for almost SNR=4.9 dB.

STBC-MIMO-OFDM with M-PSK:

BPSK/QPSK with 4 transmitters and 4 receivers. BER reaches 10^{-6} for almost SNR=12 dB.

2. PREFERED TECHNIQUES:

SFBC-MIMO-OFDM with M-QAM:

QAM 16 with 4 transmitters and 3 receivers. BER reaches 10^{-6} for almost SNR=12.1 dB.

STBC-MIMO-OFDM with M-QAM:

QAM 16 with 4 transmitters and 2 receivers. BER reaches 10^{-6} for almost SNR=18 dB.

SFBC-MIMO-OFDM with M-PSK:

BPSK with 4 transmitters and 3 receivers. BER reaches 10^{-6} for almost SNR=6.7 dB.

STBC-MIMO-OFDM with M-PSK:

QPSK with 4 transmitters and 2 receivers. BER reaches 10^{-6} for almost SNR=14 dB.

So for best performance we will choose BPSK with 4 transmitters and 4 receivers for SFBC. For cost reduction with nearer to best performance we will pick BPSK with 4 transmitters and 3 receivers for SFBC.

CHAPTER 7

Results and Analysis for Imperfect CSI

For imperfect CSI using Rayleigh Fading channels we analyzed results for only SFBC. The following Table shows the parameters we have varied.

Table 7.1 : SFBC for Imperfect CSI using Rayleigh Fading channels

Varied Parameters	Varied Numbers/Modulation Techniques/Values
Transmitter	1,2,3,4
Receiver	1,2,3,4
M-PSK	BPSK,QPSK,8PSK
M-QAM	QAM16,QAM64
σ_e^2	0,0.005,0.01,0.02,0.05

