PERFORMANCE EVALUATION OF QO-STBC ENCODED MIMO SYSTEM WITH D-QR DECOMPOSITION UNDER TWDP WIRELESS FADING CHANNEL

A Dissertation Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of

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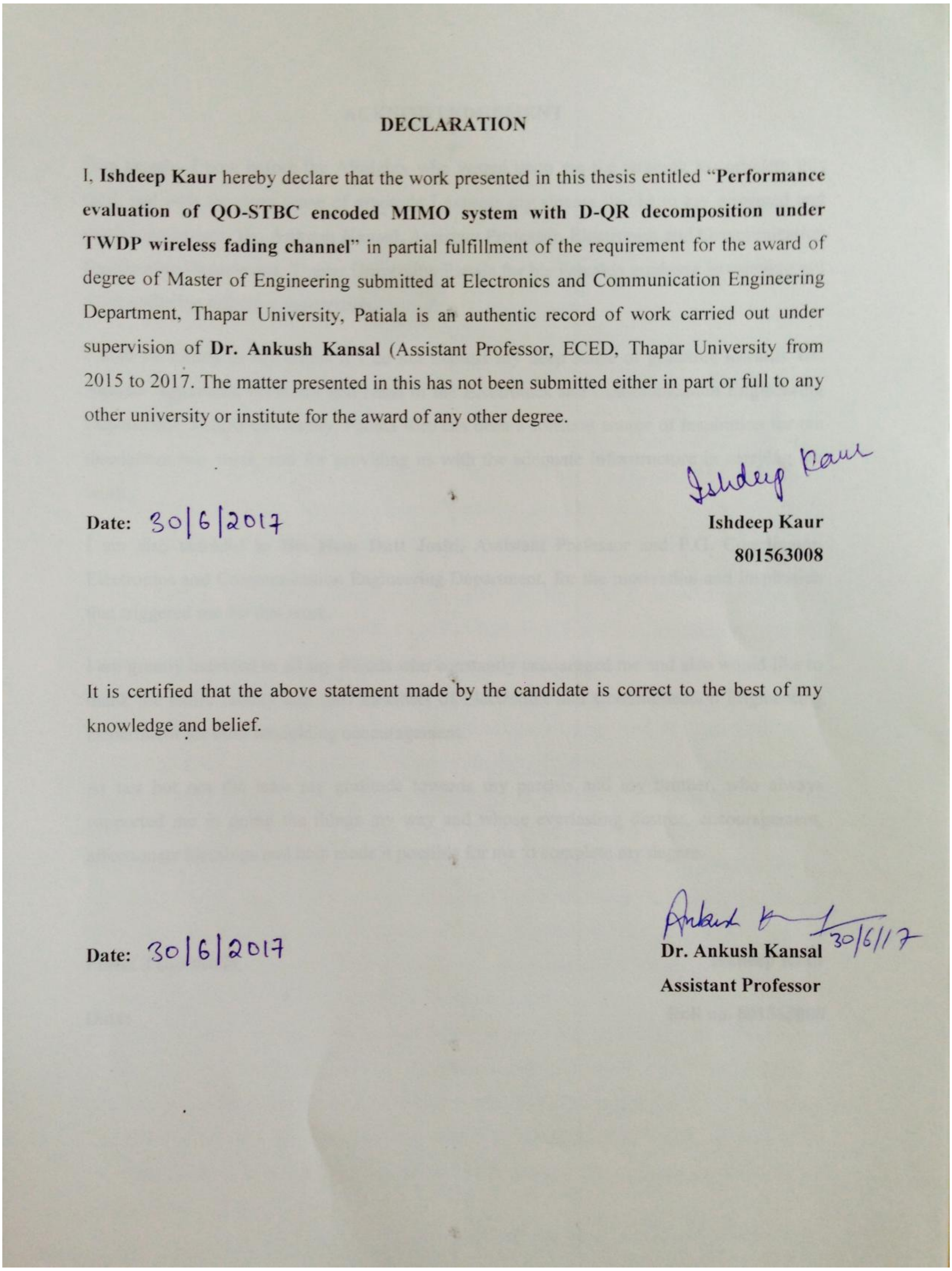

DECLARATION

I, **Ishdeep Kaur** hereby declare that the work presented in this thesis entitled "**Performance evaluation of QO-STBC encoded MIMO system with D-QR decomposition under TWDP wireless fading channel**" in partial fulfillment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Engineering Department, Thapar University, Patiala is an authentic record of work carried out under supervision of **Dr. Ankush Kansal** (Assistant Professor, ECED, Thapar University from 2015 to 2017. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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Fore mostly, I bow before the Almighty who vested upon me the strength to complete this work and with the deep sense of gratitude I express my sincere thanks to my esteemed and worthy supervisor, **Dr. Ankush Kansal,** Assistant Professor, Electronics and Communication Engineering Department, Thapar University, Patiala for his valuable guidance in carrying out work under his effective supervision.

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ABSTRACT

In the recent years, there has been swift development in remote wireless communications. With the expanding count of users and bounded bandwidth available, operators are making a decent attempt to upgrade the network for larger capacity and enhanced quality coverage. Point-to-point remote transmissions through numerous transmit and receive antennas, or the purported Multi-Input Multi-Output (MIMO) channels have gotten extensive consideration amid the previous decade because of its demonstrated capacity improvement over the regular single-antenna frameworks. The expanding necessities on data rate and quality of service for remote wireless communication frameworks convene for new systems to enhance spectrum efficiency and to ameliorate the link reliability. The utilization of numerous antennas at either ends of a wireless link guarantees substantial advancements in terms of spectral efficiency and link reliability. This technology is recognized as MIMO.

In the starting, MIMO technology was expected for the point to point communication frameworks. However, with the headway of the innovation, a few impediments too came into notice such as the throughput capability and sort of fading channel. So, this technology was further merged with the Space Time Block Codes (STBC) and other higher order forms of STBCs comprising complex symbol terms in their code structure, such as Quasi Orthogonal STBC (QO-STBC) which is widely famous for attaining full rate but having the disadvantage of less diversity gain and more decoding complexity. In this thesis, D-QR decomposed QO-STBC based MIMO system has been proposed. The comparison amid conventional QO-STBC and proposed D-QR decomposed QO-STBC has been presented. It is observed that at 10^{-4} BER, conventional system has approximately 22 dB SNR whilst proposed QO-STBC D-QR system has 3 dB. So an improvement of 19 dB is achieved. This is because we get an interference free channel matrix because of D-QR decomposition. Further, QO-STBC D-QR system is analysed for M-PSK and M-QAM schemes with M = 8, 16, 32, 64, 128, 256, 512 and 1024. In case of M-PSK modulation, 8-PSK shows 2 dB, 16-PSK shows 7 dB, 32-PSK shows 15 dB at 10^{-2} BER and likewise 1024-PSK shows 25 dB SNR at $10^{-0.2}$ BER whilst for M-QAM modulation format, 8-QAM shows 0.5dB, 16-QAM shows 4dB, 32-QAM shows 7db at 10^{-2} BER and likewise 1024-PSK shows 22 dB SNR at 10^{-2} BER. So, QO-STBC encoded MIMO system with QR decomposition is going to play an important role in the communication field in this era.