7.1 BER vs SNR curves for M-QAM using SFBC

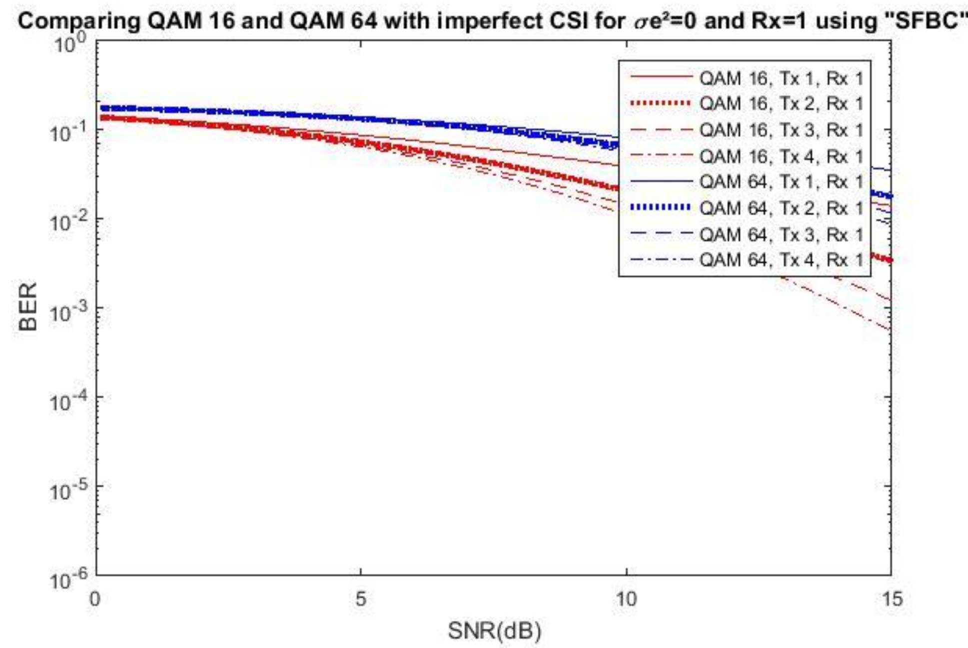

Figure 7.1: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

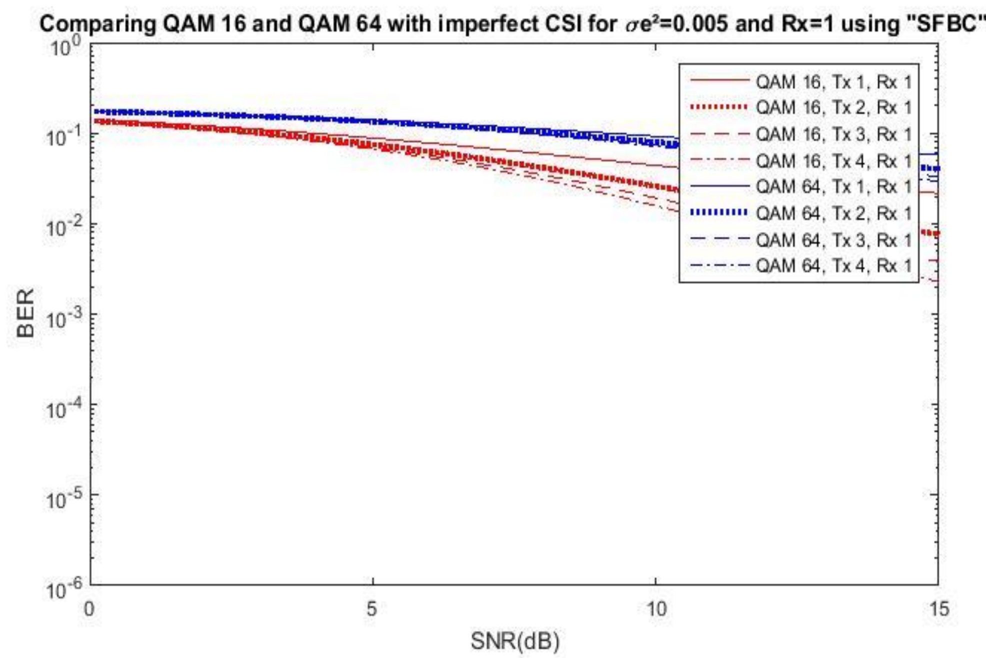

Figure 7.2: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

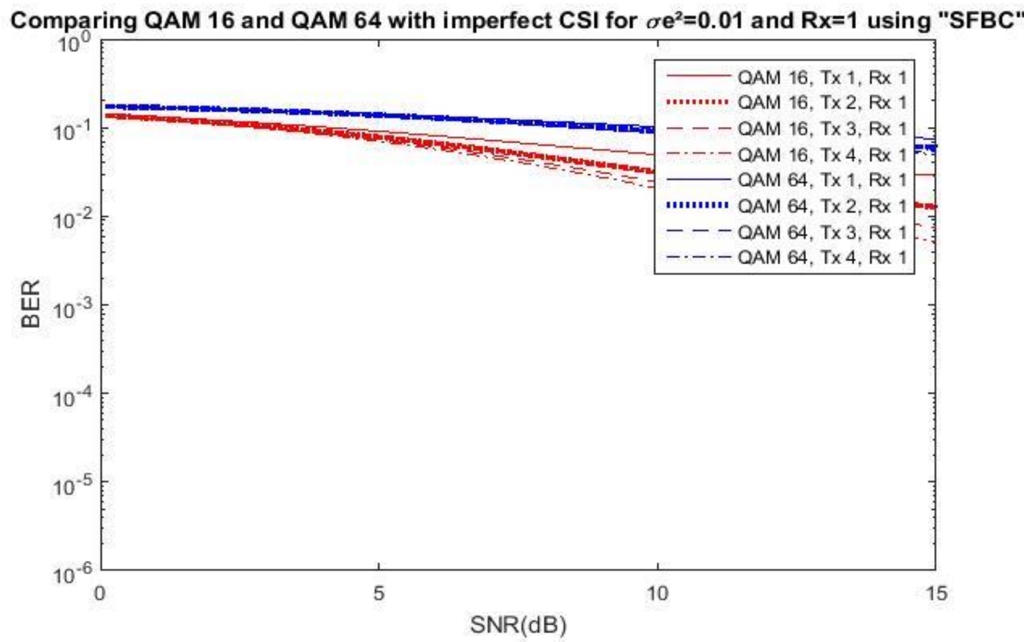

Figure 7.3: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

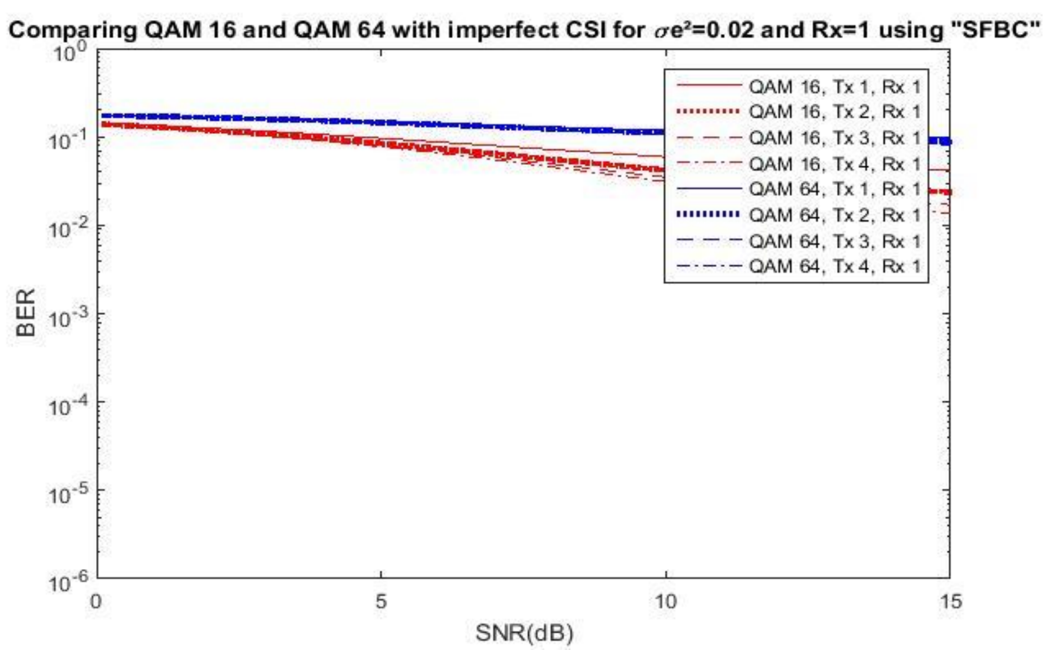

Figure 7.4: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

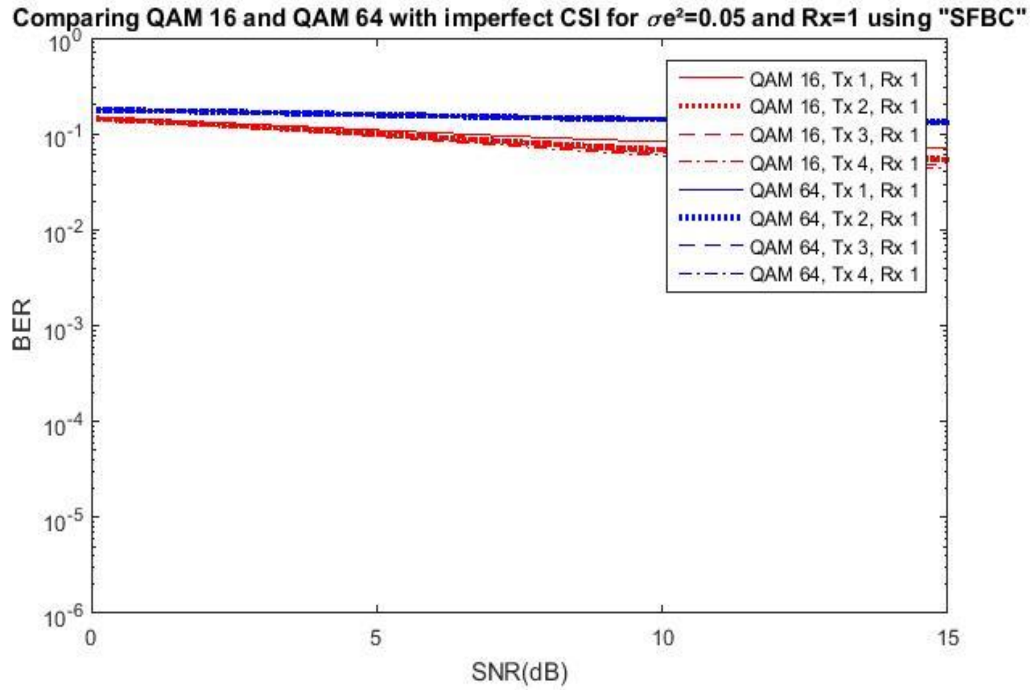

Figure 7.5: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

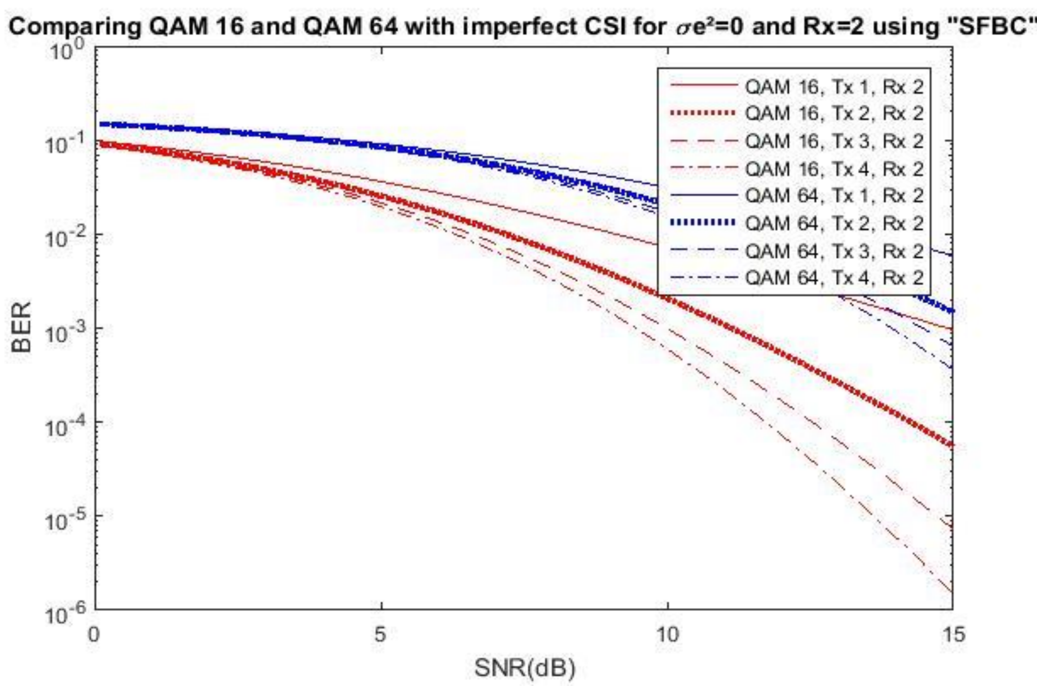

Figure 7.6: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

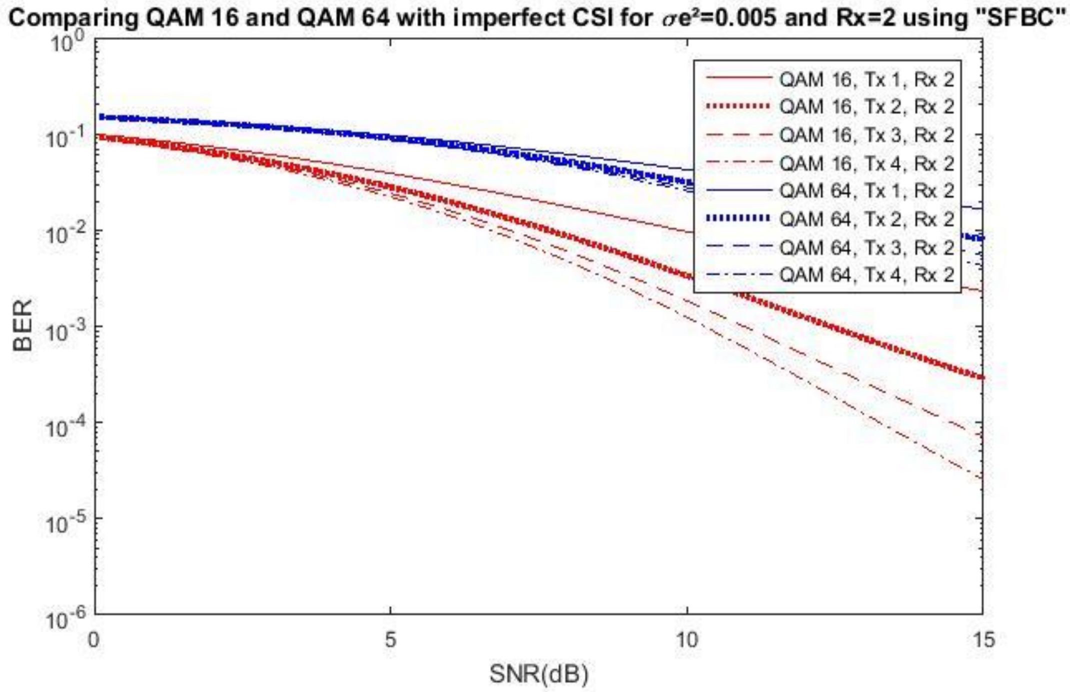

Figure 7.7: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

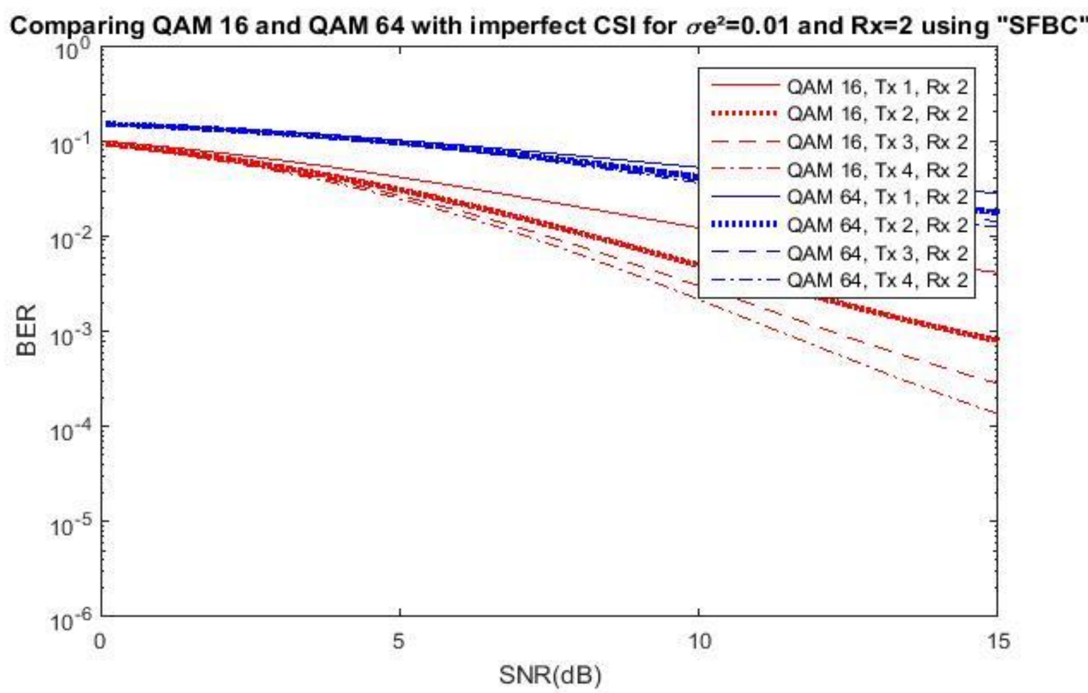

Figure 7.8: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

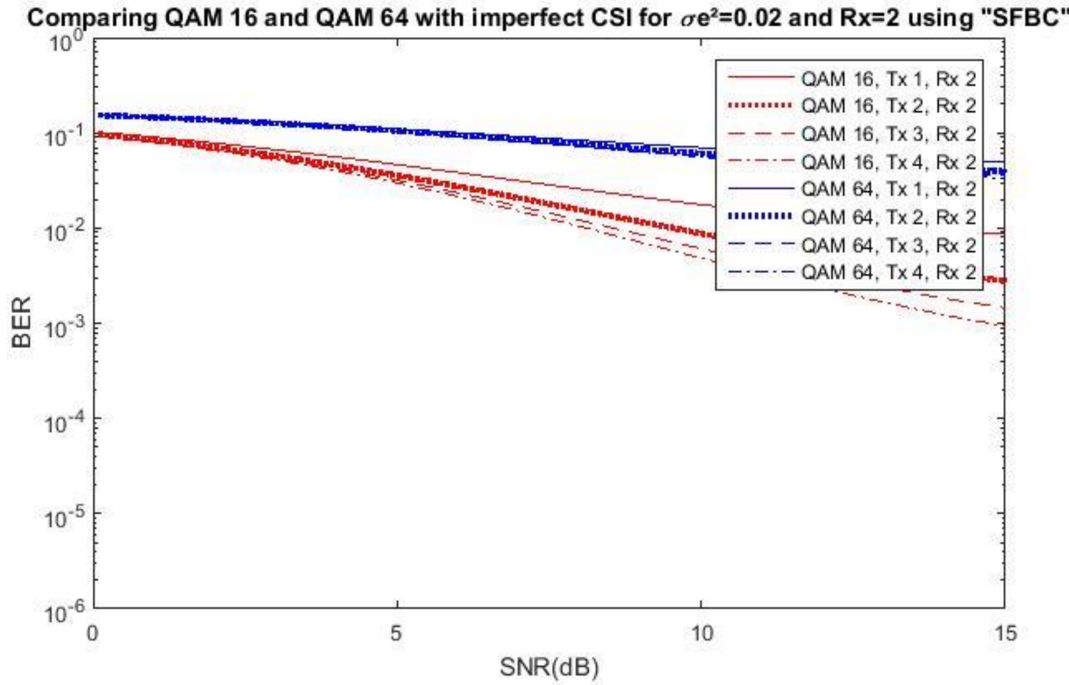

Figure 7.9: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

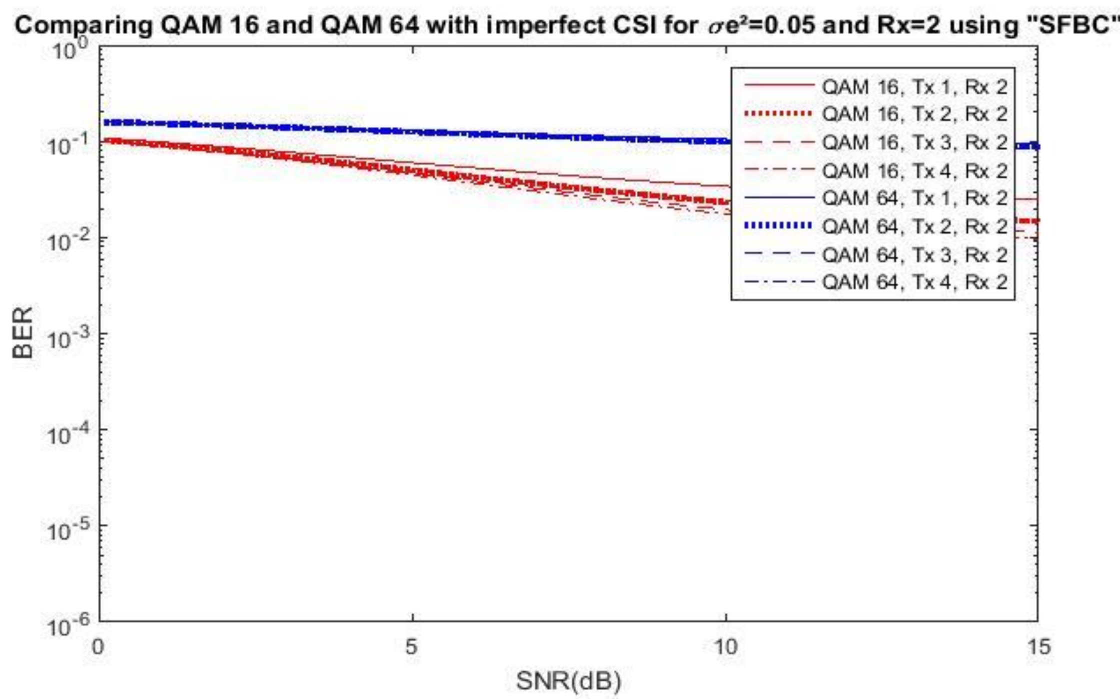

Figure 7.10: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

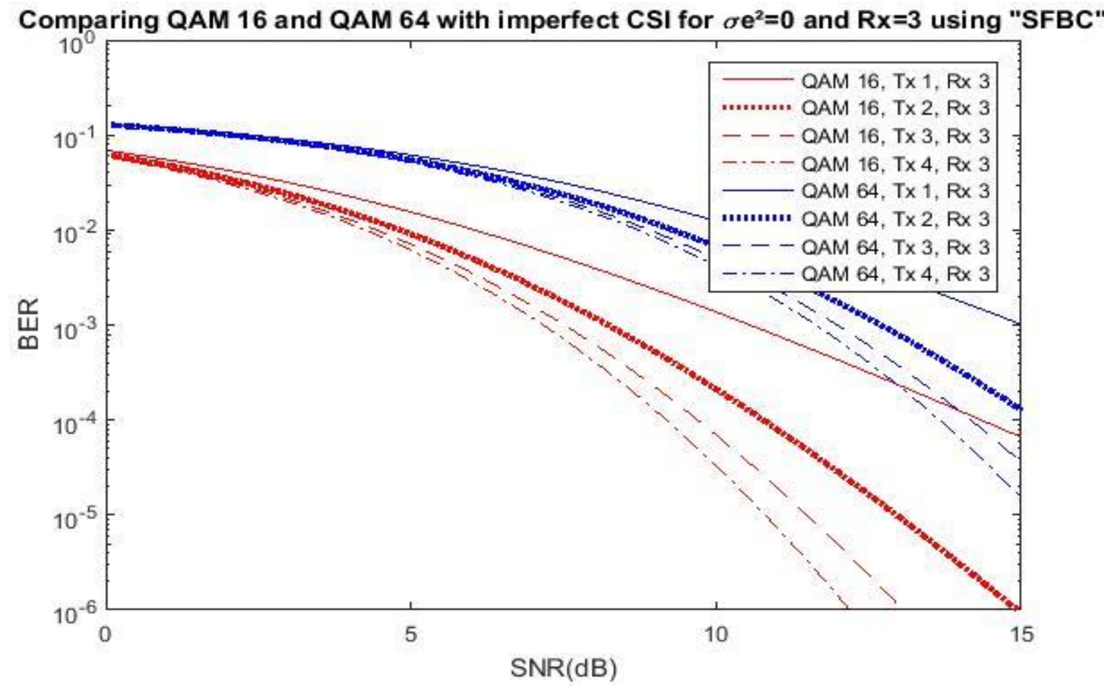

Figure 7.11: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

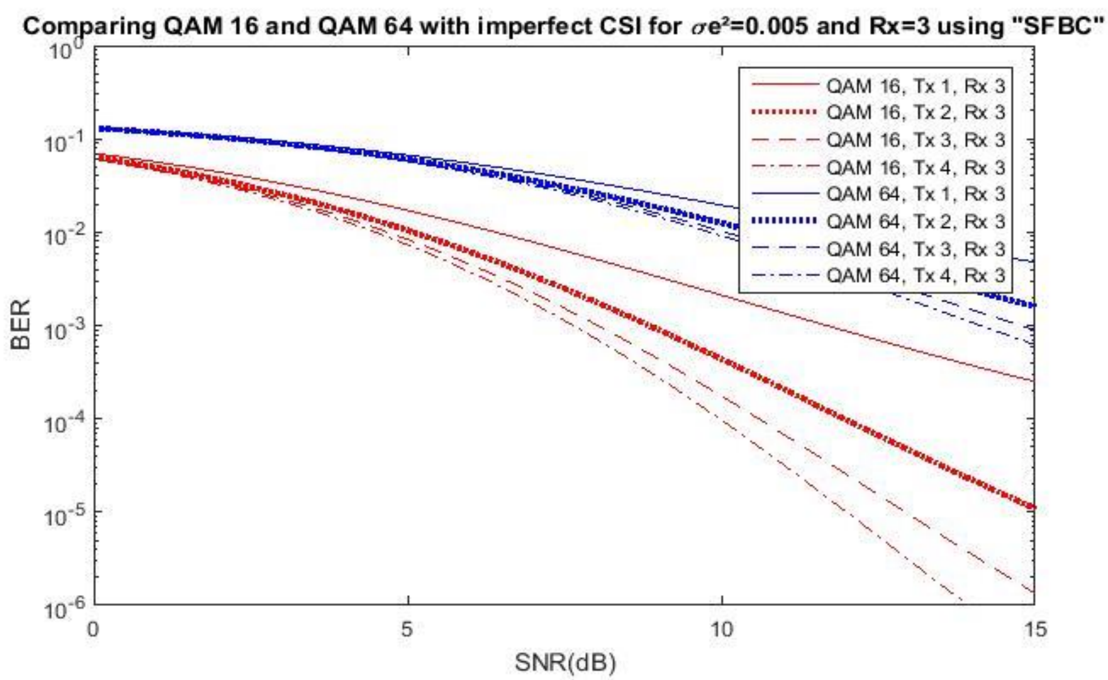

Figure 7.12: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

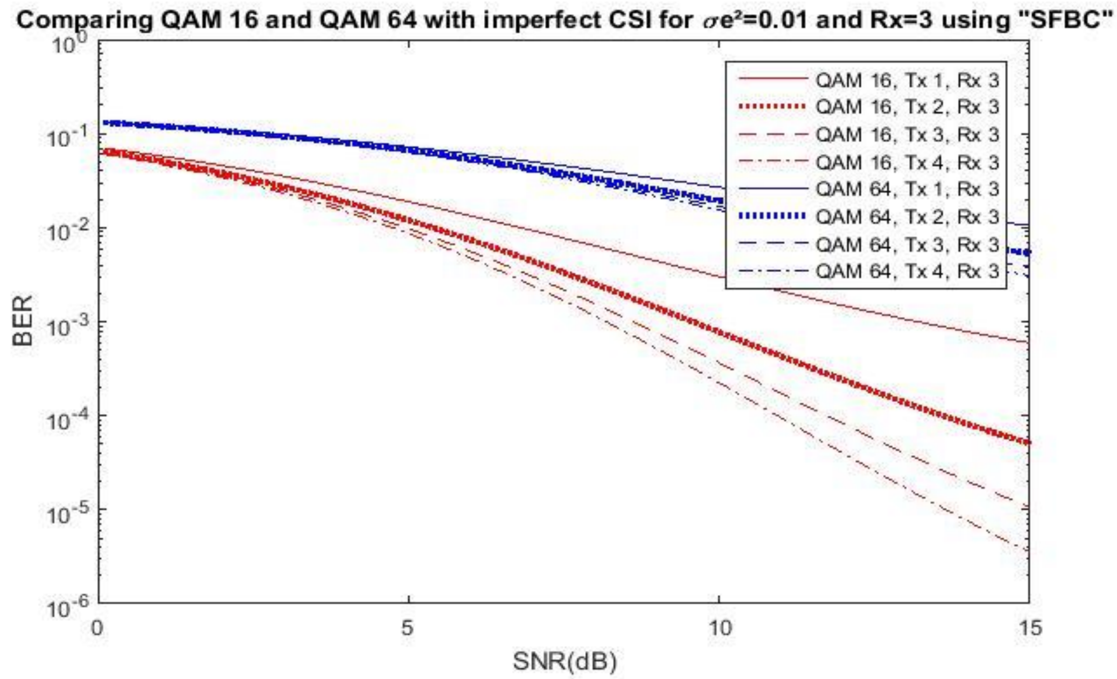

Figure 7.13: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

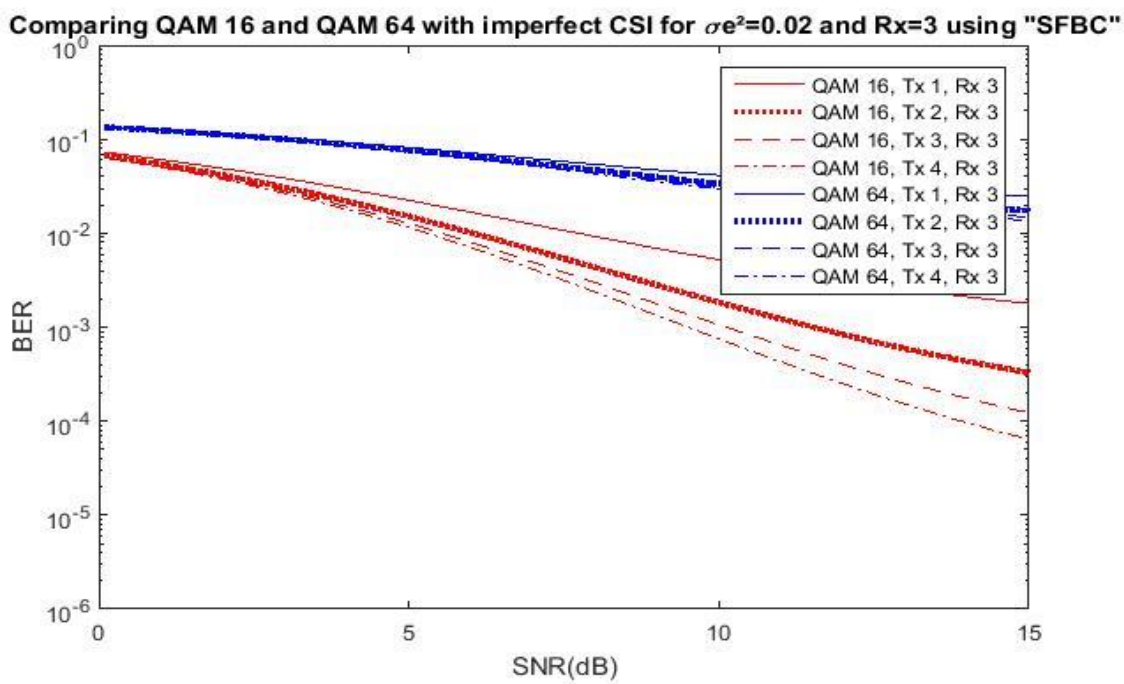

Figure 7.14: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

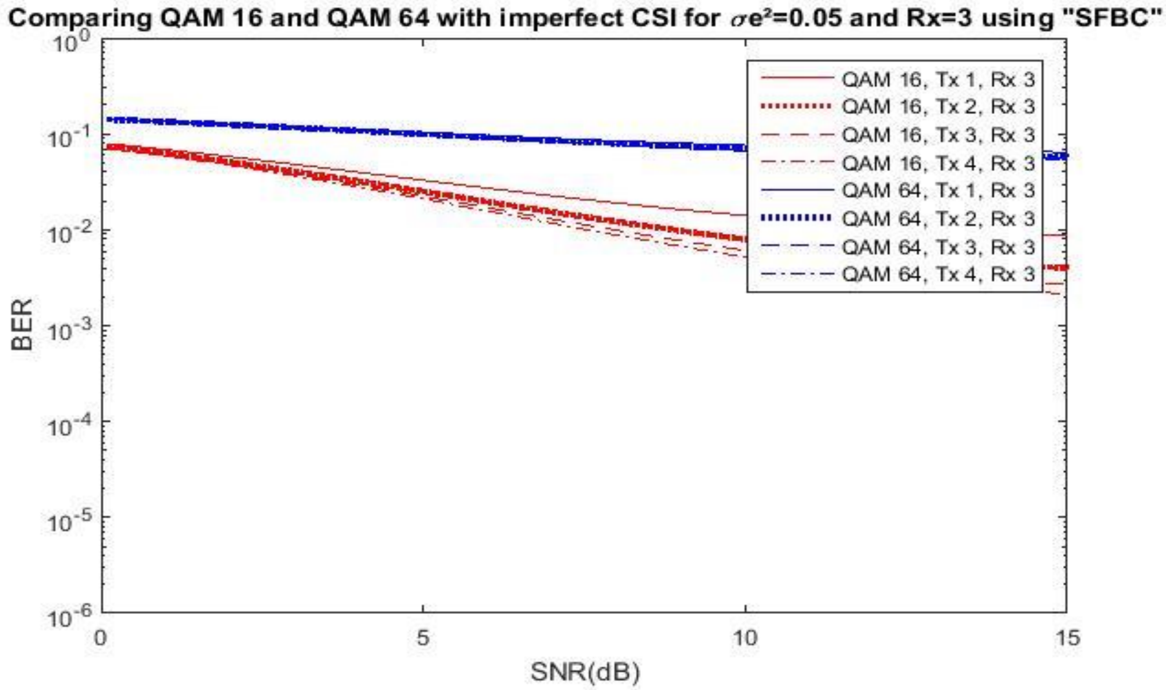

Figure 7.15: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

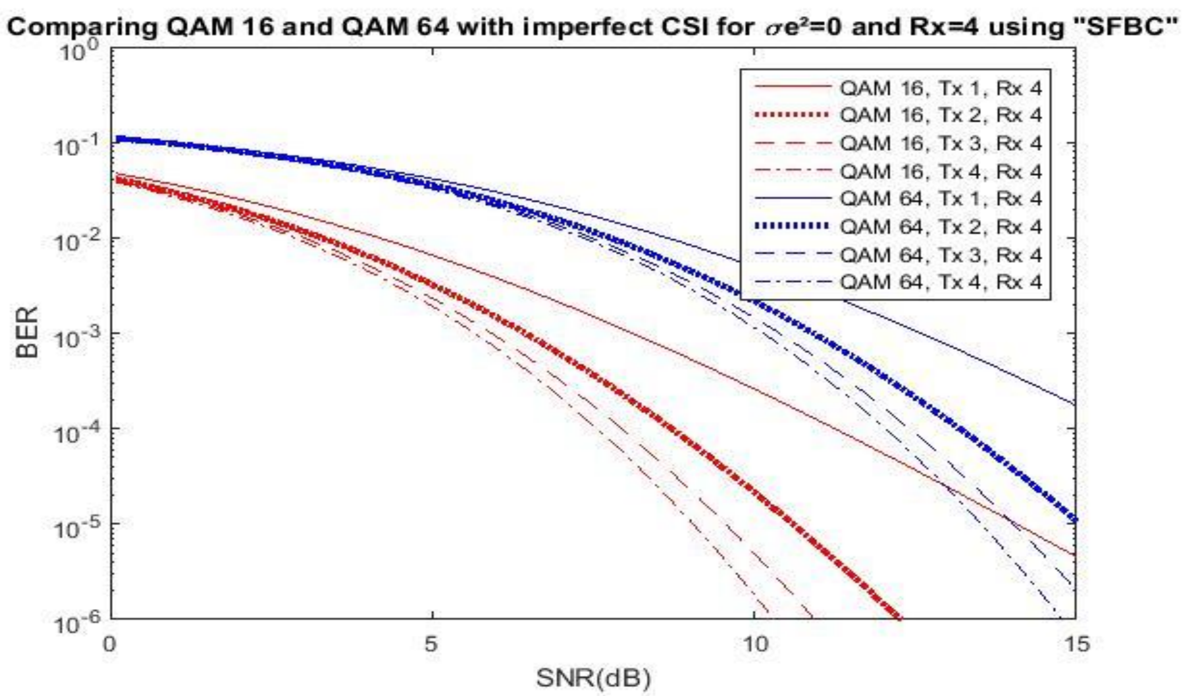

Figure 7.16: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

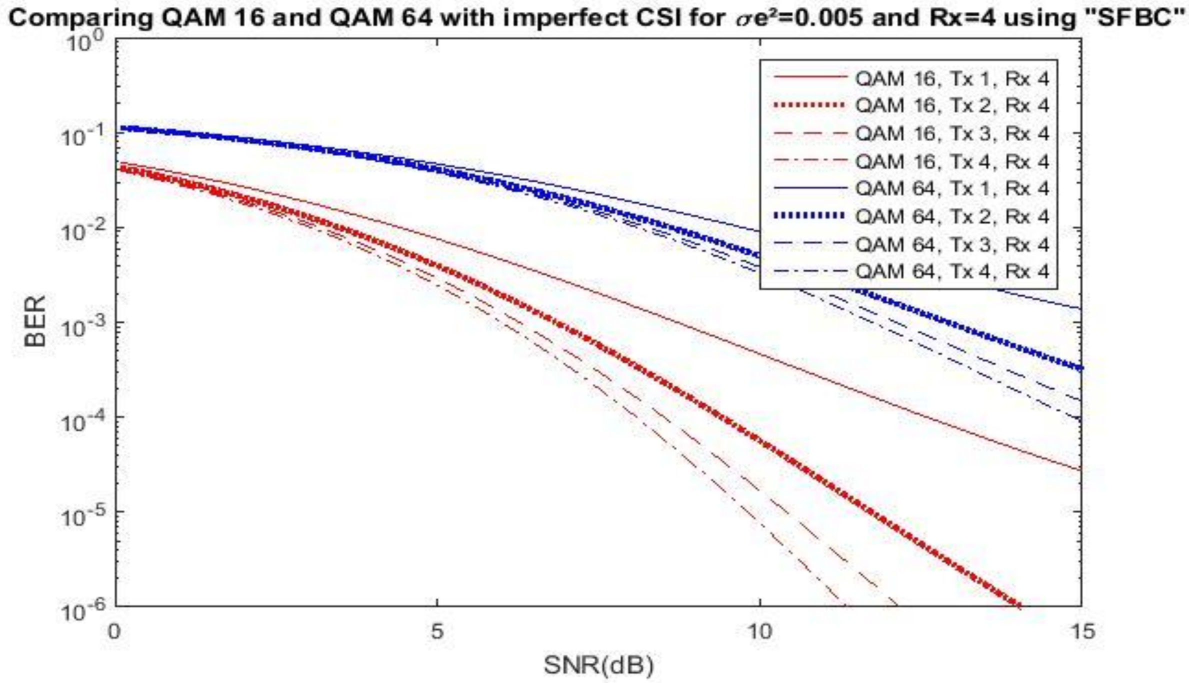

Figure 7.17: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

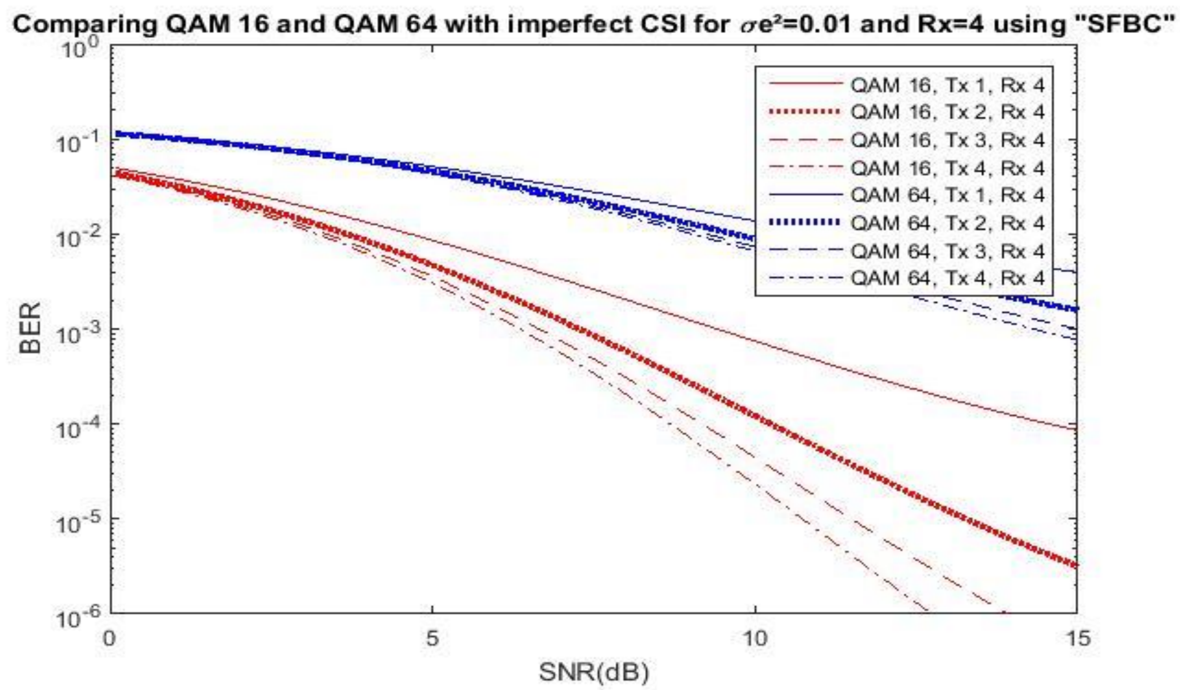

Figure 7.18: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

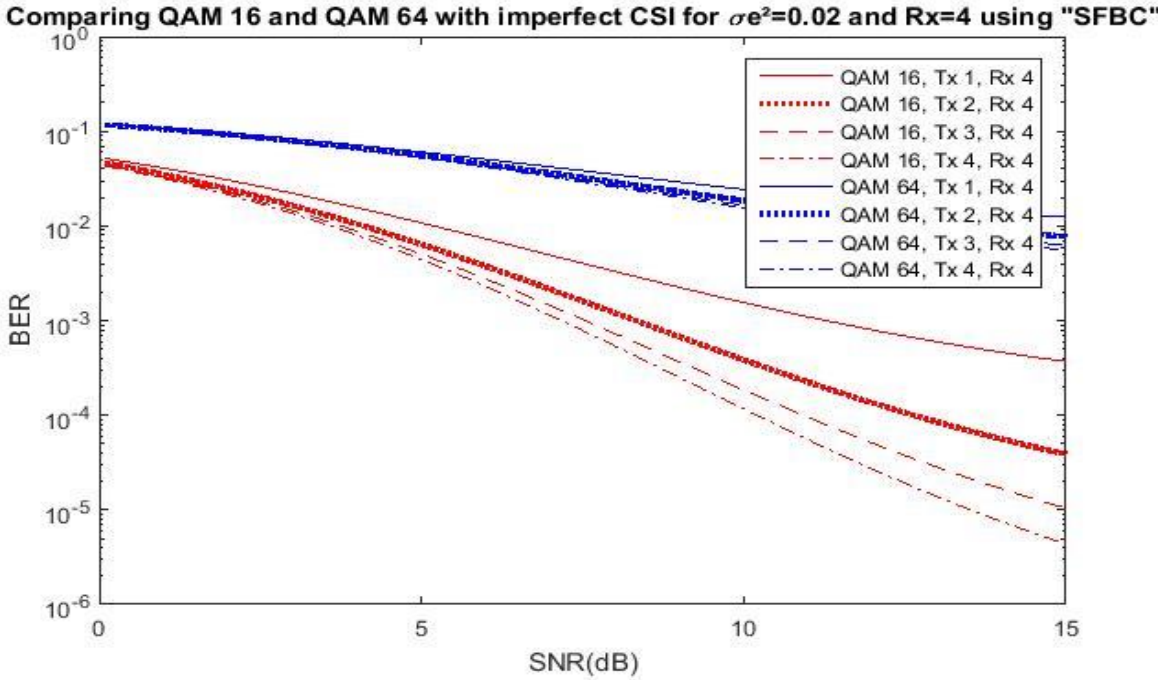

Figure 7.19: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

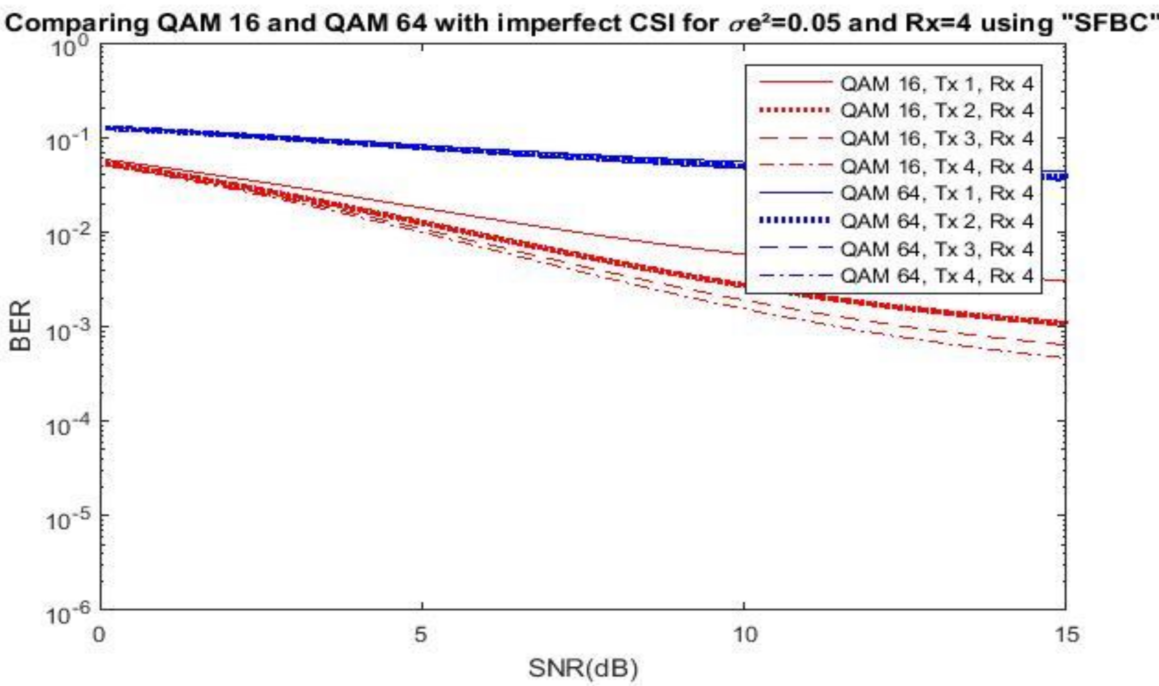

Figure 7.20: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

7.2 Important points to be noticed for M-QAM using SFBC

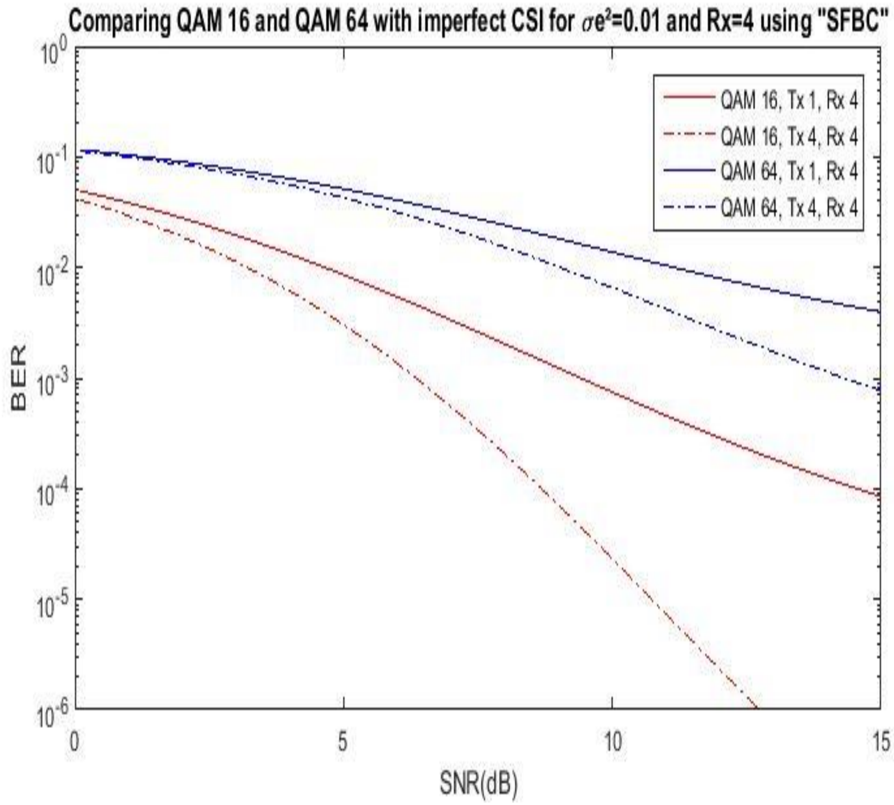

Figure 7.21: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.01, Tx=1 & 4 and Rx=4 using "SFBC"

- As we increase the number of transmitters for a fixed number of receivers, performance becomes better.
- From figure we can see for Tx=1 BER can't be 10^{-6}, but for Tx=4 BER becomes at SNR=12.5 for QAM 16.

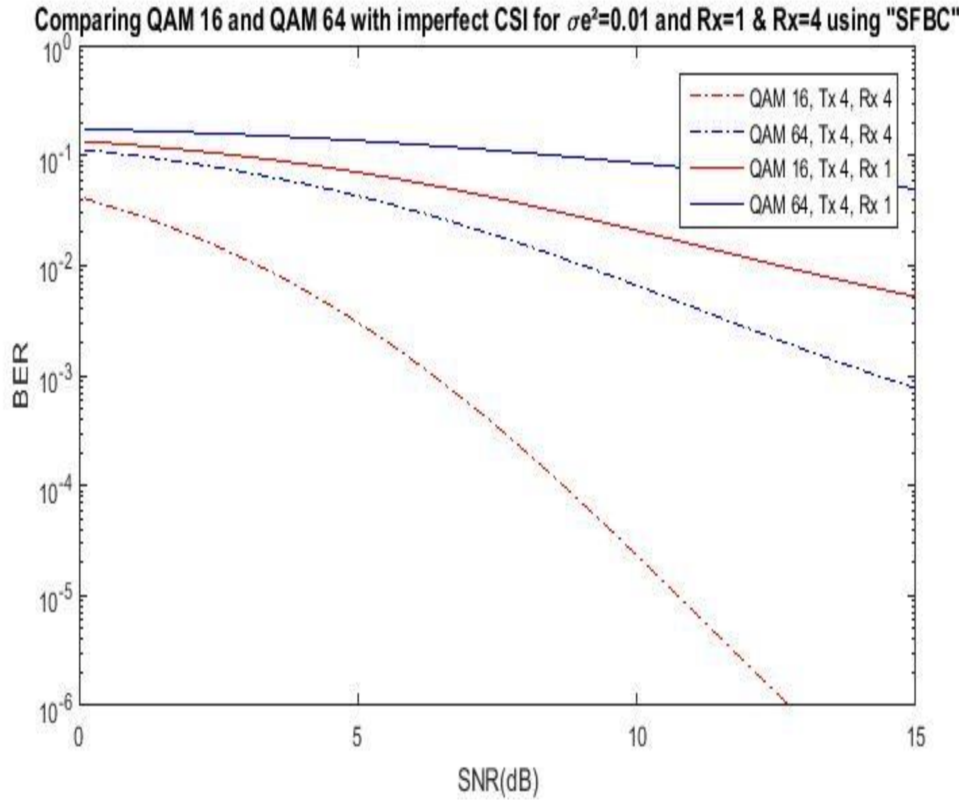

Figure 7.22: Comparing QAM 16 curves with imperfect CSI for σ_e^2=0.01, Tx=3 & 4 and Rx=1 & 4 using "SFBC"

- As we increase the number of receivers for a fixed number of transmitters, performance becomes better.
- From figure we can see for Rx=1 BER can't be 10^{-6}, but for Rx=4 BER becomes at SNR=12.5 for QAM 16.

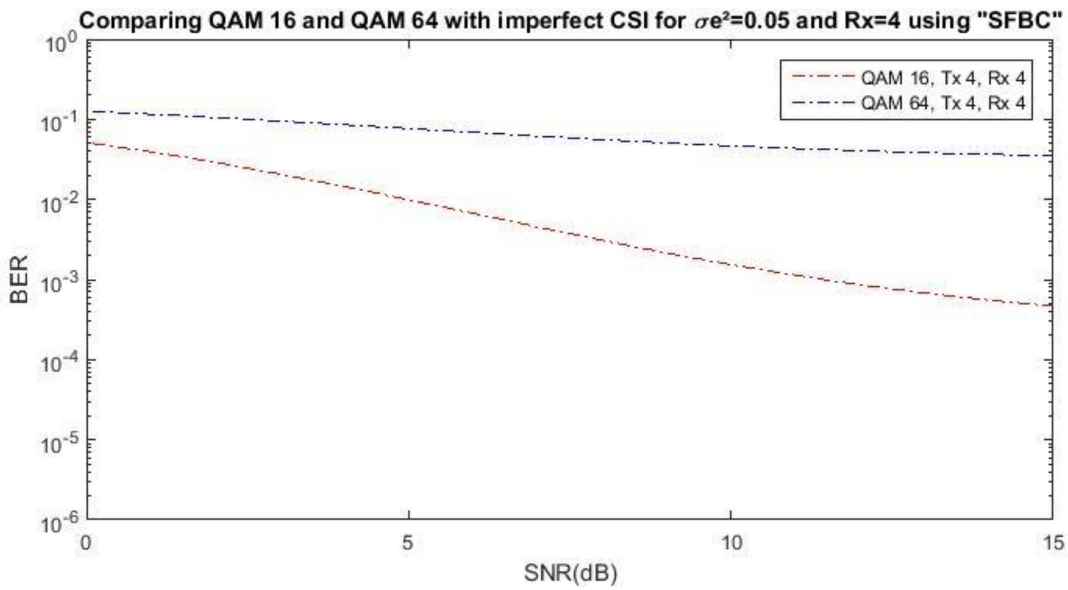

Figure 7.23: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0.05, Tx=4 and Rx=4 using "SFBC"

- Performance is better for QAM 16 than QAM 64.