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LIST OF ABBREVIATIONS

MIMO	Multiple Input Multiple Output
SISO	Single Input Single Output
SIMO	Single Input Multiple Output
MISO	Multiple Input Single Output
STTC	Space Time Trellis Code
STBC	Space Time Block Code
LSTC	Layered Space Time Code
OSTBC	Orthogonal Space Time Block Code
QOSTBC	Quasi Orthogonal Space Time Block Code
AWGN	Additive White Gaussian Noise
TWDP	Two Wave with Diffuse Power
D-QR	Double-QR
LOS	Line Of Sight
QPSK	Quadrature Phase Shift Key
BER	Bit Error Rate
SNR	Signal to Noise Ratio

CSI	Channel State Information
SDMA	Space Division Multiple Access
FDD	Frequency Division Duplexing
TDD	Time Division Duplexing
M-QAM	M-Ary Quadrature Amplitude Modulation
M-PSK	M-Ary Phase Shift Key
ZF	Zero Forcing
MRC	Maximal Ratio Combining
ML	Maximum Likelihood
PDF	Probability Density Function
ISI	Inter Symbol Interference
ICI	Inter Channel Interference

CHAPTER 1

INTRODUCTION

As the demand of high performance communications in wireless media is increasing day by day, therefore, various technologies have been developed to increase system capacity under limited bandwidth. One of these technologies is Multiple-Input-Multiple-Output (MIMO) systems. MIMO system defines the utilization of number of transmitting and receiving antennas just to deliver parallel data stream in wireless domain. Its advantage is that more data can be delivered within the available bandwidth. Since different paths are followed to transmit the information, hence, a MIMO system provides high data rates and high spectral efficiency by exploiting the multipath fading effect using spatial diversity [1]. Unlike Single-Input-Single-Output (SISO) systems, MIMO is advantageous. Its major important advantages over single antenna systems are:

1) A valuable increase in the reliability of system.

2) Increase in the capacity of system.

3) Enhancement in the spectral efficiency.

4) Spatial diversity and spatial multiplexing.

5) Reduced multipath fading effects.

1.1 MIMO

MIMO technology has gained much attention over the last decade in almost all areas of wireless communication since it allows for increased capacity and reliability without additional power or bandwidth. Multiple-input-multiple-output comprises of numerous amount of transmitter/receiver antennas at both the transmission and reception side just to bring down the fading effects and to upgrade the execution of communication system. The system capacity of MIMO systems enhances by spatial multiplexing without additional requirement of power or bandwidth [2]. On the other hand, spatial diversity is used so as to mitigate the effect of fading up to a certain level. On the basis of need either high data rate or high reliability the MIMO systems are categorized as explained below:

1.1.1 Spatial Multiplexing

To improve the data rate of MIMO system, spatial multiplexing technique is used. In this, multiple streams are transmitted via spatially separated different antennas after the conversion of a single signal with high rate into various streams with lower-rate. Its transmission is done over the same frequency channel. Then these streams are separated into parallel channels at the side of receiver. The capacity of the channel is increased at higher SNR in spatial multiplexing. Spatial multiplexing can be used when no channel state information (CSI) is known at the side of transmitter, but if CSI is known then its combination with pre-coding can be used. Spatial multiplexing can also be used to transmit streams to various receivers, at one time. This is also termed as Space-division multiple accesses. The information regarding channel is needed at the side of transmitter.

1.1.2 Diversity

Spatial diversity is the basic form of the MIMO system having large number of multiple antennas. In this diversity system, multiple copies of same information is transmitted through different transmitter antennas and the desired signals are received at the receiving side which varies in terms of SNR. The main aim of this technique is to reduce errors and make the performance better with the help of a diversity gain and a coding gain [3, 4]. Spatial diversity is used in two ways like receiver diversity and transmitter diversity. The receiver diversity consists of single input antenna at transmitter with multiple receiver antennas whereas the transmit diversity consists of single output antenna at receiver with multiple transmitter antennas.

Spatial diversity is the technique, which is used without channel state information at the side of transmission. The coding of this stream is performed by space-time coding. The transmission of the signal is done via full or near orthogonal coding. Spatial diversity takes advantage of the multipath propagation to strengthen the signal diversity. Since no state information regarding channel is used at the transmitter, therefore, no array gain is achieved from diversity coding. If any information regarding channel is present at the transmission side, then combination of diversity coding and spatial multiplexing is used.

With the use of the spatial diversity among the antennas in a MIMO system, the average capacity can be increased and the outage probability can be reduced in a fading channel. Higher the number of antenna elements, higher will be the channel capacity. Unlike the SISO and MISO systems, MIMO systems have direct increase in the channel capacity with the antenna elements in MIMO system. Its capacity is given by [3]:

$$C = \min\left(N_T, N_R\right) * B * \log_2\left(1 + SNR\right) \tag{1.1}$$

where, C stands for the capacity, N_T and N_R are the number of transmitting and receiving antennas, B is the bandwidth of the system given and SNR is the signal to noise ratio.

1.2 MIMO BLOCK DIAGRAM

MIMO innovation constitutes a leap forward in wireless communication system design. Various benefits are offered by the technology that overcomes the drawbacks and challenges occurred by the impairments in the wireless medium and resource constraints. Unlike traditional single-antenna (single-input/single-output) wireless systems, the realization of MIMO is done by taking advantage of the spatial dimension given by the various antennas at the transmission side and the receiving side. The basic elements of MIMO system are presented below in Figure 1.1.

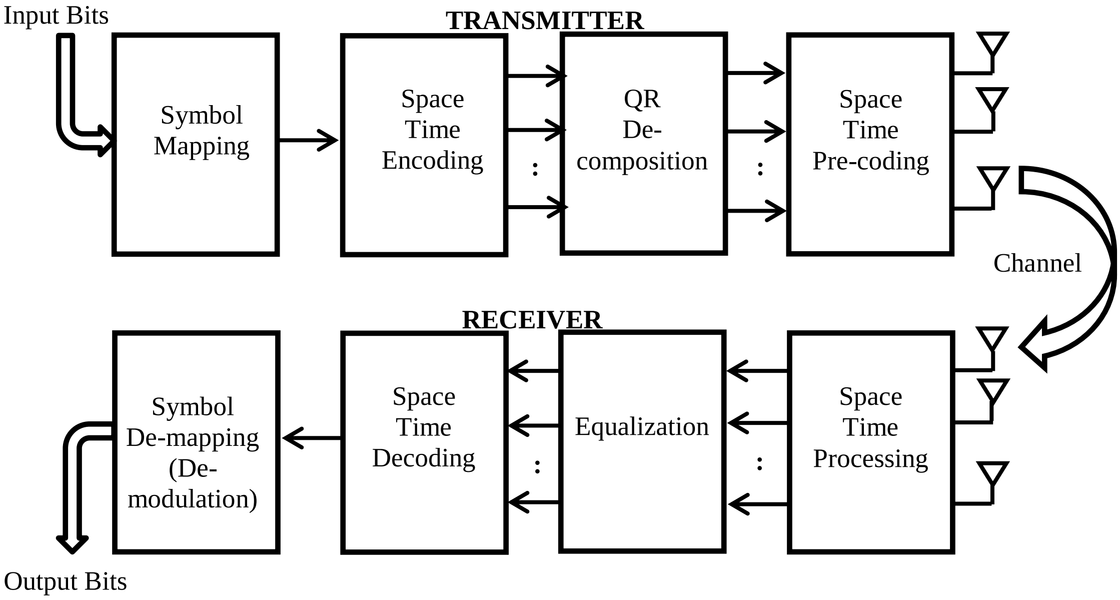

Figure 1.1 Block Diagram of MIMO Communication System [4].

Block diagram shown in Figure 1.1 describes the proposed model of QO-STBC encoded MIMO system. Initially, the input data bits are mapped to symbols like quadrature amplitude modulation (QAM) or phase shift modulation (PSK) via symbol mapper and are passed through a space-time encoder as an input which in results gives multiple spatial data streams as an output. The output obtained from this block is then fed as input to the QR decomposition block which performs operations to make channel matrix free of interference. Further QR decomposed symbols are transmitted by using space time pre-coding. These mapped signals are transmitted through the channel and are retrieved at the receiving end. Now at the receiver end, each operation of the transmitter is reversed to decode the data in which space-time processing is done followed by equalization and space-time decoding. After this, de-mapping i.e. demodulation of the symbols is done. The functions of these blocks are detailed in the following sections.

1.2.1 Modulation Techniques

Modulation is the process defined with the variation of characteristics of a continuous waveform called the carrier signal with a modulating signal that commonly includes data to be transmitted. The main motive behind the analog modulation is the transmission of an analog signal over an analog band-pass channel. This transmission is done at different frequency. In this thesis, behaviour of proposed system is analysed by modulating all input symbols using M-PSK or M-QAM modulation which stands for M-ary Phase Shift Keying and M-ary Quadrature Amplitude Modulation.