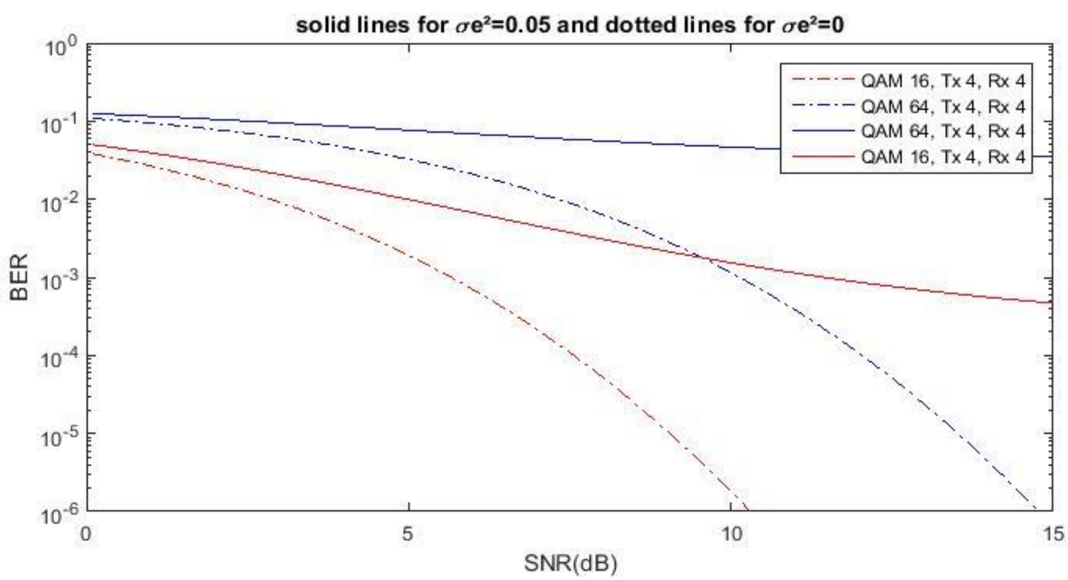

Figure 7.24: Comparing QAM 16 and QAM 64 with imperfect CSI for σ_e^2=0 & σ_e^2=0.05, Tx=4 and Rx=4 using "SFBC"

- Performance is slightly better for lower σ_e^2.
- Increasing σ_e^2 results in worse performance.

7.3 BER vs SNR curves for M-QAM using SFBC

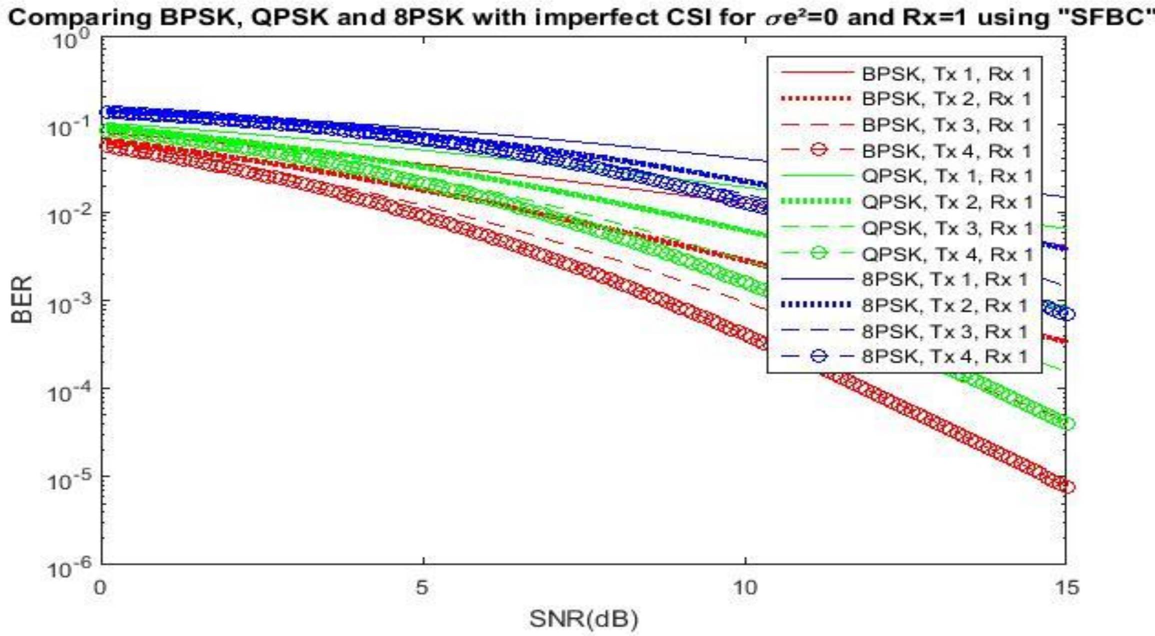

Figure 7.25: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

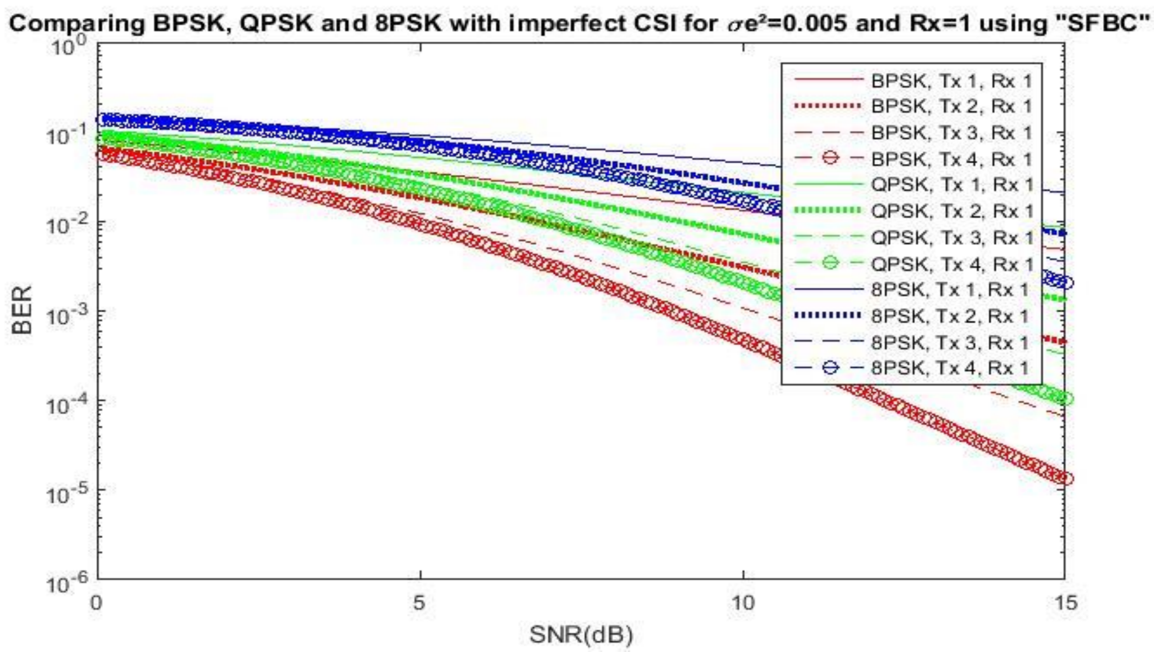

Figure 7.26: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

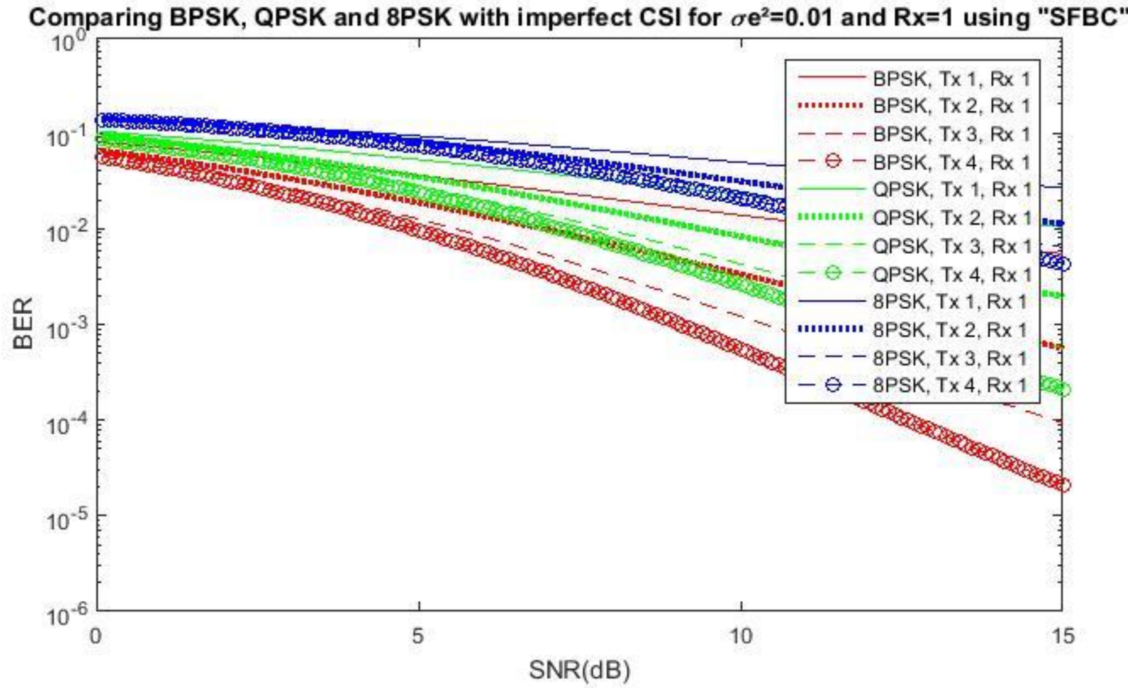

Figure 7.27: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

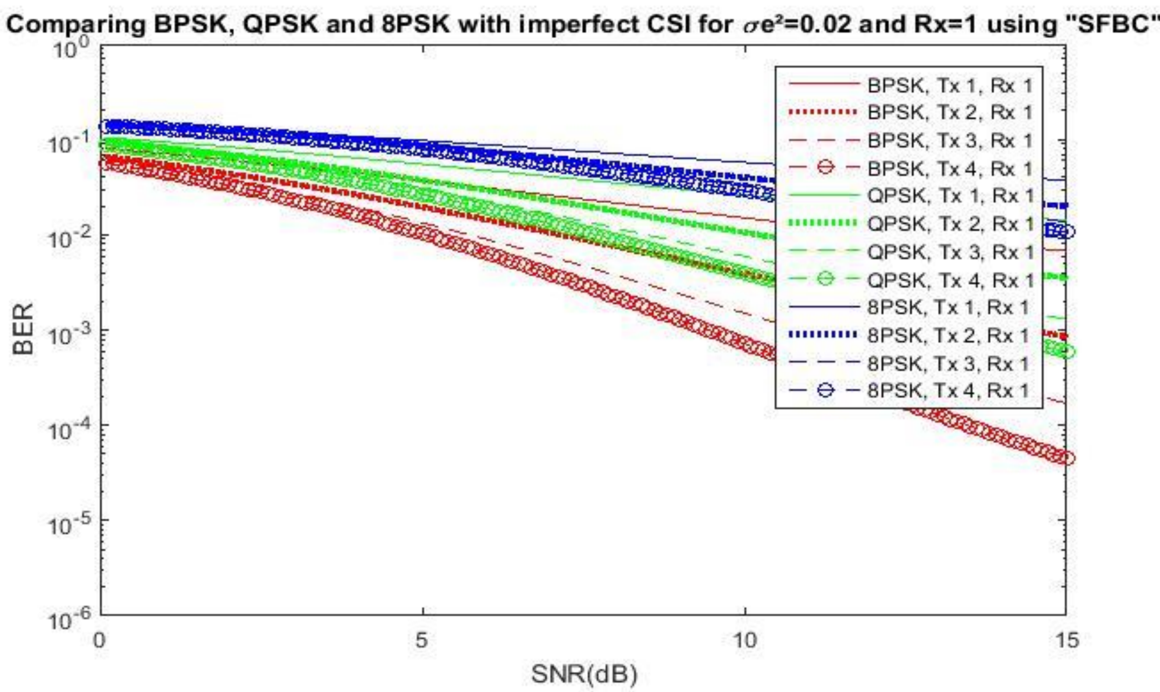

Figure 7.28: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

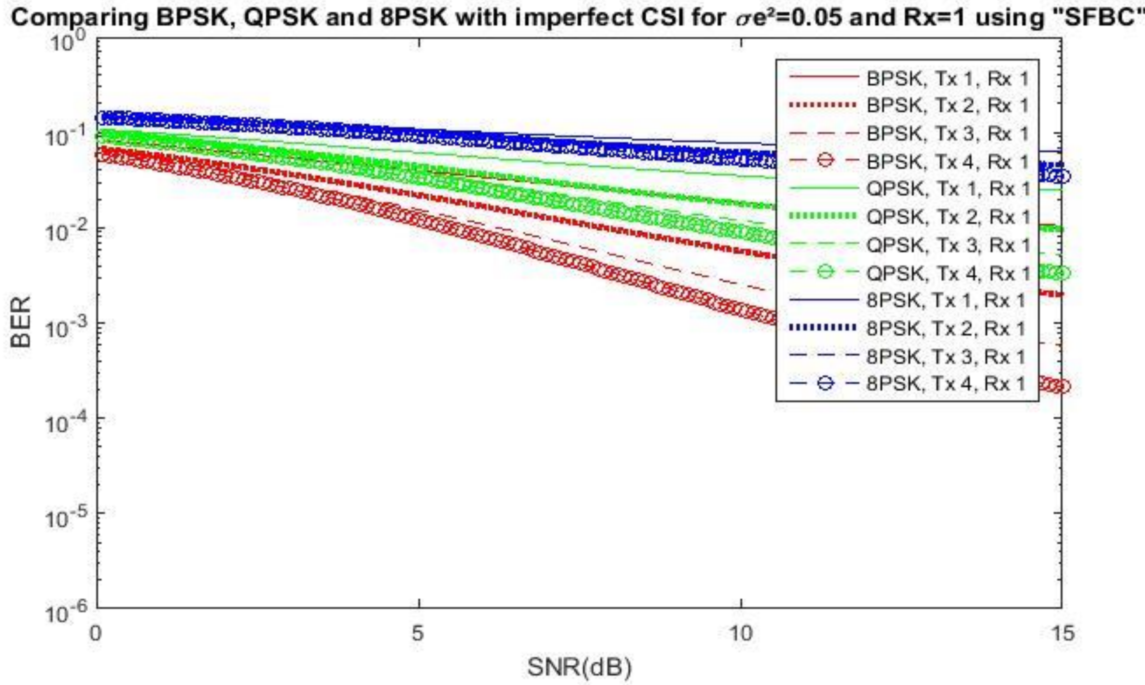

Figure 7.29: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=1 using "SFBC"

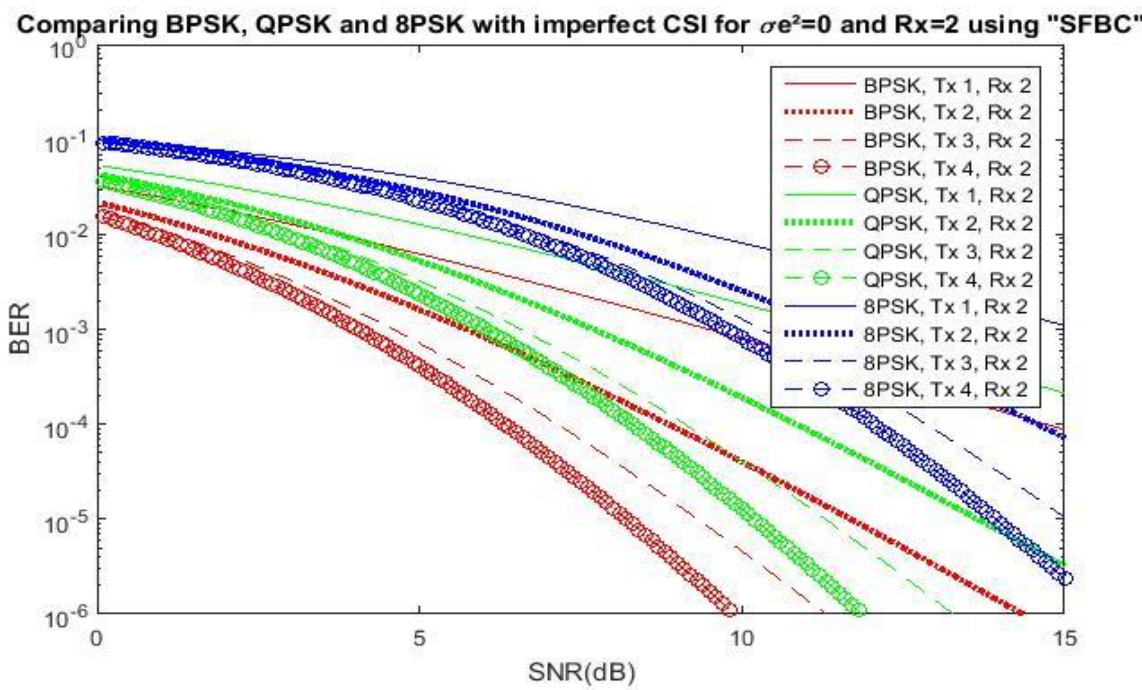

Figure 7.30: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

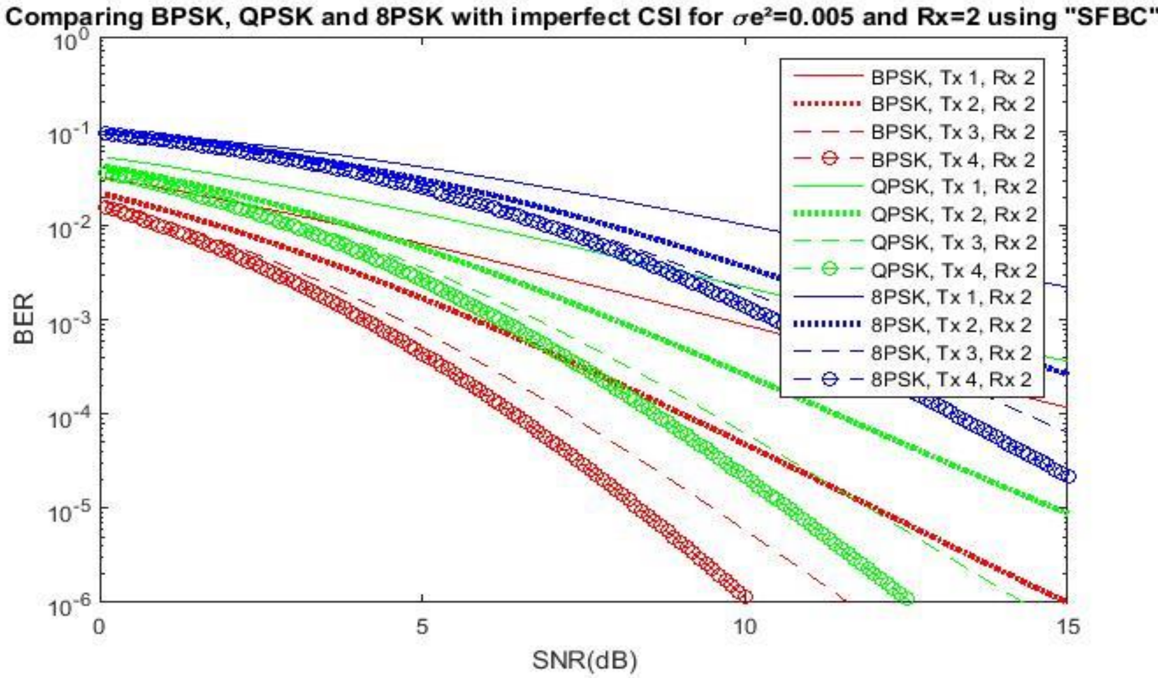

Figure 7.31: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

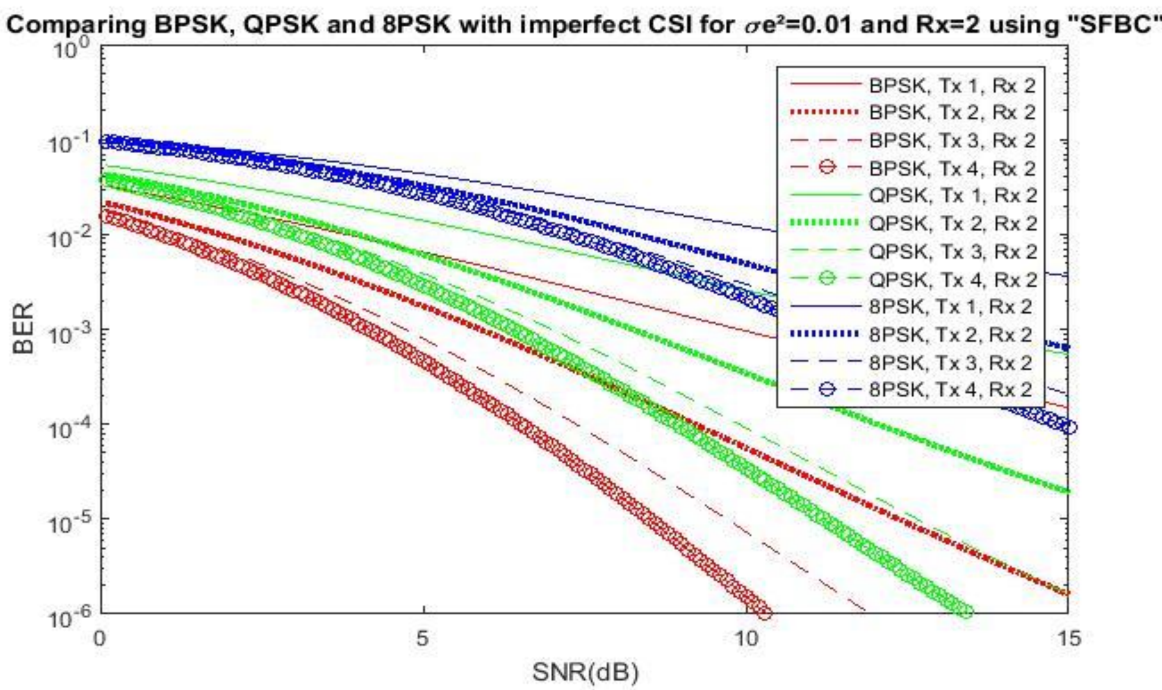

Figure 7.32: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

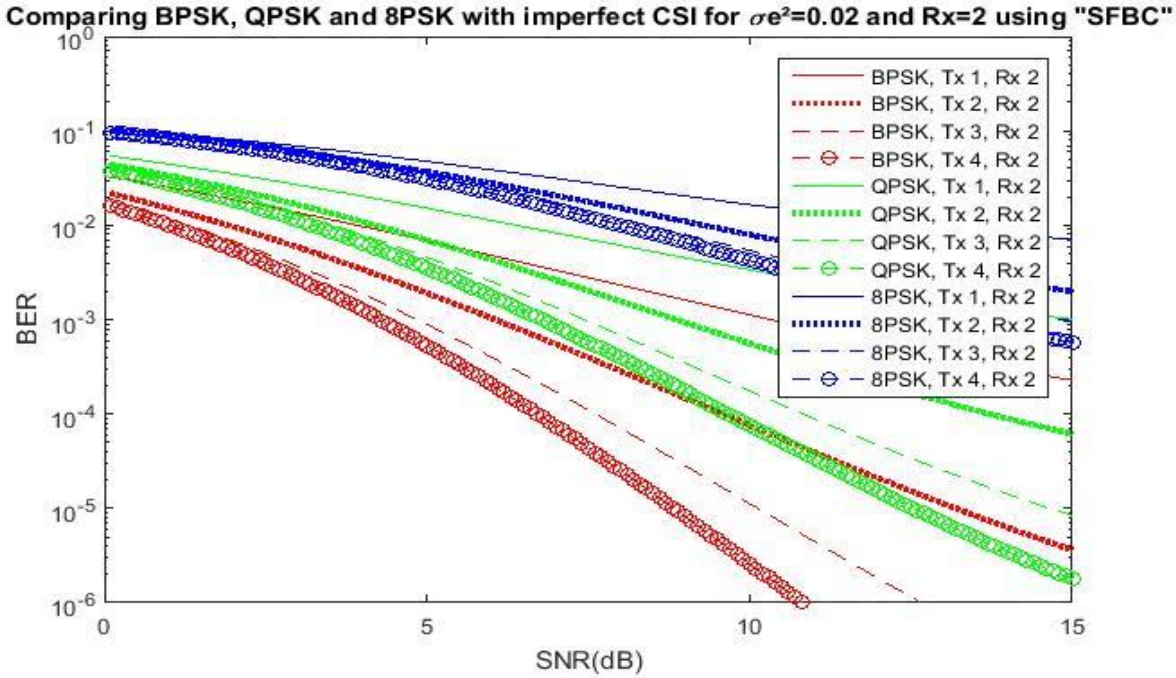

Figure 7.33: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

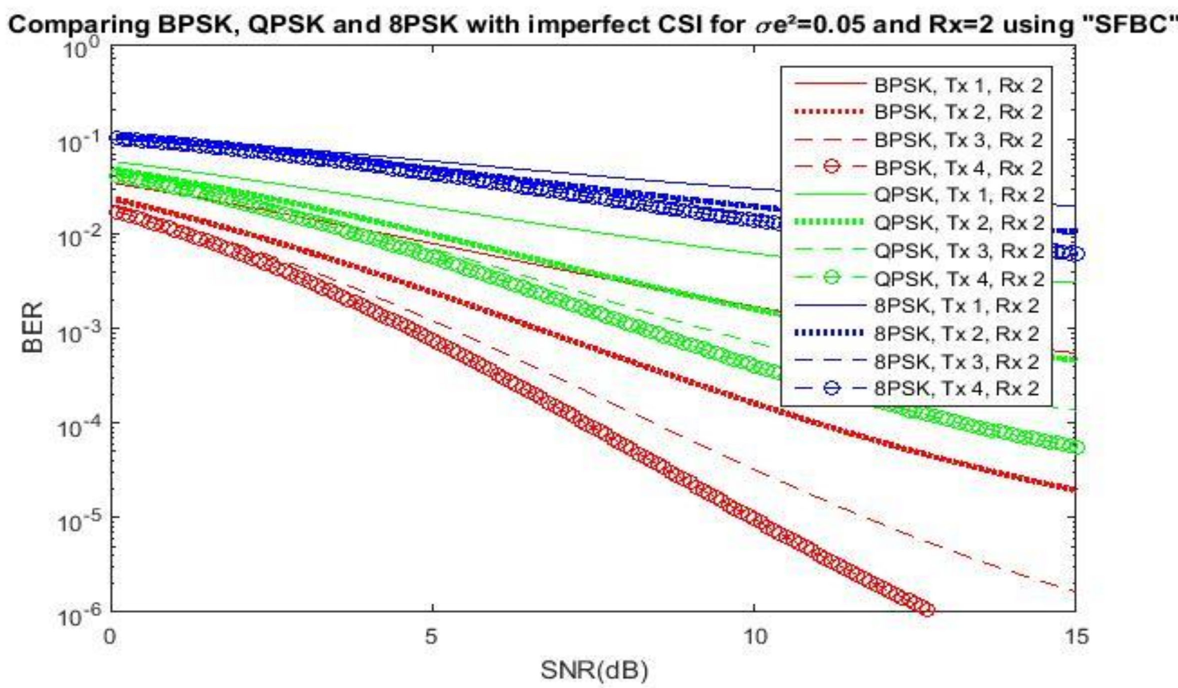

Figure 7.34: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=2 using "SFBC"