1.2.1.1 *M-ary Phase Shitf Keying (MPSK)*

PSK is the keying in which the characteristic phase of carrier signal is changed with respect to the characteristic phase of message signal. For M-ary PSK, M symbols are arranged on a circle with radius $\sqrt{E/T}$ resulting in fixed symbol energy [5]. PSK signal is represented as [6]:

$$s(t)=\sqrt{\frac{2E}{T}}cos(2\pi f_c t+\theta) \tag{1.2}$$

Where the modulated signal is *s*, energy per symbol is represented as *E*, carrier frequency as f_c, the symbol duration as *T* and θ stands for the phase of carrier which varies as

$$\theta = (2k-1)\frac{\pi}{M}, k = 1, 2, ..., M \tag{1.3}$$

where, *M* stands for M-ary in MPSK and is defined as $M = 2^b$, *b* stands for number of bits used to represent each symbol for respective modulation. For an instance, in 8-PSK modulation $b=3$ and hence $M=8$. Symbol energy is autonomous of the phases. Hence, all symbols have same energy which prompts to the organization of respective constellation. The symbol error rate for M-PSK scheme is given by [6]:

$$P_{s,M-PSK} = erfc\left[\sqrt{\frac{E_s}{N_0}}\sin\left(\frac{\pi}{M}\right)\right] \tag{1.4}$$

1.2.1.2 *M-ary Quadrature Amplitude Modulation (M-QAM)*

QAM is a modulation method in which two carriers with phase difference of 90 degrees are modulated which results variations in both phase and amplitude. So this technique is a mixture of magnitudes and phase modulation. QAM when utilized for digital wireless communication can deliver higher data rates than the customary amplitude and phase modulated schemes. Likewise PSK, the count of points on the constellation is depicted in the modulation format representation, for example: 16 QAM utilizes 16 point constellation. So in a general M-QAM constellation, symbol error rate can be expressed as in [6]:

$$P_{s,M-QAM} = 2\left(1-\frac{1}{\sqrt{M}}\right)erfc\left(\sqrt{\frac{3}{2(M-1)}\frac{E_s}{N_0}}\right)-\left(1-\frac{2}{\sqrt{M}}+\frac{1}{M}\right)erfc^2\left(\sqrt{\frac{3}{2(M-1)}\frac{E_s}{N_0}}\right) \tag{1.5}$$

When utilizing QAM, the constellation points are normally ordered in a rectangular/square shape. By utilizing higher order modulation formats, it is adventitious to send more number of bits per symbol. Usually the lowest order QAM used is 16-QAM owing to the reason that 2-QAM is equivalent to BPSK and 4-QAM as similar to QPSK. In this thesis however, the response of both M-PSK and M-QAM have been analyzed with M varying from 8,16,32,64 to 1024 i.e. b ranging from 3, 4,..,10 in $M=2^b$.

1.2.2 Space Time Encoding

A full diversity order may be attained by exploitation of MIMO channels via space-time coding techniques. As the numerous antennas used at the receiver in receive diversity helps to extract the desired signal output, therefore, it is very helpful in the reduction of harmful fading effects occurred because of multipath propagation. Some of the Space time encoded techniques are:

1.2.2.1 *Space Time Block Code (STBC)*

Space Time Block Codes are the easiest forms of spatial temporal codes that take advantage of the diversity provided in networks with fewer transmitting antennas. S. Alamouti designed a STBC system with 2 transmitting antennas. Complete diversity order was provided by this technique and non-complex operations are needed at both transmitting and receiving side. The encoding/decoding methods are done with blocks of transmission symbols. Theoretically, fewer forms can be taken by STBC but practically, linear STBCs are by far the most widely used. The main motive behind STBC is to scatter data symbols spatially in time to enhance either the diversity gain, or the spatial multiplexing rate, or both the diversity gain and the spatial multiplexing rate. It provides diversity gain however no coding gain [7, 8].

1.2.2.1 *Quasi Orthogonal Space Time Block Code (QO-STBC)*

Space time block code (STBC) and Space time trellis code (STTC) have been proposed to utilize the transmit diversity schemes to make MIMO systems level-headed. These techniques can achieve diversity gains with considerable complexity and give adequate BER performance [9]. But when the number of antennas at the transmitter side is fixed, there is increase in decoding complexity of STTC. Further, orthogonality of STBCs designed by Alamouti [10], and TFC [11, 12] pulled significant attention owing to their full diversity and maximum likelihood (ML) decoding. But when the count of transmitting antennas is more than two, both full rate and full diversity cannot be accomplished. As of late, QO-STBC has been designed for four transmit antennas in [13]; which offered full rate with half of the maximum possible diversity.

1.2.3 QR Decomposition

Quasi – Orthogonal STBC-MIMO system gives a detection matrix which consists of both diagonal and non-diagonal elements. To achieve higher data rates and more efficiency, higher order M-ary modulation techniques have been used but this higher order of M introduces higher inter-symbol interference too. So to compensate for this, QR decomposition is used twice at the receiver side in a way that it keeps only the diagonal elements and spot out the non-diagonal elements of detection matrix thus producing an interference-free detection matrix [14].

1.2.4 Pre-coding

Pre-coding is characterized as beam-forming of various streams which are regarded as spatial processing implemented on the side of transmission. Conventionally, the single-stream beam-forming transmits similar information from each transmitter antenna with proper phase and gain and the maximum signal power at the receiver input. It is a technique in which transmit diversity is exploited by transmitting the coded information to the recipient keeping in mind to have the information of the channel. There is necessity of knowledge of CSI on the transmitting side and receiving side in pre-coding.

1.2.5 Wireless Channels

The transmission with wireless medium utilizes air to transfer data. The radio spread is rough unlike transmission with wired medium because signal arrived is coming specifically from the sender, as well as mix of reflected, diffracted, and scattered duplicates of sent signal. The striking of a signal on the surface where fractional vitality is reflected and the rest is sent into the surface causes Reflection. Reflection coefficient is utilized for determining the proportion of reflection and transmission relies on the characteristics of objects. Diffraction happens if a signal is deterred by an abrupt obstacle which infers optional waves. The causes of Scattering are if a signal encroaches on harsh surfaces, or little objects. Arrived signal is sometime more grounded as compared to the reflected and diffracted signal because it scatters the vitality in every way and subsequently gives extra vitality for the receiving side which can get more than one duplicates of the signal in numerous ways with various stages and powers.

Communication channels might be named as fast fading channels and slow fading channels. The formula of Shannon’s capacity is estimated hypothetically, the most extreme attainable transmission rate for a pre-defined bandwidth B with power P in white channel is expressed as:

$$C = B\log_2\left(1+\frac{P}{N_0 B}\right) \tag{1.6}$$

1.2.5.1 *Additive White Gaussian Noise Channel*

Additive White Gaussian Noise is a general form of channel. It is used for examining modulation techniques. It adds the White Gaussian noise to the signal, i.e. the amplitude frequency response of the channel is flat and phase frequency response of the channel is straight in order to send the modulated signals having not any decrease in amplitude and deformation in phase of frequency parts [15]. The only distortion added is by the AWGN with no any fading existence. The received signal for AWGN channel is represented as:

$$y = s + n \tag{1.7}$$

where s is the transmitted signal and n is the complex white Gaussian random variable with zero mean and Power Spectral Density of $N_0/2$.

1.2.5.2 *Rayleigh Channel*

Rayleigh Channel is an innovative and damaging quality of different paths segments in flat fading channels which is estimated by Rayleigh distribution having no observable pathway which implies no immediate way is there amongst sender and receiver i.e. no LOS path is present. The simplification of arrived signal can be [16]:

$$r(t) = h(t) * s(t) + n(t) \tag{1.8}$$

where $h(t)$ represents the channel matrix and $n(t)$ denotes the AWGN. The Rayleigh distribution is defined as the magnitude of the summation of 2 equivalent unique orthogonal Gaussian random variables. The PDF of this distribution is expressed as [16]:

$$p(r) = \begin{cases} \frac{r}{\sigma^2} e^{(-r^2/2\sigma^2)} & ,(0 \le r \le \infty) \\ 0 & ,(r < 0) \end{cases} \tag{1.9}$$

where σ^2 is the average power of the received signal. The phase and the gain components of a channel's deformation are symbolized as a complex number often. It is assumed for the exhibition of Rayleigh fading that the modeling of response’s real and imaginary parts is done by individually allocated zero-mean Gaussian processes.

1.2.5.3 *Rician Channel*

Rician distribution is defined as a distribution with the presence of a line of sight between transmitting side and receiving side, i.e. direct path between transmission and reception end which goes into more fade as contrasted with the multipath parts. In Rician fading, the characterization of gain of amplitude is done by a Rician distribution. Its PDF is given by [16]:

$$p(r)=\frac{r}{\sigma^2}\exp\left[-\left(\frac{r^2+d^2}{2\sigma^2}\right)I_0\left(\frac{rd}{\sigma^2}\right)\right] \tag{1.10}$$

1.2.5.4 *TWDP Channel*

TWDP stands for Two-Wave with Diffuse Power. This channel model assumes that the signal received has relatively two strong multipath components i.e. unlike Rayleigh which has no LOS path and Rician which has one LOS path component; TWDP has two LOS path components.

The mathematical TWDP fading model is expressed as [17]

$$V=V_1e^{i\theta_1}+V_2e^{i\theta_2}+V_{dif} \tag{1.11}$$

where V is the signal received, V_1,V_2 the amplitudes of two LOS components and θ_1,θ_2 represent the phases of those two components. Different PDF representations for this channel have been proposed in work done afterwards.

1.2.6 Signal Detection

An issue experienced in the plan of receivers for exchanging information digitally is the recognition of information from estimations with noise in the sent data. Accordingly, planning a receiver with the characteristics of likelihood of error is insignificant and is engaging, practically and hypothetically. Lamentably, such outlines tend to bring out computationally complex receivers and hence they are frequently surrendered for computationally less complex yet problematic recipients. It is outstanding that for some situation, the gap in execution amongst problematic and the ideal receivers is considerable. This by itself makes the ideal recipients fascinating. Furthermore, the diminishing expense of calculation will bring about computationally attainable ideal outlines.

1.2.6.1 *Zero Forcing Equalizer*

Zero-Forcing Equalizer is a linear detection strategy that is utilized in the transmission systems for detection purpose. In this algorithm, the frequency response of channel is reversed. The signal received at the receiving side is multiplied by the inverse of the channel which results in removal of the inter-symbol interference (ISI). It is ideal for a channel without having any noise whereas for a channel with noise, the noise also gets amplified greatly at frequency f where the little magnitude is there in channel response in the attempt to reduce the channel completely. At the side of transmission, if the channel state information (CSI) is known perfectly, then the system capacity can be achieved for big count of users by ZF-pre-coding. For the incomplete channel state information available at the transmitter (CSIT), the performance of ZF-pre-coding decreases depending on the accuracy of CSIT. To attain the complete multiplexing gain, ZF pre-coding requires the essential feedback overhead. Due to multiuser hindrances, incomplete CSIT lowers the throughput. The nullification of these hindrances is done with beams made by incomplete CSIT. In the matrix form, relation between received and transmitted signal is expressed as:

$$Y = Hx + n \tag{1.12}$$

To calculate the value of x, it is required to find a matrix W which fulfills $WH = 1$. To fulfill this constraint, the Zero Forcing (ZF) linear detector is given by:

$$W = \left(H^H H\right)^{-1} H^H \tag{1.13}$$

It is otherwise called the pseudo reverse for a common m x n matrix. Notice that the off askew terms in the matrix H are non-zero. Due to non-zero off diagonal terms, the zero forcing equalizer tries to invalidate the interfering terms when executing the equalization, i.e. when explaining for x_1, interference from x_2 is attempted to be zero and vice versa [18]. At same time, amplification of noise may be there. Hence Zero Forcing equalizer is not the best one. However, it is non-complex and implementation is very easy.

1.3 ORGANIZATION OF WORK

This thesis includes total five chapters which are arranged as:

Chapter 1: Introduction, it consists of an overview, the rationale of study, scopes and objectives of the study, introduction to MIMO system, then a brief introduction about the nonlinear channels, modulation techniques and space time block coding techniques. The detection algorithm for signal detection in MIMO system is also discussed.

Chapter 2: Literature Review, the study of work done in the field of MIMO systems for STBC, QO-STBC, QR decomposition and effects of fading on the system is discussed; research papers of related field in sequence are also discussed.

Chapter 3: Space time block encoding, in this chapter, the MIMO system with Space time block encoding techniques such as Alamouti space time block code, Orthogonal space time block code and Quasi-orthogonal space time block code have been discussed in detail. Also parameters such as spectral efficiency and achievable rate are discussed.

Chapter 4: Results and Discussion, in this chapter the expected outcome of the study is discussed. All the results simulated in MATLAB-2013a have been discussed over various channel approximations for QPSK modulation format and over TWDP channel for M-PSK and M-QAM modulation technique. A complete analysis of BER is presented for the various fading channels. Also the spectral efficiency and achievable rate graphs have been plotted.

Chapter 5: Conclusion, this chapter concludes the whole work done and discusses about the future scope.

CHAPTER 2

LITERATURE REVIEW

The use of coding techniques in Multiple Input Multiple Output (MIMO) systems is an effective means to gain higher data rate over wireless channels. But the increase in the complexity in the implementation of these systems is of main concern. The main applications of MIMO systems are current standards with wireless medium. Even under the circumstances of interferences because of multipath propagation, the scheme holds improved data throughput. The main motive behind the evolution of MIMO systems is the increasing requirement for the large data rates over the large distances and the utilization of MIMO system with STBC and other coding schemes is to improve the system efficiency.

2.1 MIMO SYSTEM

Multiple-Input, Multiple-Output (MIMO) is a technique included in the wireless systems which enhances the spectral efficiency with the utilization of spatial multiplexing and increases reliability via spatial diversity. The effects of the selection of an antenna on the MIMO system's performance over nonlinear communication channels are discussed by **V. S. Hendre** [19]. The PWEP performance of space-time trellis codes was evaluated with the derivation of analytical expressions over nonlinear MIMO channel, case of Rayleigh fading, when the employment of choosing antenna is done at the receiving side. With the less number of receiver antennas selected at the receiving side, degradation in the system performance get reduced because of nonlinearity in the channel.

An approach to take the advantage of the MIMO system capacity was explained by **K. Tan** [20]. It was spatial multiplexing where transmission of distinct data streams is done from the antennas with their separation at the receiving side by using some of the detection techniques like ML which attains ideal efficiency or linear receivers like ZF which give sub-optimal efficiency. The computational complexity also gets reduced with the utilization of this Zero-forcing detector, with the bearable performance degradation.

X. Wang et al. [21] compares the typical Single-Input Single-Output (SISO) system with the MIMO system. The link throughput is also enhanced along with the improvement in the spectral efficiency by the MIMO system. Over continuous flat fading channels, the BER analysis of MPSK for MIMO using ZF receiver was presented by the authors. It was concluded from the results that the BER performance depends on Doppler spread along with the channel estimation error and the variations between amount of transmitter and receiver antennas. Better BER performance depends upon the larger difference between these antennas.

S. Alamouti [10] allows the transmission of two signals at a time by utilizing two transmit antennas. The diversity is optional at the receiver side. The utilization of one transmitting antenna with two receiving antennas provides the diversity order similar to the diversity order of MRRC. The diversity order of 2N can be attained by utilizing two antennas at the transmitter end and N antennas at the receiver end. No any extra bandwidth and feedback from receiver to transmitter is required in this scheme. The computational complexity provided in this scheme is equivalent to that of MRRC.