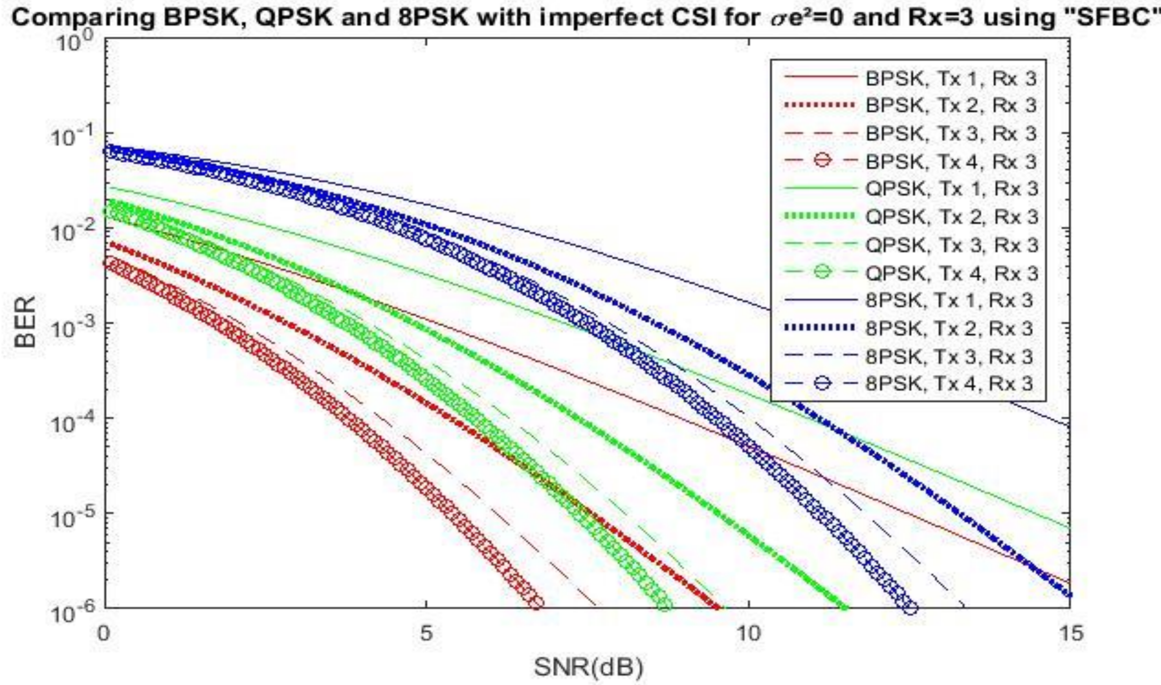

Figure 7.35: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

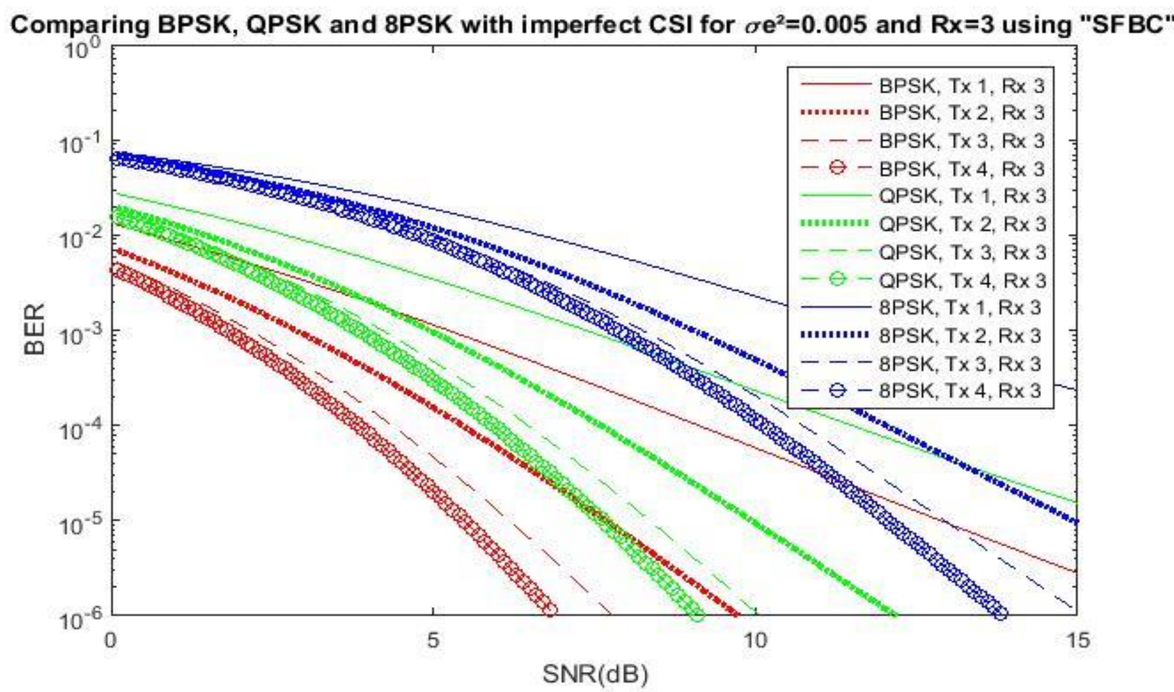

Figure 7.36: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

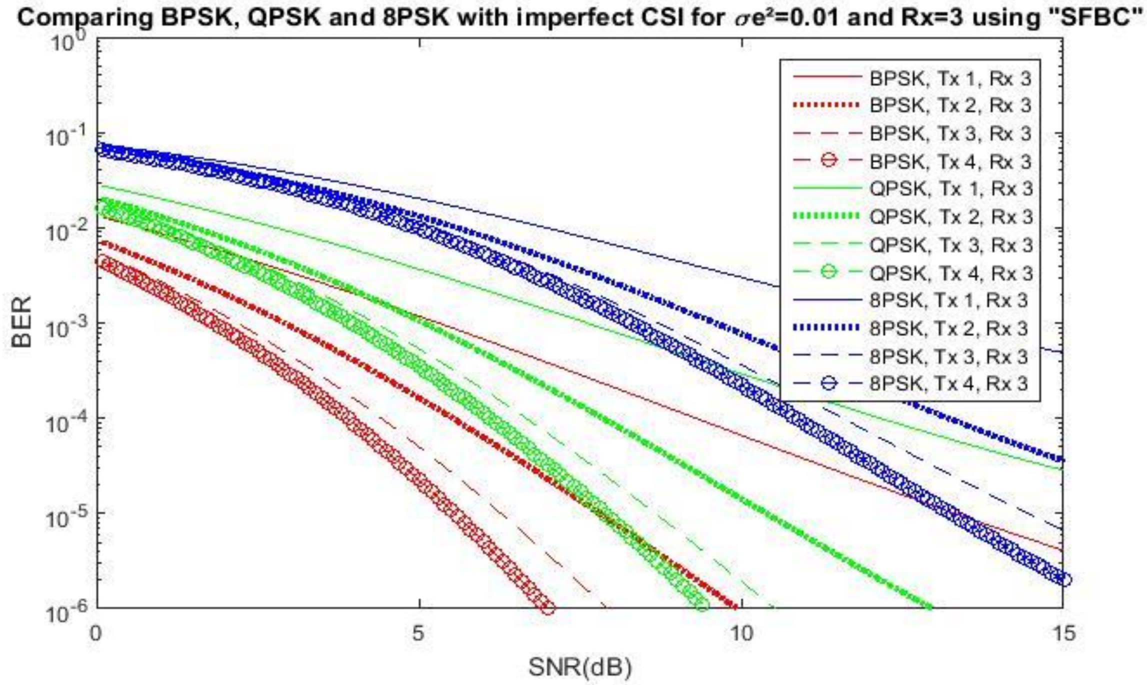

Figure 7.37: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

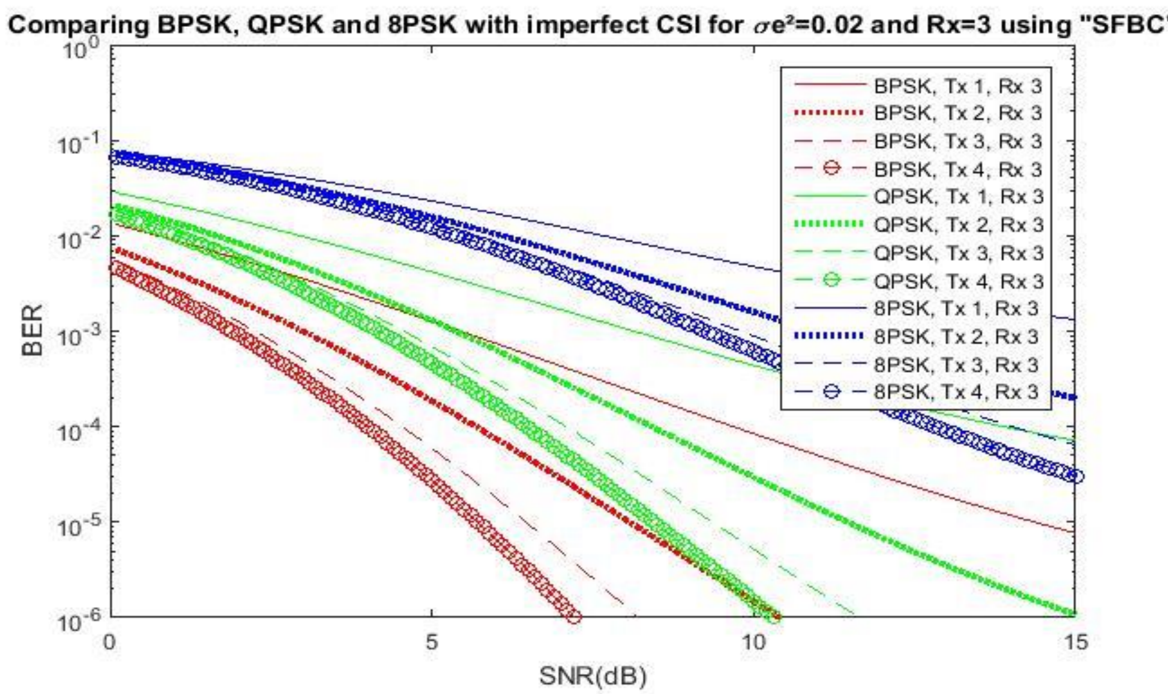

Figure 7.38: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

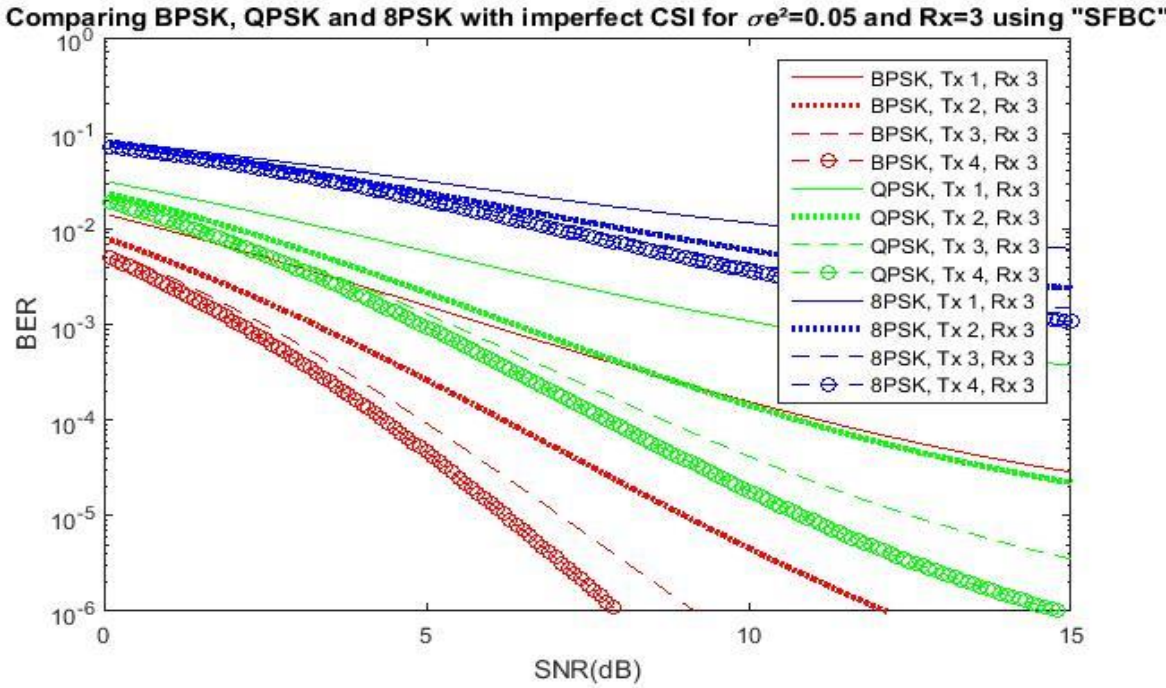

Figure 7.39: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=3 using "SFBC"

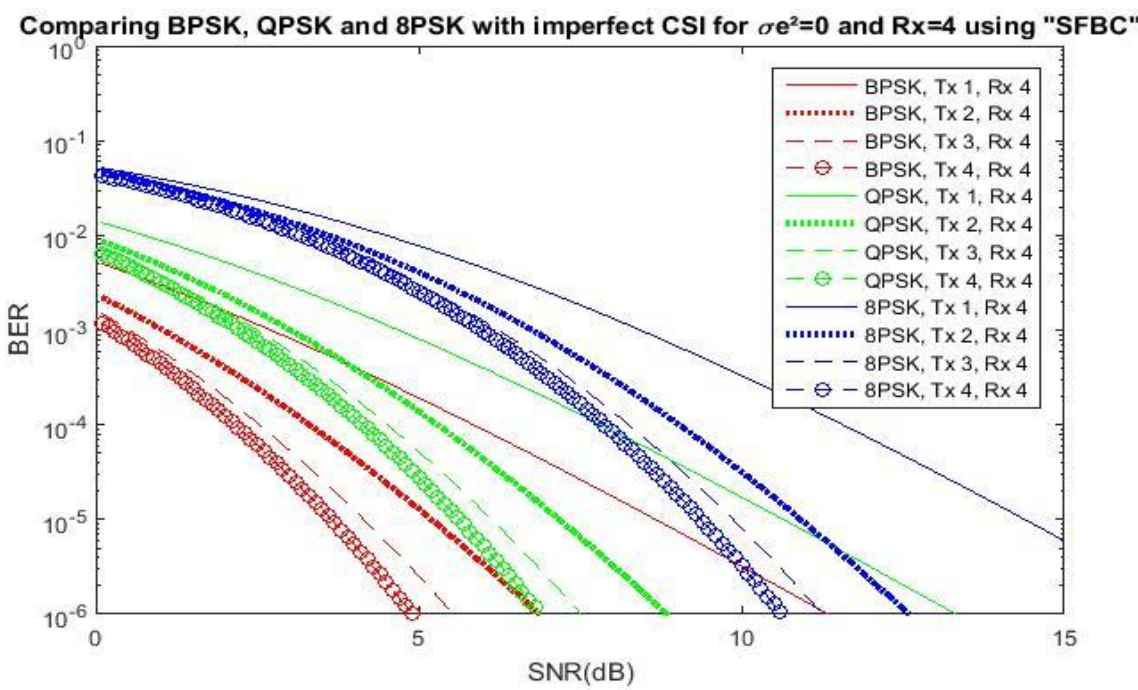

Figure 7.40: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

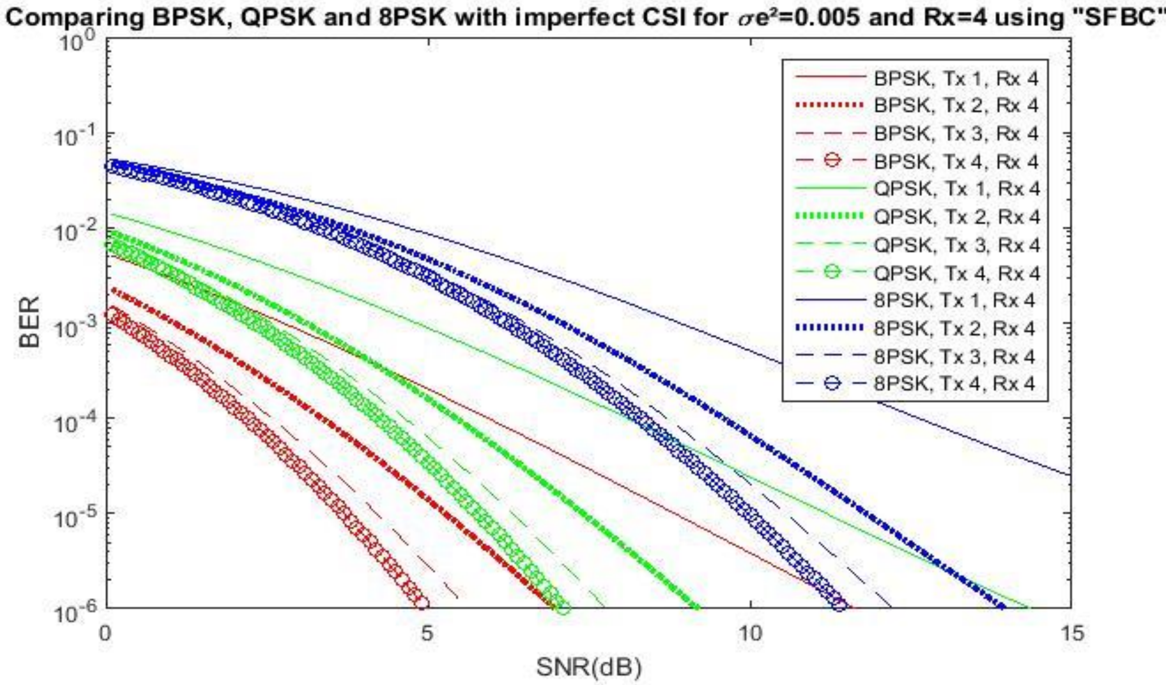

Figure 7.41: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.005, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

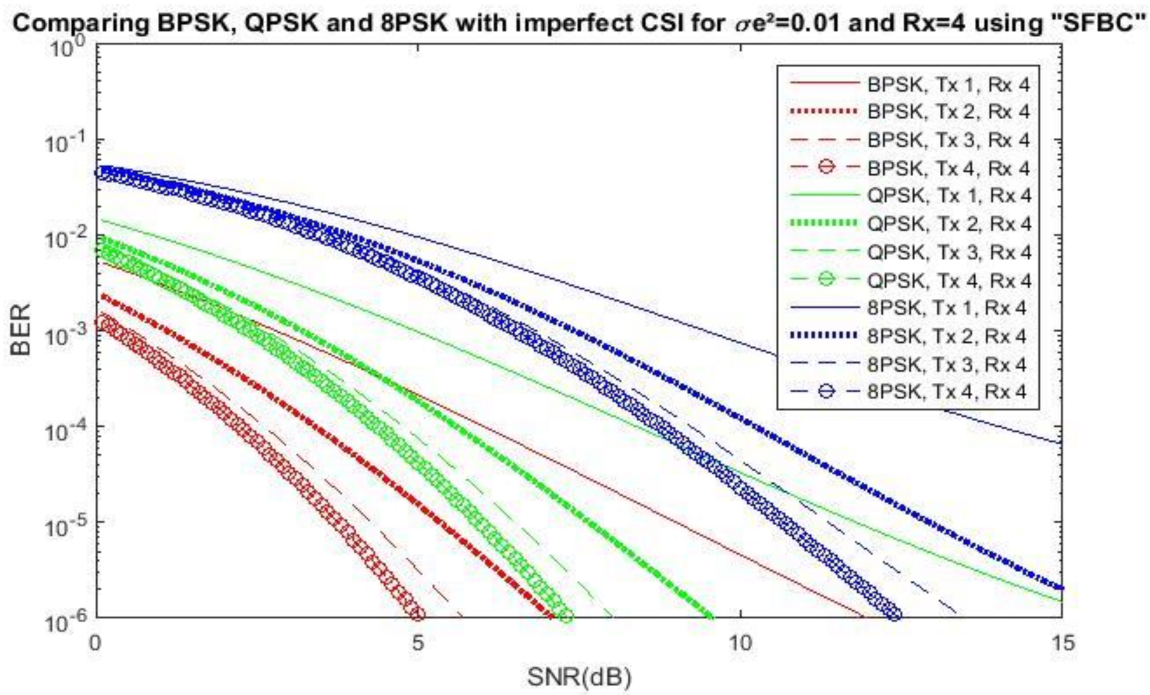

Figure 7.42: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.01, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

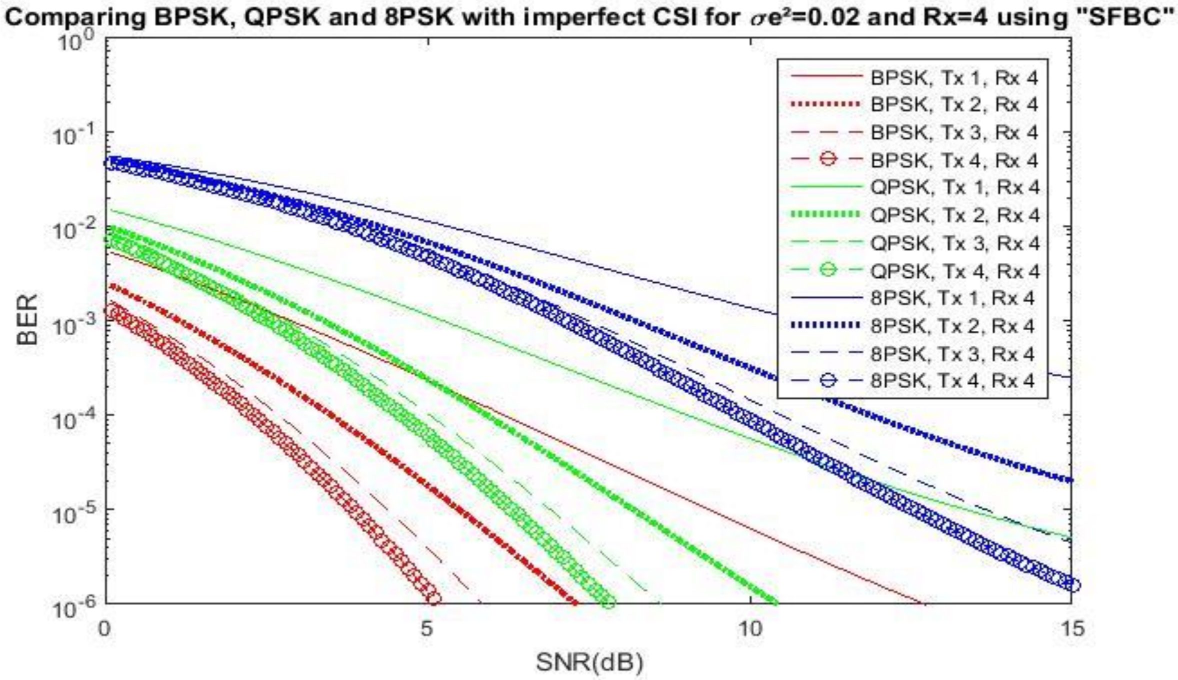

Figure 7.43: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.02, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

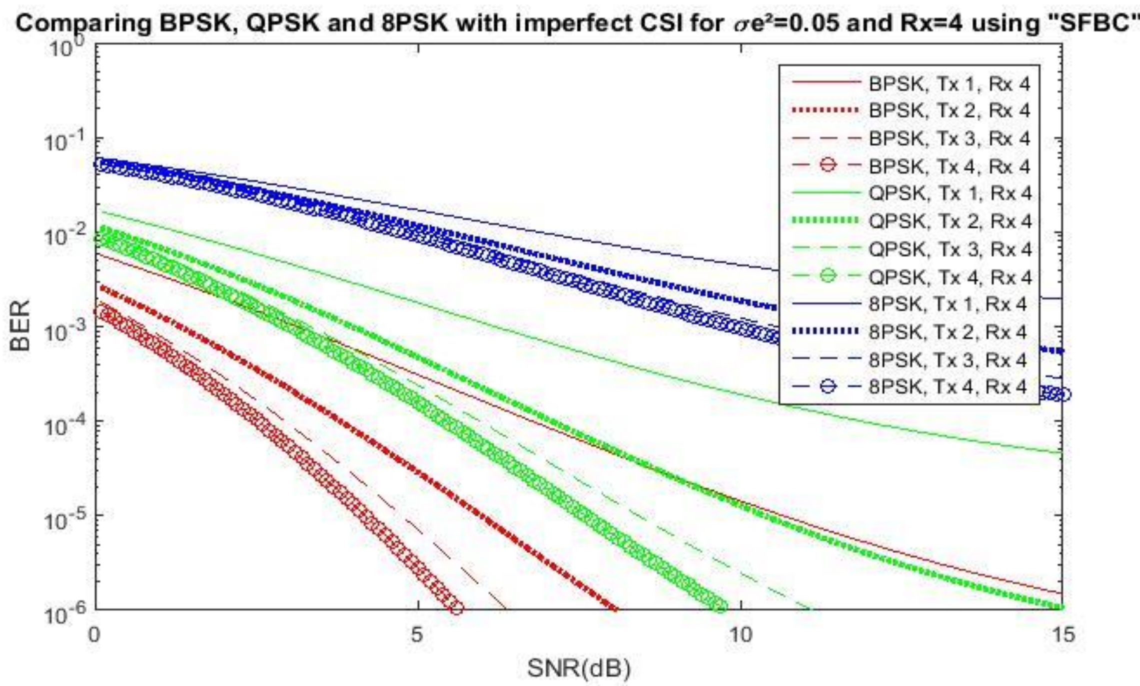

Figure 7.44: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.05, Tx=1, 2, 3 & 4 and Rx=4 using "SFBC"

7.4 Important points to be noticed for M-PSK using SFBC

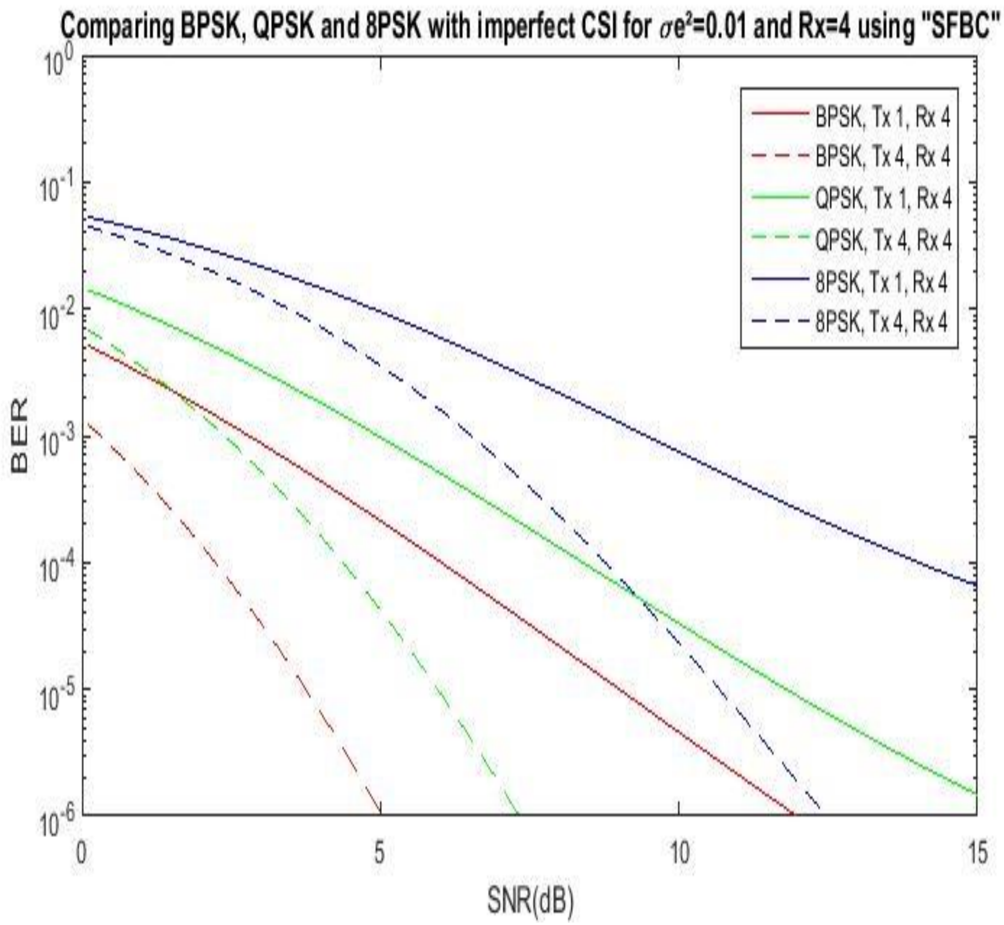

Figure 7.45: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.01, Tx=1 & 4 and Rx=4 using "SFBC"

- As we increase the number of transmitters for a fixed number of receivers, performance becomes better.
- BPSK gives best performance.
- From figure we can see for Tx=4, BER reaches 10^{-6} for lower SNR than for Tx=1.
- BER for BPSK reaches 10^{-6} faster than the other two.