R. Tanbourgi et al. [22] proposed a low-rate feedback channel method which was used in multimode antenna selection just to enhance the multiplexing system's error rate execution with the linear receivers. On the basis of limited feedback from the receiving side, dynamic adjustment of mapping of sub-streams to the antennas is done for a defined complete data rate. The diversity gain is attained by using the dual-mode selection, where selection of spatial multiplexing or selection diversity is done. Dynamic selection of any amount of sub-streams enhances the additional array gain and this process is known as multimode selection. The different ways for the selection of amount of sub-streams and for mapping the sub-streams to transmit antennas was derived by the authors. Between the selection process and the Eigen modes of the channel, the relationship is created. A probabilistic evaluation of the selection process is offered for Rayleigh fading channels.

2.2 MIMO SYSTEM WITH SPACE TIME BLOCK CODING

By designing the channel codes, the performance of data rates and the reliability of the communication is enhanced over the Rayleigh channel with the utilization of multiple antennas at the transmitter side, by **V. Tarokh et al.** [23]. Encoding of the data is done using a channel code and is divided into various streams for the simultaneous transmission using various transmitter antennas. On the receiving side, the reached signal is a linear superposition of the various sent signals distorted by noise. The performance criterion was derived by the authors for making such codes under the supposition of slow and frequency non-selective fading. The observation of performance is done by the matrices generated from pairs of individual code orders. Among these matrices, the diversity gain is quantified by the minimum rank whereas the coding gain is quantified by the minimum determinant. Then, the results were advanced to the fast fading channels. To acquire the MIMO system capacity, the useful way is the utilization of space-time (ST) coding, which is made with the use of various transmitter antennas. The signals are sent via various antennas at the different time periods and they are correlated by performing the coding in both spatial and temporal domains. The exploitation of MIMO channel fading and the minimization of the transmission errors at the receiving side are done by this spatial-temporal correlation. Transmit diversity and power gain can be attained by using space-time coding over spatially encoded systems without extra requirement of bandwidth.

Some of the methods of coding, named as STTC, STBC and LST codes were described by **H. Wang et al.** [24]. STTC stands for space time trellis codes, STBC stands for space-time block codes, and LST stands for layered space-time codes. Here, the main work is to take the advantage of effects of multipath propagation, to attain higher spectral efficiencies and performance gains. The applications of Space-time coding are the cellular communications and wireless LAN. Some of the works on space-time coding is to improve the performance of the probability of wrongly recovered data packets by using additional sender antennas. Generally, the space-time code's implementation is done to find a matrices constellation satisfying the optimality criteria. Particularly, there is a trade-off among the system complexity, the error performance and the information rate with designing of space-time coding schemes. Initially, the research of STC concentrated on narrowband flat-fading channels only. For multi-user wideband frequency-selective channels, there is requirement for developing some novel and high-performance signal processing algorithms for the purpose of channel estimation, joint equalization and decoding, and suppression of interference.

The trade-off among data rate, advantage of diversity, and complexity of trellis is provided by these designed codes. For wideband wireless communications, an effective space-time coding was implemented. Using trellis codes and fading, the enhanced performance and diversity gains of a space time (ST) coding system was introduced by **O. Bayer et al.** [25]. The designed simulator's versatility for guessing the ST coding system's performance was presented by the results under various coding and channel conditions. The multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) scheme was implemented over frequency selective fading channels, in order to attain spectrally efficient transmissions which in results enhance the capacity or throughput of the system for distinct users. OFDM is used in this proposed scheme to convert the frequency selective fading into flat fading. A single frequency selective fading channel is converted into various flat fading sub-channels, on which space-time block coding is employed.

The performance analysis of a wireless communication system using multi-carrier OFDM with MIMO system along with Space-Time Block Coding (STBC) was evaluated by **M. M. Kamruzamman et al.** [26]. The Bit Error Rate (BER) was evaluated for the PSK modulation. The results presents that power penalty is there because of fading which can be decreased by incrementing the amount of receiving antennas. It is observed that, QPSK provides the best system performance among all the different modulation schemes. The receiver's SNR of STBC (space-time block codes) over Rayleigh fading channels was elaborated, on which basis; the closed impression of BER (bit error rate) of STBC is inferred with M-PSK modulation. It was concluded that the efficiency of system in environment of multipath propagation is enhanced with the addition of STBC to MIMO-OFDM system. In order to lowers the decoding complexity as much possible; simplified decoding is used at the receiver end.

A novel expanded space–time coding waveform scheme for multiple-input–multiple-output synthetic aperture radar execution is presented by **F. He** *et al.* [27]. The expansions incorporate the accomplishment of the two Alamouti periods in one transmit-span limiting the time-variant channel impact and the new type of the basic orthogonal waveforms. The fundamental points of interest of the proposed waveform model incorporate cross-channel obstruction mutual cancelation, concurrent transmission by means of orthogonal transmition channels etc. The proposed methodologies are verified by respective simulations.

2.3 MIMO SYSTEM WITH QUASI-ORTHOGONAL STBC

The comparison between the quasi-orthogonal space-time block coding (QO-STBC) and orthogonal space-time block coding (OSTBC) such as Alamouti code was done by **H. Jafarkhani** [12]. To improve the diversity gain of a system, an algorithm for the code selection between QO-STBCs was introduced by authors on the basis of QO-STBC having 4 antennas at the transmitting side. As compared to general closed-loop algorithm dependent on QO-STBC, the diversity gain and the system efficiency is enhanced by this algorithm, without a rate loss. As the computational complexity of maximum likelihood receiver is very high, hence, only receivers which are linear, such as the ZF receiver MMSE receiver can utilize this algorithm. The probability density function (PDF) of two SINRs is derived and by utilizing the PDF derived, an approximated bit error rate (BER) performance of the designed system is also derived and expressed.

W. Su et al. [28], analysed that the execution of quasi-orthogonal space-time codes can be enhanced by phase-shifting the constellations of the symbols constituting the code. The ideal turn of the symbols builds the minimum distance of the comparing space time code words, prompting significantly enhanced execution. A few new examples to enhance the group of quasi-orthogonal STBC dependent upon the investigation of existing transmission matrices of quasi-orthogonal space-time block codes were also derived. It is desired to have the quasi-orthogonal STBCs with complete diversity to guarantee good performance achievement at high SNR. Specifically, it was proposed that half of the symbols of quasi-orthogonal design are selected from a signal constellation set and the rest half is chosen from a rotated constellation. The STBCs that are obtained from results can assure both full diversity and fast ML decoding. Additionally, the rotation angles selected optimally for some everyday used signal constellations are accomplished. The designed codes outstrip the already existing codes of orthogonal designs at both low and high SNRs.

A. Lotfi-Rezaabad et al. [29], analysed the efficiency of a quasi-orthogonal space-time block code with antenna choice. The antenna choice at transmitter and receiver is discussed. The authors designed a new selection rule which minimizes the normal BER and accomplishes complete diversity regardless of the possibility that a simple zero-forcing receiver is utilized. QO-STBC accomplish complete code rate at the expense of loss in diversity gain.

For QO-STBCs to achieve full diversity and full code rate two feedback methods are designed by **D. Mishra** [30]. The first method performs when the signals radiated from different antennas are rotated by phasors with respect to the feedback from the receiver, whilst the second method is based upon antenna weighting/selection. Improvement in performance is observed and analysed when the signal transmitted is error controlled coded for the closed-loop methods.

After analysing the number of structures and characters of various issues of the quasi-orthogonal space-time block code (QO-STBC), **J. Hu et al.** [31], designed two new quasi-orthogonal space-time block codes for four antennas. Experiment results show that these two codes perform good as Jafarkhani schemes, whilst the decoding complexity is equivalent to other quasi-orthogonal codes. By using zero-forcing decoding equalization for the above codes, results that are simulated show that zero-forcing equalization has better bit error rate performance compared to the already existing emblematic codes and can further cut down the computation complexity at receiver side.