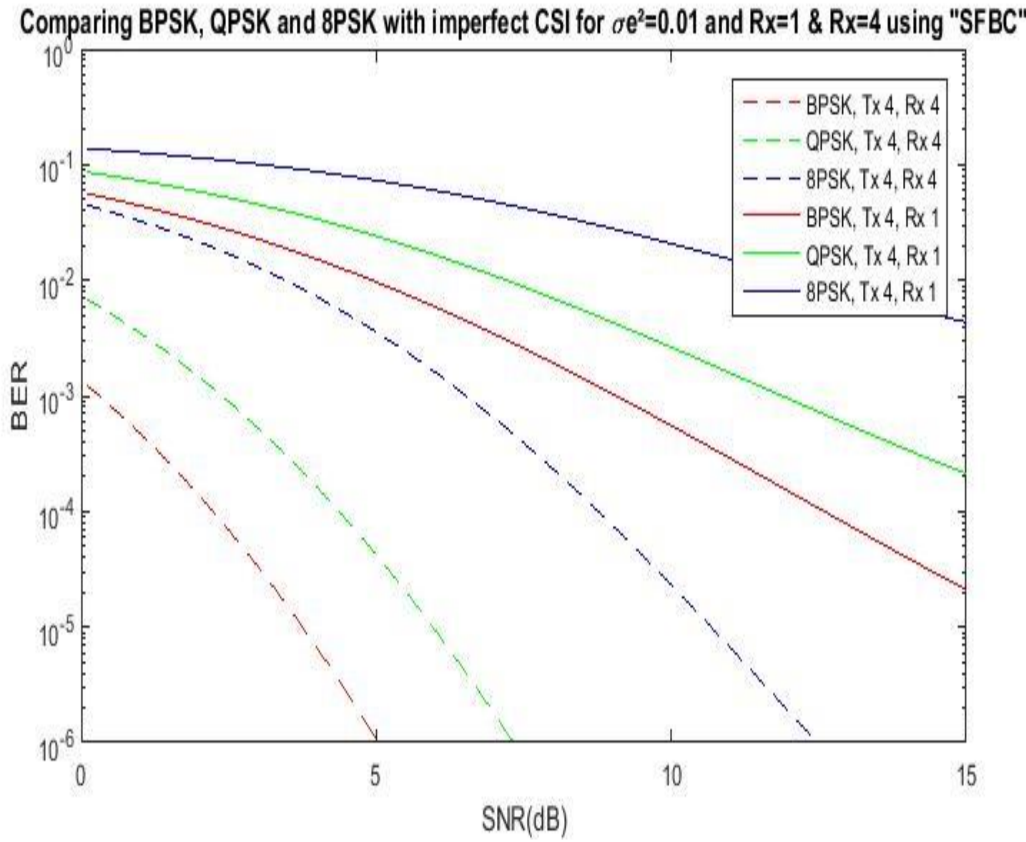

Figure 7.46: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.01, Tx=4 and Rx=1 & 4 using "SFBC"

- As we increase the number of receivers for a fixed number of transmitters, performance becomes better.
- BPSK gives better performances.
- From figure we can see for Rx=4, BER reaches 10^{-6} for lower SNR than for Rx=1.
- BPSK reaches to 10^{-6} for lowest SNR.

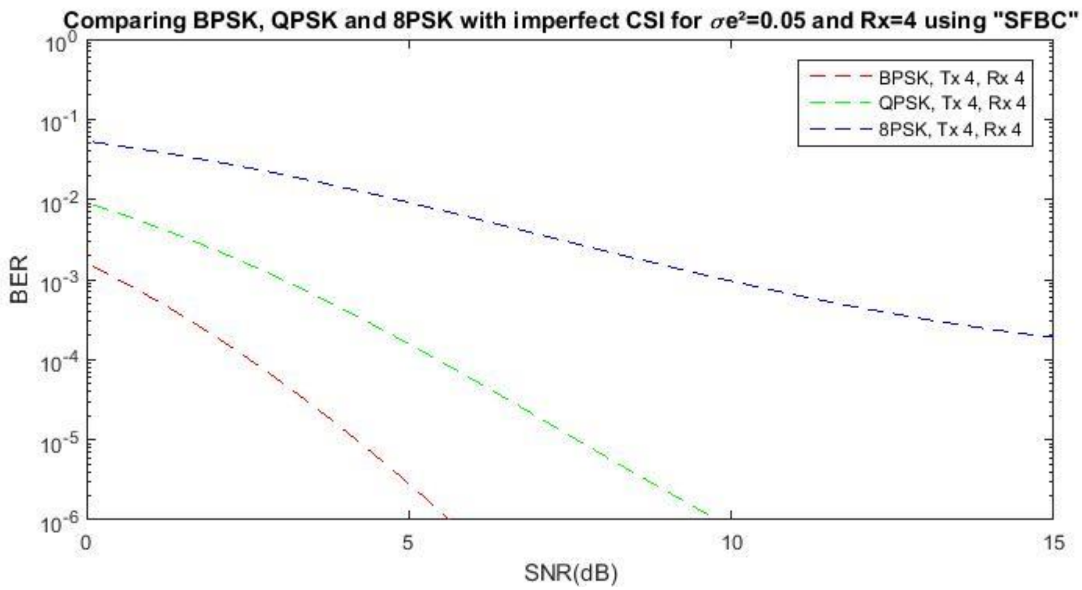

Figure 7.47: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0.05, Tx=4 and Rx=4 using "SFBC"

- Performance is best for BPSK, better for QPSK and then 8PSK.

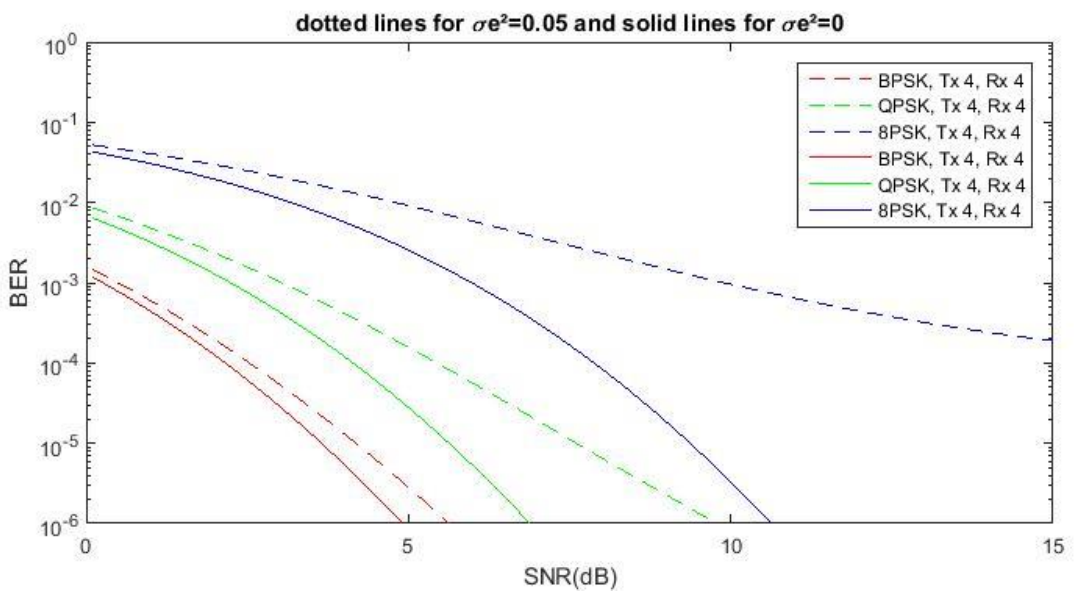

Figure 7.48: Comparing BPSK, QPSK and 8PSK with imperfect CSI for σ_e^2=0 & σ_e^2=0.05, Tx=4 and Rx=4 using "SFBC"

- Performance is slightly better for BPSK than the other two for both higher and lower σ_e^2.
- Increasing σ_e^2 results in worse performance.

CHAPTER 8

CONCLUSION

From our research, we have found that BPSK with 4 transmit and 4 receive antennae gives the best performance for both perfect and imperfect CSI. For imperfect CSI, the lesser the value of σ_e^2, better the performance we get. Using 3 receivers instead of 4 can be the best option because performance is almost similar but the cost can be reduced.

We have done our research works considering static channels. We haven't considered the effect of Doppler shift. So we can observe the effect of Doppler shift by using the dynamic channel. We have used Rayleigh fading type channel for our experimental purposes. We can see the effects for other types like Nakagami fading channel. We can also observe the effect of Space Time-Frequency Block Coding (STFBC) by combining Space-Time Block Coding and Space Frequency Block Coding.

So, if make the list of future works and preferred modifications, they are:

- We can use Nakagami Fading Channel instead of Rayleigh Fading Channel.
- We have worked on Static Channel. We can also work on Dynamic Channel.
- We can also analyze combining both STBC and SFBC, which is known as STFBC (Space Time Frequency Block Coding).

REFERENCES

[1] Fabien Delestre, “Channel Estimation and Performance Analysis of MIMO-OFDM Communications using Space-Time and Space-Frequency Coding Schemes” Ph.D. Thesis, University of Hertfordshire, United Kingdom 2011. [pp.10-11; p. 17; pp. 48-50; pp. 53-54; pp. 56-59]

[2] https://en.wikipedia.org/wiki/MIMO **;** accessed on 4th December, 2017

[3] http://www.radio-electronics.com/info/antennas/mimo/multiple-input-multiple-output-technology-tutorial.php ; accessed on 23th January, 2018

[4] http://www.radio-electronics.com/info/rf-technology-design/ofdm/ofdm-basics-tutorial.php ; accessed on 20th January, 2018

[5] https://blog.taitradio.com/2015/09/23/9-channel-concepts-every-system-designer-needs-to-understand/ ; accessed on 12th February, 2018

[6] http://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/lte-mimo.php ; accessed on 26th December, 2017

[7] https://www.gaussianwaves.com/2014/08/mimo-diversity-and-spatial-multiplexing/ ; accessed on 1st February, 2018

[8] http://www.ni.com/white-paper/3740/en/ ; accessed on 9th February, 2018

[9] https://www.slideshare.net/nimay1/mimo-ofdm-for-4-g-network ; accessed on 2nd March, 2018

[10] https://www.youtube.com/watch?v=hIl4ZQb-A70 ; accessed on 3rd January, 2018

[11] Publik.tuwien.ac.at, 2018. [Online].

Available: https://publik.tuwien.ac.at/files/pub-et_10819.pdf

pp. 15, [Accessed: 22- Aug- 2017].

[12] “A Novel Alamouti STBC Technique for MIMO System Using 16- QAM Modulation and Moving Average Filter", *Academia.edu*, 2018. [Online].

Available:http://www.academia.edu/8357256/A_Novel_Alamouti_STBC_Technique_for_MIMO_System_Using_16-_QAM_Modulation_and_Moving_Average_Filter

[Accessed: 27- Oct- 2017].

[13] “Space-Time Block Coding (STBC) for Wireless Networks", *International Journal of Distributed and Parallel systems*, vol. 3, no. 4, 2012.

[14] *Eurasip.org*, 2018. [Online].

Available: https://www.eurasip.org/Proceedings/Ext/IST05/papers/372.pdf

[Accessed: 16- Dec- 2017].

[15] SHARMA, "Space time coding in MIMO", *Slideshare.net*, 2018. [Online].

Available: https://www.slideshare.net/ila102001/space-time-coding-in-mimo

Accessed: 15- Jan- 2018].

[16] “Space–time block code", *En.wikipedia.org*, 2018. [Online].

Available: https://en.wikipedia.org/wiki/Space-time_block_code

[Accessed: 11- Feb- 2018].

[17] Gerhard Bauch DoCoMo Euro-Labs “Space-Time Block Codes Versus Space-Frequency Block Codes” IEEE 2003 accessed on 12th Feb 2018.

[18] Mohammad Torabi, Sonia A¨ıssa, Senior Member, IEEE, and M. Reza Soleymani, Senior Member “On the BER Performance of Space-Frequency Block Coded OFDM Systems in Fading MIMO Channels” IEEE TRANS. ON WIRELESS COMM., VOL. 6, NO. 4, APRIL 2007 accessed on 15th Feb 2018.

[19] http://www.sharetechnote.com/html/Handbook_LTE_SFBC.html , accessed on 2nd April, 2018

[20]
https://www.tutorialspoint.com/digital_communication/digital_communication_phase_shift_keying.htm ; accessed on 5th April, 2018.

[21]

https://en.wikipedia.org/wiki/Phase-_kshifteying ; accessed on 10th April, 2018.

[22]

https://en.wikipedia.org/wiki/Quadrature_amplitude_modulation ;accessed on 10th April, 2018.

Appendix – A

Codes for Comparing QAM 16 and QAM 64 using both SFBC and STBC for Perfect CSI

```
close all

clear all

clc

for LL=1:4

figure(10+LL)

M=[16 64];

for J=1:length(M)

B=log2(M(J));

tx=[1 2 3 4];

rx=LL.*[1 1 1 1];

Rc=1; % code rate assume

L=tx.*rx;

N=512;

yb=0.1:.1:35;

ys=yb;

Ys=B*10.^(ys/10);

for i=1:length(L)

BERMQAM_avg(i,:)=0.2*(1+((1.6.*Ys)/(Rc*tx(i)*((2.^B)-1)))).^(-L(i));
```

```
if (J==1 && i==1)

semilogy(yb,BERMQAM_avg(i,:),'r')

else if J==1 && i==2

semilogy(yb,BERMQAM_avg(i,:),'r:','LineWidth',2)

else if J==1 && i==3

semilogy(yb,BERMQAM_avg(i,:),'r--')

else if J==1 && i==4

semilogy(yb,BERMQAM_avg(i,:),'r--o')

else if J==2 && i==1

semilogy(yb,BERMQAM_avg(i,:),'b')

else if J==2 && i==2

semilogy(yb,BERMQAM_avg(i,:),'b:','LineWidth',2)

else if J==2 && i==3

semilogy(yb,BERMQAM_avg(i,:),'b--')

else

semilogy(yb,BERMQAM_avg(i,:),'b--o')

end

end

end

end

end
```

```
end

end

hold on

ylim([1e-6 1]);

xlabel('SNR(dB)');

ylabel('BER');

if LL==1

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=1 using "SFBC"')

legend('QAM 16, Tx 1, Rx 1','QAM 16, Tx 2, Rx 1','QAM 16, Tx 3, Rx 1','QAM 16, Tx 4, Rx 1','QAM 64, Tx 1, Rx 1','QAM 64, Tx 2, Rx 1','QAM 64, Tx 3, Rx 1','QAM 64, Tx 4, Rx 1');

else if LL==2

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=2 using "SFBC"')

legend('QAM 16, Tx 1, Rx 2','QAM 16, Tx 2, Rx 2','QAM 16, Tx 3, Rx 2','QAM 16, Tx 4, Rx 2','QAM 64, Tx 1, Rx 2','QAM 64, Tx 2, Rx 2','QAM 64, Tx 3, Rx 2','QAM 64, Tx 4, Rx 2');

else if LL==3

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=3 using "SFBC"')

legend('QAM 16, Tx 1, Rx 3','QAM 16, Tx 2, Rx 3','QAM 16, Tx 3, Rx 3','QAM 16, Tx 4, Rx 3','QAM 64, Tx 1, Rx 3','QAM 64, Tx 2, Rx 3','QAM 64, Tx 3, Rx 3','QAM 64, Tx 4, Rx 3');

else

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=4 using "SFBC"')

legend('QAM 16, Tx 1, Rx 4','QAM 16, Tx 2, Rx 4','QAM 16, Tx 3, Rx 4','QAM 16, Tx 4, Rx 4','QAM 64, Tx 1, Rx 4','QAM 64, Tx 2, Rx 4','QAM 64, Tx 3, Rx 4','QAM 64, Tx 4, Rx 4');
```

```
end

end

end

end

MM(J,:,:)=BERMQAM_avg(:,:);

end

end

clear BERMQAM_avg


EbNo = .1:.1:35;

for LL=1:4

MM=[16 64];

for J=1:length(MM)

figure(20+LL);

M=MM(J);

B=log2(M);

tx=[1 2 3 4];

rx=LL.*[1 1 1 1];

L = tx.*rx; %L=1 Start without diversity

for i=1:length(L)

ber(i,:) = berfading(EbNo,'qam',M,L(i));
```

```
BERMQAM_avg(i,:)=ber(i,:);

yb=EbNo;

if (J==1 && i==1)

semilogy(yb,BERMQAM_avg(i,:),'r')

else if J==1 && i==2

semilogy(yb,BERMQAM_avg(i,:),'r:','LineWidth',2)

else if J==1 && i==3

semilogy(yb,BERMQAM_avg(i,:),'r--')

else if J==1 && i==4

semilogy(yb,BERMQAM_avg(i,:),'r--o')

else if J==2 && i==1

semilogy(yb,BERMQAM_avg(i,:),'b')

else if J==2 && i==2

semilogy(yb,BERMQAM_avg(i,:),'b:','LineWidth',2)

else if J==2 && i==3

semilogy(yb,BERMQAM_avg(i,:),'b--')

else

semilogy(yb,BERMQAM_avg(i,:),'b--o')

end

end

end
```

```
end

end

end

end

ylim([1e-6 1]);

hold on

xlabel('SNR(dB)');

ylabel('BER');

if LL==1

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=1 using "STBC"')

legend('QAM 16, Tx 1, Rx 1','QAM 16, Tx 2, Rx 1','QAM 16, Tx 3, Rx 1','QAM 16, Tx 4, Rx 1','QAM 64, Tx 1, Rx 1','QAM 64, Tx 2, Rx 1','QAM 64, Tx 3, Rx 1','QAM 64, Tx 4, Rx 1');

else if LL==2

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=2 using "STBC"')

legend('QAM 16, Tx 1, Rx 2','QAM 16, Tx 2, Rx 2','QAM 16, Tx 3, Rx 2','QAM 16, Tx 4, Rx 2','QAM 64, Tx 1, Rx 2','QAM 64, Tx 2, Rx 2','QAM 64, Tx 3, Rx 2','QAM 64, Tx 4, Rx 2');

else if LL==3

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=3 using "STBC"')

legend('QAM 16, Tx 1, Rx 3','QAM 16, Tx 2, Rx 3','QAM 16, Tx 3, Rx 3','QAM 16, Tx 4, Rx 3','QAM 64, Tx 1, Rx 3','QAM 64, Tx 2, Rx 3','QAM 64, Tx 3, Rx 3','QAM 64, Tx 4, Rx 3');

else

title('Comparing QAM 16 and QAM 64 with perfect CSI for Rx=4 using "STBC"')
```

```
legend('QAM 16, Tx 1, Rx 4','QAM 16, Tx 2, Rx 4','QAM 16, Tx 3, Rx 4','QAM 16, Tx 4, Rx 4','QAM 64, Tx 1, Rx 4','QAM 64, Tx 2, Rx 4','QAM 64, Tx 3, Rx 4','QAM 64, Tx 4, Rx 4');

end

end

end

end

end

end
```