Z. Li et al. [32], proposed new decoding schemes for reducing complexity at the decoder. By using Quasi-ZF based on the traditional Zero Forcing technique and Quasi-MMSE based on the traditional minimum mean squared error (MMSE) technique, we can have channel interference parameter be zero. As a result, only diagonal components remain. Eventually, we can detect the transmitted symbols easily with single ML detector. The proposed scheme can be used in case that all channel interference parameters are pure imaginary values in QO-STBC. Quasi-orthogonal space-time block code (QO-STBC) accomplishes complete code rate however at the cost of loss in diversity gain. With a specific end goal to increase complete diversity and code rate, two feedback strategies are utilized for QO-STBC. In the primary technique, signals sent from different antennas are pivoted by phasors as per input from the recipient, though the second strategy depends on antenna weighting/determination. The execution enhancement is additionally examined for these closed-loop strategies when the sent signal is error control coded.

K. O. O. Anoh *et al.* [33] designed a simple QO-STBC implementation and assesed with improved performance. The Hadamard matrix is the basis for attaining full diversity. Hadamard matrix has the trademark that diagonalizes a quasi-cyclic matrix and therefore, a decoding matrix that allows linear decoding is achieved. The results showed full diversity and better performance.

Statistical relativity amid phases of the transmitted and received vectors has been a motivation to develop a fast decoding method for quasi-orthogonal space-time block codes (QO-STBCs) as presented by **A. Ahmadi** *et al.* [34] in this paper. The proposed algorithm can work with any sort of modulation format and supports orthogonal designs of STBC. It does so by exploiting phases of different vectors. The system designed outperforms existing models in terms of complexity in decoding due to fewer operations applied for computations.

A new method of expanding any QO-STBC to a closed-loop design for four transmit antennas is proposed on the basis of circulant matrix. With the assistance of QO-STBC code word entries multiplication by the befitting phase factors which rely on the channel information, the designed system can improve its diversity at transmitter side as said by **Z. Chen** *et al.* [35]. The simulations suggest that there is a considerable SNR reward in the designed scheme which is possible to be designed easily.

Space Time Block Codes (STBC) are broadly utilized as a part of MIMO systems for improvement in link performance. Quasi Orthogonal STBC (QO-STBC) and Constellation Rotation QO-STBC (CRQO-STBC) are examined to be suitable for more than two transmitting antennas. The performance of various STBC systems is influenced by correlated channel as proposed by **H. K. Shah** *et al.* [36]. The effects of correlation over CRQO-STBC and QO-STBC systems are presented in this paper. The comparison between CRQO-STBC and QO-STBC over correlated and uncorrelated channels is also discussed.

2.4 MIMO QO-STBC SYSTEM WITH QR DECOMPOSITION

A very low-complexity ML detection criterion on the basis of QR decomposition for QO-STBC i.e. LC-ML decoder has been designed by **Minh-Tuan Le** *et al.* [37]. This system appeared to remarkably reduce the complexity in detection as contrasted to the original ML decoder and can be employed in parallel.

M. Gao *et al.* [14] proposed two improved decoding algorithms based on conventional low-complexity maximum likelihood (LC-ML) detection algorithm for the quasi-orthogonal space-time block code (QO-STBC) with four transmit antennas. The decoding complexities of the proposed algorithms are both lower than LC-ML decoder. The first algorithm can detect the four signals individually by using QR decomposition while the second uses interference cancellation method twice.

2.5 TWDP FADING CHANNEL

G. D. Durgin *et al.* [38] presented different cases of prominent multipath wave components in the presence of various other diffuse paths to generate new pdfs to be referred in future. An appaling variety of fading behaviour is modelled in this paper which are responsible for analysing these fading measurements in newer ways. The pdfs and consecutive analysis for TWDP fading are the contributions in this paper.

S. A. Saberali *et al.* [17] derived two convergent infinite series for TWDP fading as PDF and CDF over the practical TWDP fading parameters range. For their evaluation, a low complexity criterion is designed. For the TWDP moments, infinite series solution are derived and expressed. At the end, BPSK system is evaluated in terms of BER under TWDP fading model.

The performance of SFBC-OFDM framework operated in TWDP fading environment is analysed and a general closed-form average BER equations for both M-QAM and M-PSK modulation formats are derived using TWDP fading model approximations by **D. Singh** *et al.* [39].

2.6 MIMO SYSTEM WITH SPECTRAL EFFICIENCY

In this letter by **B. Saikia** *et al.* [40], probability density function of SNR is utilized to get the equations for spectral efficiency with uncoded M-QAM operated in Two Wave Diffuse Power (TWDP) channel approximations. The TWDP characteristics is seen in an assortment of propagation situations and may happen for narrow band receiver operation in typical, utilization of directional antennas and wide band signals improve the TWDP small-scale fading likelihood. Simulations have been carried out for different parameters of interest and are then equated with the available particular case results for comparison.

The optimisation of energy consumption of a two-way AF cooperative MIMO system based on OSTBC under the constraint of data rate has been addressed by **E. B. Yahia** [41]. A geometric programs in posynomial form (gpposy) has been employed to solve the problem of minimizing the energy. Investigation has been carried out for different count of antennas; the location of relay and the predefined transmission of data rate on the total consumption of transmit energy. A comparison amid one- and two-way relaying energy consumption is done. Results simulated shows the considerable saving in transmit energy for the designed system. Additionally, results depict that for high data rates two-way MIMO systems are more energy efficient.

S. Verdu [42] in his paper, finds the basic bandwidth-power trade-off for a usual group of channels in the wideband regime defined on the basis of lesser spectral efficiency and energy per bit near to the lowest value required for trusted communication. A noval scheme is designed compared to the traditional scheme which proves out to be substantive for communication in a delimited bandwidth scenario.

The ideal fading gain exchanging thresholds for accomplishing maximum possible SE subject to a pre-decided BER and average power limitation are derived by **X. Yu** *et al.* [43]. MIMO systems with M-ary QAM and STBC operated in Rayleigh channel approximation are analysed for imperfect CSI. Lagrange multiplier existence is tested, which shows its existence and uniqueness when CSI is imperfect. Simulations have been done for spectral efficiency showing VP-AM scheme an effective reason of enhancing the spectral efficiency.

2.7 MIMO SYSTEM WITH ACHIEVABLE RATE

A Linear Pre-coding – LMMSE algorithm has been designed for linearly coded frameworks, along with the analytical techniques which are established to carry simulations for achievable rate of the above said algorithm in varied signalling. An area theorem is designed to show LP-LMMSE algorithm is lossless in terms of information for unconstrained data. The same theorem is designed in a way to evaluate AR of the algorithm with limited discrete data. In all, it is shown that a LP-LMMSE algorithm designed properly can accomplish the water-filling capacity of the channel by **X. Yuan** *et al.* [44].

Applications and the potential benefits of MIMO in spectrum sharing frameworks have been considered by **L. Wang** *et al.* [45]. A lower bound on the average achievable rate has been derived first which can be utilized to evaluate the performance later for as many number of antennas. Importance of using this system in the future band-sharing framework like 5G has been established on the basis of their analysis.

A MIMO fading broadcast channel is considered and ergodic achievable rates are measured by **G. Caire** *et al.* [46] for the case when CSI is not known to the receiver. This is then fed to the transmitter by feedback network. Among digital and analog, digital channel feedback is proved to be superior potentially. Both the case of non-faded AWGN feedback and faded MIMO multiple access are discussed in this paper after a comprehensive and rigorous analysis. The system focuses on FDD, though it can be expanded to TDD systems also.

H. Chong *et al.* [47] designed an improved model of QO-STBC for CCI that precludes the recurrent transmission of symbols by mapping them into the other symbol domain that will maximize the Euclidean distance between them. The codes designed have lesser decoding complexity relatively performing close to the linear decoder. Achievable rates for different transmitting schemes have been simulated. Simulations carried are validated by MC-simulation and is shown to be having higher coding gain than the conventional methods.