Appendix – B

Codes for Comparing BPSK, QPSK and 8PSK using both SFBC and STBC for Perfect CSI

```
close all

clear all

clc

for LL=1:4

figure(10+LL)

M=[2 4 8];

for J=1:length(M)

B=log2(M(J));

tx=[1 2 3 4];

rx=LL.*[1 1 1 1];

Rc=1; % code rate assume

L=tx.*rx;

N=512;

yb=0.1:.1:35;

ys=yb;

Ys=B*10.^(ys/10);

for i=1:length(L)

BERMPSK_avg(i,:)=0.2*(1+((7.*Ys)./(Rc*tx(i)*((2.^(1.9*B))+1)))).^(-L(i));
```

```
if (J==1 && i==1)

semilogy(yb,BERMPSK_avg(i,:),'r')

else if J==1 && i==2

semilogy(yb,BERMPSK_avg(i,:),'r:','LineWidth',2)

else if J==1 && i==3

semilogy(yb,BERMPSK_avg(i,:),'r--')

else if J==1 && i==4

semilogy(yb,BERMPSK_avg(i,:),'r--o')

else if J==2 && i==1

semilogy(yb,BERMPSK_avg(i,:),'g')

else if J==2 && i==2

semilogy(yb,BERMPSK_avg(i,:),'g:','LineWidth',2)

else if J==2 && i==3

semilogy(yb,BERMPSK_avg(i,:),'g--')

else if J==2 && i==4

semilogy(yb,BERMPSK_avg(i,:),'g--o')

else if J==3 && i==1

semilogy(yb,BERMPSK_avg(i,:),'b')

else if J==3 && i==2

semilogy(yb,BERMPSK_avg(i,:),'b:','LineWidth',2)

else if J==3 && i==3
```

```
semilogy(yb,BERMPSK_avg(i,:),'b--')
else
semilogy(yb,BERMPSK_avg(i,:),'b--o')
end
end
end
end
end
end
end
end
end
end
end
ylim([1e-6 1]);
hold on
xlabel('SNR(dB)');
ylabel('BER');
if LL==1
title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=1 using "SFBC"')
```

```
legend('BPSK, Tx 1, Rx 1','BPSK, Tx 2, Rx 1','BPSK, Tx 3, Rx 1','BPSK, Tx 4, Rx 1','QPSK, Tx 1, Rx 1','QPSK, Tx 2, Rx 1','QPSK, Tx 3, Rx 1','QPSK, Tx 4, Rx 1','8PSK, Tx 1, Rx 1','8PSK, Tx 2, Rx 1','8PSK, Tx 3, Rx 1','8PSK, Tx 4, Rx 1');

else if LL==2

title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=2 using "SFBC"')

legend('BPSK, Tx 1, Rx 2','BPSK, Tx 2, Rx 2','BPSK, Tx 3, Rx 2','BPSK, Tx 4, Rx 2','QPSK, Tx 1, Rx 2','QPSK, Tx 2, Rx 2','QPSK, Tx 3, Rx 2','QPSK, Tx 4, Rx 2','8PSK, Tx 1, Rx 2','8PSK, Tx 2, Rx 2','8PSK, Tx 3, Rx 2','8PSK, Tx 4, Rx 2');

else if LL==3

title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=3 using "SFBC"')

legend('BPSK, Tx 1, Rx 3','BPSK, Tx 2, Rx 3','BPSK, Tx 3, Rx 3','BPSK, Tx 4, Rx 3','QPSK, Tx 1, Rx 3','QPSK, Tx 2, Rx 3','QPSK, Tx 3, Rx 3','QPSK, Tx 4, Rx 3','8PSK, Tx 1, Rx 3','8PSK, Tx 2, Rx 3','8PSK, Tx 3, Rx 3','8PSK, Tx 4, Rx 3');

else

title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=4 using "SFBC"')

legend('BPSK, Tx 1, Rx 4','BPSK, Tx 2, Rx 4','BPSK, Tx 3, Rx 4','BPSK, Tx 4, Rx 4','QPSK, Tx 1, Rx 4','QPSK, Tx 2, Rx 4','QPSK, Tx 3, Rx 4','QPSK, Tx 4, Rx 4','8PSK, Tx 1, Rx 4','8PSK, Tx 2, Rx 4','8PSK, Tx 3, Rx 4','8PSK, Tx 4, Rx 4');

end

end

end

end

MM(J,:,:)=BERMPSK_avg(:,:);

end
```

```
end

hold on

clear BERMPSK_avg


EbNo = .1:.1:35;

for LL=1:4

MM=[2 4 8];

for J=1:length(MM)

figure(20+LL);

M=MM(J);

B=log2(M);

tx=[1 2 3 4];

rx=LL.*[1 1 1 1];

L = tx.*rx; %L=1 Start without diversity

for i=1:length(L)

ber(i,:) = berfading(EbNo,'psk',M,L(i));

BERMPSK_avg(i,:)=ber(i,:);

yb=EbNo;

if (J==1 && i==1)

semilogy(yb,BERMPSK_avg(i,:),'r')

else if J==1 && i==2
```

```
semilogy(yb,BERMPSK_avg(i,:),'r:','LineWidth',2)

else if J==1 && i==3

semilogy(yb,BERMPSK_avg(i,:),'r--')

else if J==1 && i==4

semilogy(yb,BERMPSK_avg(i,:),'r--o')

else if J==2 && i==1

semilogy(yb,BERMPSK_avg(i,:),'g--o')

else if J==2 && i==2

semilogy(yb,BERMPSK_avg(i,:),'g--')

else if J==2 && i==3

semilogy(yb,BERMPSK_avg(i,:),'gx')

else if J==2 && i==4

semilogy(yb,BERMPSK_avg(i,:),'g')

else if J==3 && i==1

semilogy(yb,BERMPSK_avg(i,:),'b')

else if J==3 && i==2

semilogy(yb,BERMPSK_avg(i,:),'b:','LineWidth',2)

else if J==3 && i==3

semilogy(yb,BERMPSK_avg(i,:),'b--')

else

semilogy(yb,BERMPSK_avg(i,:),'b--o')
```

```
end

end

end

end

end

end

end

end

end

end

end

hold on

end

ylim([1e-6 1]);

hold on

xlabel('SNR(dB)');

ylabel('BER');

if LL==1

title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=1 using "STBC"')

legend('BPSK, Tx 1, Rx 1','BPSK, Tx 2, Rx 1','BPSK, Tx 3, Rx 1','BPSK, Tx 4, Rx 1','QPSK, Tx 1, Rx 1','QPSK, Tx 2, Rx 1','QPSK, Tx 3, Rx 1','QPSK, Tx 4, Rx 1','8PSK, Tx 1, Rx 1','8PSK, Tx 2, Rx 1','8PSK, Tx 3, Rx 1','8PSK, Tx 4, Rx 1');
```

```
else if LL==2

title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=2 using "STBC"')

legend('BPSK, Tx 1, Rx 2','BPSK, Tx 2, Rx 2','BPSK, Tx 3, Rx 2','BPSK, Tx 4, Rx 2','QPSK, Tx 1, Rx 2','QPSK, Tx 2, Rx 2','QPSK, Tx 3, Rx 2','QPSK, Tx 4, Rx 2','8PSK, Tx 1, Rx 2','8PSK, Tx 2, Rx 2','8PSK, Tx 3, Rx 2','8PSK, Tx 4, Rx 2');

else if LL==3

title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=3 using "STBC"')

legend('BPSK, Tx 1, Rx 3','BPSK, Tx 2, Rx 3','BPSK, Tx 3, Rx 3','BPSK, Tx 4, Rx 3','QPSK, Tx 1, Rx 3','QPSK, Tx 2, Rx 3','QPSK, Tx 3, Rx 3','QPSK, Tx 4, Rx 3','8PSK, Tx 1, Rx 3','8PSK, Tx 2, Rx 3','8PSK, Tx 3, Rx 3','8PSK, Tx 4, Rx 3');

else

title('Comparing BPSK, QPSK and 8PSK with perfect CSI for Rx=4 using "STBC"')

legend('BPSK, Tx 1, Rx 4','BPSK, Tx 2, Rx 4','BPSK, Tx 3, Rx 4','BPSK, Tx 4, Rx 4','QPSK, Tx 1, Rx 4','QPSK, Tx 2, Rx 4','QPSK, Tx 3, Rx 4','QPSK, Tx 4, Rx 4','8PSK, Tx 1, Rx 4','8PSK, Tx 2, Rx 4','8PSK, Tx 3, Rx 4','8PSK, Tx 4, Rx 4');

end

end

end

end

hold on

end
```

Appendix – C

Codes for Comparing QAM 16 and QAM 64 using SFBC for Imperfect CSI

```
close all

clear all

clc

Qe2=[0 .005 .01 .02 .05];

for LL=1:4

for i=1:length(Qe2)

figure(300+LL*10+i)

M=[16 64];

for J=1:length(M)

B=log2(M(J));

tx=[1 2 3 4];

rx=LL.*[1 1 1 1];

Rc=1; % code rate assume

L=tx.*rx;

N=512;

yb=0.1:.1:35;

ys=yb;

Ys=B*10.^(ys/10);
```

```
for j=1:length(L)

BERMQAM_avg(i,j,:)=0.2*(1+((1.6.*Ys)./(Rc*tx(j)*((2.^B)-1)*(1+Qe2(i).*Ys)))).^(-L(j));

m(1,:)=BERMQAM_avg(i,j,:);

if (J==1 && j==1)

semilogy(yb,m(1,:),'r')

else if J==1 && j==2

semilogy(yb,m(1,:),'r:','LineWidth',2)

else if J==1 && j==3

semilogy(yb,m(1,:),'r--')

else if J==1 && j==4

semilogy(yb,m(1,:),'r-.')

else if J==2 && j==1

semilogy(yb,m(1,:),'b')

else if J==2 && j==2

semilogy(yb,m(1,:),'b:','LineWidth',2)

else if J==2 && j==3

semilogy(yb,m(1,:),'b--')

else

semilogy(yb,m(1,:),'b-.')

end

end
```

```
end

end

end

end

end

ylim([1e-6 1]);

xlim([0 15]);

hold on

xlabel('SNR(dB)');

ylabel('BER');

if LL==1

if i==1

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0 and Rx=1 using "SFBC"')

else if i==2

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.005 and Rx=1 using "SFBC"')

else if i==3

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.01 and Rx=1 using "SFBC"')

else if i==4
```

```
title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.02 and Rx=1 using "SFBC"')

else

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.05 and Rx=1 using "SFBC"')

end

end

end

end

legend('QAM 16, Tx 1, Rx 1','QAM 16, Tx 2, Rx 1','QAM 16, Tx 3, Rx 1','QAM 16, Tx 4, Rx 1','QAM 64, Tx 1, Rx 1','QAM 64, Tx 2, Rx 1','QAM 64, Tx 3, Rx 1','QAM 64, Tx 4, Rx 1');

else if LL==2

if i==1

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0 and Rx=2 using "SFBC"')

else if i==2

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.005 and Rx=2 using "SFBC"')

else if i==3

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.01 and Rx=2 using "SFBC"')

else if i==4
```

```
title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.02 and Rx=2 using "SFBC"')

else

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.05 and Rx=2 using "SFBC"')

end

end

end

end

legend('QAM 16, Tx 1, Rx 2','QAM 16, Tx 2, Rx 2','QAM 16, Tx 3, Rx 2','QAM 16, Tx 4, Rx 2','QAM 64, Tx 1, Rx 2','QAM 64, Tx 2, Rx 2','QAM 64, Tx 3, Rx 2','QAM 64, Tx 4, Rx 2');

else if LL==3

if i==1

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0 and Rx=3 using "SFBC"')

else if i==2

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.005 and Rx=3 using "SFBC"')

else if i==3

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.01 and Rx=3 using "SFBC"')

else if i==4
```

```
title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.02 and Rx=3 using "SFBC"')

else

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.05 and Rx=3 using "SFBC"')

end

end

end

end

legend('QAM 16, Tx 1, Rx 3','QAM 16, Tx 2, Rx 3','QAM 16, Tx 3, Rx 3','QAM 16, Tx 4, Rx 3','QAM 64, Tx 1, Rx 3','QAM 64, Tx 2, Rx 3','QAM 64, Tx 3, Rx 3','QAM 64, Tx 4, Rx 3');

else

if i==1

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0 and Rx=4 using "SFBC"')

else if i==2

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.005 and Rx=4 using "SFBC"')

else if i==3

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.01 and Rx=4 using "SFBC"')

else if i==4
```

```
title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.02 and Rx=4 using "SFBC"')

else

title('Comparing QAM 16 and QAM 64 with imperfect CSI for \sigmae²=0.05 and Rx=4 using "SFBC"')

end

end

end

end

legend('QAM 16, Tx 1, Rx 4','QAM 16, Tx 2, Rx 4','QAM 16, Tx 3, Rx 4','QAM 16, Tx 4, Rx 4','QAM 64, Tx 1, Rx 4','QAM 64, Tx 2, Rx 4','QAM 64, Tx 3, Rx 4','QAM 64, Tx 4, Rx 4');

end

end

end

end

MM(J,i,j,:)=m(1,:);

end

end

end
```

Appendix – D

Codes for Comparing BPSK, QPSK and 8PSK using SFBC for Imperfect CSI

```
close all
clear all
clc
Qe2=[0 .005 .01 .02 .05];
for LL=1:4
for i=1:length(Qe2)
figure(400+LL*10+i)
M=[2 4 8];
for J=1:length(M)
B=log2(M(J));
tx=[1 2 3 4];
rx=LL.*[1 1 1 1];
Rc=1; % code rate assume
L=tx.*rx;
N=512;
yb=0.1:.1:35;
ys=yb;
Ys=B*10.^(ys/10);
for j=1:length(L)
BERMPSK_avg(i,j,:)=0.2*(1+((7.*Ys)./(Rc*tx(j)*((2.^(1.9*B))+1)*(1+Qe2(i).*Ys)))).^(-L(j));
m(1,:)=BERMPSK_avg(i,j,:);
if (J==1 && j==1)
semilogy(yb,m(1,:),'r')
else if J==1 && j==2
```

```
semilogy(yb,m(1,:),'r:','LineWidth',2)
else if J==1 && j==3
semilogy(yb,m(1,:),'r--')
else if J==1 && j==4
semilogy(yb,m(1,:),'r--o')
else if J==2 && j==1
semilogy(yb,m(1,:),'g')
else if J==2 && j==2
semilogy(yb,m(1,:),'g:','LineWidth',2)
else if J==2 && j==3
semilogy(yb,m(1,:),'g--')
else if J==2 && j==4
semilogy(yb,m(1,:),'g--o')
else if J==3 && j==1
semilogy(yb,m(1,:),'b')
else if J==3 && j==2
semilogy(yb,m(1,:),'b:','LineWidth',2)
else if J==3 && j==3
semilogy(yb,m(1,:),'b--')
else
semilogy(yb,m(1,:),'b--o')
end
end
end
end
end
end
end
```

```
end
end
end
end
ylim([1e-6 1]);
xlim([0 15]);
hold on
xlabel('SNR(dB)');
ylabel('BER');
if LL==1
if i==1
title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0 and Rx=1 using "SFBC"')
else if i==2
title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.005 and Rx=1 using "SFBC"')
else if i==3
title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.01 and Rx=1 using "SFBC"')
else if i==4
title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.02 and Rx=1 using "SFBC"')
else
title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.05 and Rx=1 using "SFBC"')
end
end
end
end
```

```
legend('BPSK, Tx 1, Rx 1','BPSK, Tx 2, Rx 1','BPSK, Tx 3, Rx 1','BPSK, Tx 4, Rx 1','QPSK, Tx 1, Rx 1','QPSK, Tx 2, Rx 1','QPSK, Tx 3, Rx 1','QPSK, Tx 4, Rx 1','8PSK, Tx 1, Rx 1','8PSK, Tx 2, Rx 1','8PSK, Tx 3, Rx 1','8PSK, Tx 4, Rx 1');

else if LL==2

if i==1

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0 and Rx=2 using "SFBC"')

else if i==2

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.005 and Rx=2 using "SFBC"')

else if i==3

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.01 and Rx=2 using "SFBC"')

else if i==4

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.02 and Rx=2 using "SFBC"')

else

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.05 and Rx=2 using "SFBC"')

end

end

end

end

legend('BPSK, Tx 1, Rx 2','BPSK, Tx 2, Rx 2','BPSK, Tx 3, Rx 2','BPSK, Tx 4, Rx 2','QPSK, Tx 1, Rx 2','QPSK, Tx 2, Rx 2','QPSK, Tx 3, Rx 2','QPSK, Tx 4, Rx 2','8PSK, Tx 1, Rx 2','8PSK, Tx 2, Rx 2','8PSK, Tx 3, Rx 2','8PSK, Tx 4, Rx 2');

else if LL==3

if i==1

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0 and Rx=3 using "SFBC"')

else if i==2
```

```
title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.005 and Rx=3 using "SFBC"')

else if i==3

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.01 and Rx=3 using "SFBC"')

else if i==4

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.02 and Rx=3 using "SFBC"')

else

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.05 and Rx=3 using "SFBC"')

end

end

end

end

legend('BPSK, Tx 1, Rx 3','BPSK, Tx 2, Rx 3','BPSK, Tx 3, Rx 3','BPSK, Tx 4, Rx 3','QPSK, Tx 1, Rx 3','QPSK, Tx 2, Rx 3','QPSK, Tx 3, Rx 3','QPSK, Tx 4, Rx 3','8PSK, Tx 1, Rx 3','8PSK, Tx 2, Rx 3','8PSK, Tx 3, Rx 3','8PSK, Tx 4, Rx 3');

else  if i==1

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0 and Rx=4 using "SFBC"')

else if i==2

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.005 and Rx=4 using "SFBC"')

else if i==3

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.01 and Rx=4 using "SFBC"')

else if i==4

title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.02 and Rx=4 using "SFBC"')

else
```

```
title('Comparing BPSK, QPSK and 8PSK with imperfect CSI for \sigmae²=0.05 and Rx=4 using "SFBC"')

end

end

end

end

legend('BPSK, Tx 1, Rx 4','BPSK, Tx 2, Rx 4','BPSK, Tx 3, Rx 4','BPSK, Tx 4, Rx 4','QPSK, Tx 1, Rx 4','QPSK, Tx 2, Rx 4','QPSK, Tx 3, Rx 4','QPSK, Tx 4, Rx 4','8PSK, Tx 1, Rx 4','8PSK, Tx 2, Rx 4','8PSK, Tx 3, Rx 4','8PSK, Tx 4, Rx 4');

end

end

end

end

MM(J,i,j,:)=m(1,:);

end

end

end
```