2.8 GAPS IN THE STUDY

From the literature survey done above, following gaps are encountered:

1. Due to the different coding schemes used, performance and capacity of the system varies and makes it difficult to define best suitable system [23, 24].

2. Due to imperfect knowledge of channel conditions and its random nature, there is ICI which leads to performance degradation [38]. More work needs to be carried out for reduction of ICI.

3. Error minimization and fading effects differ owing to the different detection algorithms used [14].

4. Different modulation methods can be used to observe the performance variations, but higher the modulation level, higher is the interference caused [48].

5. QO-STBC detection matrix has non-diagonal elements in it which cause interference, by using QR decomposition over it interfering elements are eliminated [37].

6. Due to different channel approximations used, BER performance varies for QO-STBC-D-QR [14, 30].

7. Spectral efficiency has not been considered for QO-STBC system [28].

8. Achievable rate has not been analysed for QO-STBC-D-QR system [47].

2.9 OBJECTIVE OF THE THESIS

The main objective of this research is to combine MIMO along with Quasi-Orthogonal Space time block codes over the TWDP channel and to investigate the results with their improved behaviour and also study its performance. Specific objectives of the research are:

1. To study the performance of existing MIMO-STBC systems and QR decomposition.
2. To propose a model with MIMO QO-STBC Double – QR decomposition using ZF detection and study its performance under TWDP wireless fading channel.
3. Performance analysis of proposed system with existing MIMO system with respect to metrics like BER, spectral efficiency and achievable rate.
4. To maximise the achievable rate of proposed system in comparison to the conventional system.

2.10 METHODOLOGY

To accomplish the objectives, first a MIMO system is considered with four transmitting and four receiving antennas. Then the input bits given to MIMO system are modulating using either M-ary PSK or M-ary QAM modulation techniques which were then pre-coded using quasi orthogonal space-time code in a way to produce multiple streams thus achieving spatial diversity and increased efficiency. Channel approximations used are AWGN, Rayleigh, Rician and TWDP models. At the receiver side, the interference and noise introduced due to the M-ary modelling and channel considerations are compensated by using double QR decomposition along with ZF detector. ZF detector is the inverse of the channel approximation.

Finally, the signal received is decoded and then demodulated with respect to the coding and modulation performed at transmitter side to recover the signals transmitted. Performance comparisons between conventional QO-STBC and QO-STBC-D-QR are done on the basis of parameters like bit error rate (BER), spectral efficiency and achievable rate plotted against signal to noise ratio (SNR).

CHAPTER 3

SPACE-TIME BLOCK ENCODING

Depending on requests for limit in wireless communications, controlled by mobile network, web and multimedia, services have been quickly expanding across the globe. Whilst on the other side, the accessible radio range is restricted and the correspondence limit demands can’t be achieved besides a noteworthy increment in correspondence spectral efficiency. Enhancements in spectral efficiency parameter are accessible via incrementing the count of antennas at either ends i.e. the transmitting and the receiving side, which is referred as multiple-input multiple-output (MIMO) channels. The limits on capacity feature the reasonable spectral efficiency of MIMO channels, which develops approximately in linear fashion with the amount of antennas, supposing perfect propagation. The limit is communicated by the most extreme achievable information rate for an arbitrarily low error probability, provided signal may be encoded by an arbitrarily long space-time code. In the communication having wireless medium, the attention has been attracted by MIMO technology, as considerable enhancement in data throughput and range of link is offered by it, without any demand of excessive bandwidth or transmit power. This intent is attained by scattering the equal total transmit power over the antennas in order to attain an array gain which improves the spectral efficiency or to acquire a diversity gain that enhances the reliability of the link, i.e. decreased effects of fading. Owing to these features, MIMO is a necessary unit of current communication standards having wireless medium like IEEE 802.11n, 4G, 3GPP LTE, Wi-MAX etc.

Space Time Block Codes are the easiest forms of spatial temporal codes that take advantage of the diversity provided in networks with fewer transmitting antennas. In 1998, a simple technique for diversity transmission was designed by S. Alamouti [10]. It consists of a system with 2 transmitting antennas. Complete diversity order was provided by this technique and non-complex operations are needed at both transmitting and receiving side. The encoding/decoding methods are done with blocks of transmission symbols. Theoretically, fewer forms can be taken by STBC but realistically, linear STBCs are far and away the most widely used. The main motive behind STBC is to scatter data symbols spatially in time to improve diversity gain/spatial multiplexing rate or both.

3.1 SPACE TIME CODING TECHNIQUES

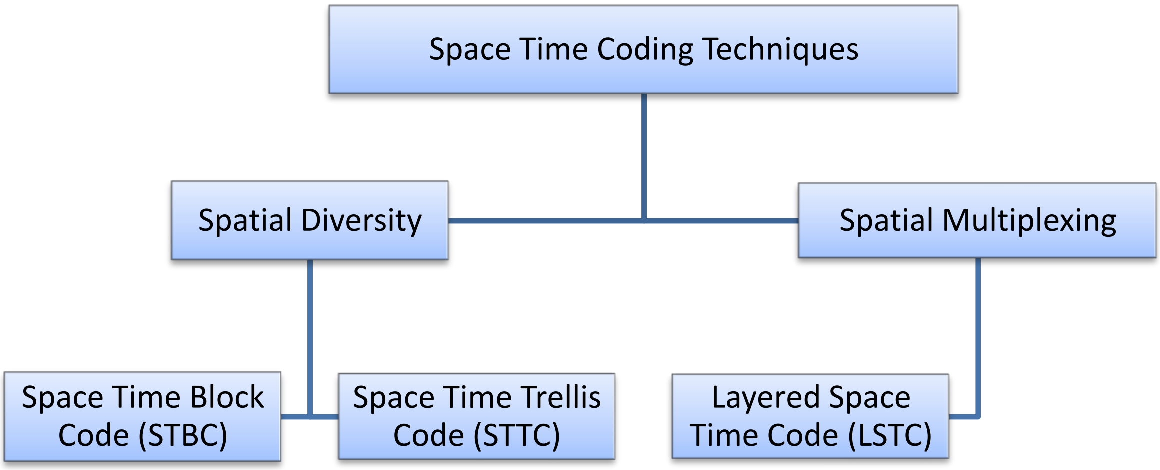

Figure 3.1 Space-Time Coding Techniques

Space time coding techniques are categorized accordingly two functions namely spatial diversity and spatial multiplexing. Dependent on these functions, they are classified as:

3.1.1 Spatial Diversity

a. Space Time Block Code (STBC)

Space time block coding is a least complex and useful way of acquiring transmits diversity. The generalization of these codes can be done easily to the instance of various receiving antennas, hence, providing receive diversity in addition to transmit diversity. Also, the decoding can be done efficiently at the receiver by applying linear processing on received signals at distinct receiver antennas. It provides diversity gain however no coding gain [8].

b. Space Time Trellis Code (STTC)

Space time trellis coding is an alternate coding method for MIMO systems. Its concept is equivalent to the concept of convolutional coding having a basic trellis structure that distinguishes the (coded) symbols to be transmitted via different antenna. Its main advantage is its “coding advantage” provided over the technique of STBC, only at the cost of large decoding complexity. It provides both diversity gain and coding gain.

3.1.2 Spatial Multiplexing

a. Layered Space Time Code (LSTC)

Based on the code structure, layered space time code provides bandwidth efficiency, transmission rate and diversity gain. A layered space time (LST) code is a channel code that is designed and processed according to the LST architecture

3.2 MIMO - SPACE TIME BLOCK CODING

Space time block codes have developed progressively throughout the years. Initially they fetched much importance because of their low decoding complexity and renewed interest owing to diversity-multiplexing trade off. Space Time Block Codes are the easiest sorts of spatial temporal codes that endeavour the diversity provided in systems with lesser count of transmitting antennas. In this, Q symbols (complex or real) are mapped onto a codeword (C). These codewords uncoded as error amending code are not used in STBC. Theoretically, STBCs may take a few structures, however for all intents and purposes; linear STBCs are by long shot the most generally utilized. The thought behind linear STBCs is to scatter information symbols in space and time with a specific end goal to improve diversity gain, spatial multiplexing rate or both [8, 49].

3.2.1 Alamouti Space-Time Coding

One of the 1st space time codes is because of Alamouti, who described the instance of two transmitting antennas (N_T = 2). In transmit diversity scheme [50, 51] consider we have sequence $[x_1, x_2, x_3, ..., x_n]$

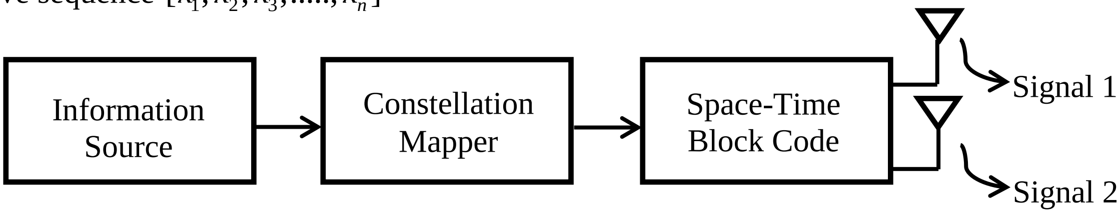

Figure 3.2 Spatial transmit diversity with Alamouti's space-time block code

Normally, x_1 is transmitted in 1st time slot and x_2 in 2nd time slot and so on. Alamouti suggested grouping the symbols into groups of two and simultaneously transmitting 2 complex symbols x_1 and x_2 during two time intervals by transmitting the following matrix:

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \tag{3.1}$$

In 1st time slot, S_1 and S_2 will be transmitted from antenna T_1 and T_2 and in 2nd time slot, S_2^* and S_1^* will be transmitted from antenna T_1 and T_2. Though the two symbols are grouped, still two time slots are required to transmit 2 symbols, i.e. no change in data rate. Now, in receive diversity scheme, in 1st time slot, the received signal will be:

$$Y_1 = h_1 x_1 + h_2 x_2 + n_1 = \begin{bmatrix} h_1 & h_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \tag{3.2}$$

And in 2nd time slot, the received signal will be

$$Y_2 = -h_1 x_2^* + h_2 x_1^* + n_2 = \begin{bmatrix} h_1 & h_2 \end{bmatrix} \begin{bmatrix} -x_2^* \\ x_1^* \end{bmatrix} + n_2 \tag{3.3}$$

where Y_1 and Y_2 are the symbols arrived in the 1st and 2nd slot, h_1 and h_2 are the channels from 1st and 2nd transmitter to receiver antennas respectively. x_1 and x_2 are symbols to be sent and n_1 and n_2 are noise on the 1st and 2nd time slot respectively.

$$E = \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \begin{bmatrix} n_1^* & n_2 \end{bmatrix} = \begin{bmatrix} |n_1|^2 & 0 \\ 0 & |n_2|^2 \end{bmatrix} \tag{3.4}$$

It is observed in [10] that BER for this system is similar to that of Maximal Ratio Combining (MRC). When transmitting from two antennas, total transmitter power will be twice with that used in MRC i.e. BER performance of 2 transmitters, 1 receiver case is 3dB poorer than 1 transmitter, 2 receivers MRC case [10, 52].

3.2.2 Orthogonal Space Time Block Code

S. Alamouti [10] designed the transmit diversity method using two transmit antennas only. This method belongs to a common category of codes namely STBC or OSTBCs, since they are dependent on the theory of orthogonal designs. The uncommon sub-class of linear STBC is orthogonal space time block codes (OSTBC) [53]. They have surprising features which to a great extent make them to be simply decodable, while accomplishing a full-diversity. To be sure, the end goal of OSTBC's is to decouple the MIMO ML decoding into few SIMO ML decoding. Within the same block, every transmitted symbol is decoded in this manner autonomously with respect to other transmitted symbols. However, OSTBCs have a substantially lesser spatial multiplexing rate than Spatial Multiplexing methods [54]. OSTBCs are linear STBCs described by the two following properties:

- The basis matrices are wide unitary.
- The basis matrices are pair wise skew-hermitian.

The attribution of 1st discussed OSTBC for 2 transmit antennas is given to Alamouti [10]. The advancement in the construction is done to higher amount of antennas in [11]. The development of codes is dependent on the theory of amicable orthogonal designs. The orthogonal codes are classified into two classes, namely real symbol constellations (real OSTBC) or complex symbol constellations (complex OSTBC). The designing of real OSTBCs with spatial multiplexing rate = 1 can be done for any amount of transmit antennas. The main motive of STBCs development is dependent on distinguishing coding matrices X that can fulfill the following condition:

$$X.X^H = p.\sum_{i=1}^{n} |x_i|^2 .I_{M_T} \tag{3.5}$$

In this equation, X^H denotes the Hermitian of X, I_{M_T} denotes the identity matrix of order M_T x M_T, where M_T is the amount of transmit antennas, and n is the total transmitted symbols (x_i) per transmission block in X. By the orthogonality property of STBC, it is meant that orthogonality lies among all rows of matrix *X*, i.e. the series sent from 2 distinct antenna elements are orthogonal to each other for each transmission block. It is possible for a real signal to achieve full rate. But for complex signals, it is not possible. The encoding/decoding is done as the pattern mentioned in Alamouti's scheme [55]. For complex signals, the coding matrices can be generated by using theory of orthogonal designs which achieve a transmission rate of 1/2 for the cases of 3 and 4 transmission antennas:

$$X_{1/2} = \begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \end{bmatrix} \tag{3.6}$$

For generating STBC's, the study of orthogonal design may not be the optimal approach. For 3 or 4 amount of transmit antennas, some sporadic provides the transmission rate of 3/4.

$$X_{3/4} = \begin{bmatrix} x_1 & -x_2^* & -x_3^* & 0 \\ x_2 & x_1^* & 0 & -x_3^* \\ x_3 & 0 & -x_1^* & x_2^* \end{bmatrix} \tag{3.7}$$

$$X_{3/4} = \begin{bmatrix} x_1 & 0 & x_2 & -x_3 \\ 0 & x_1 & x_3^* & x_2^* \\ -x_2^* & -x_3 & x_1^* & 0 \\ x_3^* & -x_2 & 0 & x_1^* \end{bmatrix} \tag{3.8}$$

While transmitting a block of symbols *X*, it must be noticed that the coefficients of channel must be fixed. The deduction of STBC's decoding from the encoding matrix is easy.

3.2.3 Quasi Orthogonal Space Time Block Code

STTC has been designed which joins the signal processing at the destination with coding structure suitable to numerous transmitting antennas and further gives a huge gain over [11]. But this system is complex so to improve on further, the space time coding gives the most ideal tradeoff amid constellation size, data rate, diversity advantage, and trellis complexity. After this various STBC techniques have been examined, Space Time Block Codes are the easiest forms of spatial temporal codes that take advantage of the diversity provided in networks with fewer transmitting antennas. A simple technique for diversity transmission designed by S. Alamouti [10] consists of a system with two transmitting antennas.

Strangely Orthogonal-STBC endures decreased code rates when complex constellation is required by high transmission rate necessity, and when the number of transmitting antennas is more than two. So to get over this, a new STBC technique – QO-STBC has been developed in [13], and [56]. This technique provided full rate with half of the maximum possible diversity. Development of this code depends on essential quasi-orthogonal designs. QO-STBC can be performed for more than two transmitting antennas unlike O-STBC. Rather than individual symbols, pair of transmitted symbols is decoded at same time in QO-STBC, and hence expanding the computational load which permits decoding to be done linearly [48].

$$X_{12} = \begin{bmatrix} x_1 & x_2 \\ x_2^* & x_1^* \end{bmatrix} \text{ and } X_{34} = \begin{bmatrix} x_3 & x_4 \\ x_4^* & x_3^* \end{bmatrix} \tag{3.9}$$

Now, the space time block code for 4X4 matrix having number of transmitter antennas (N_T) equals to number of receiver antennas (N_R = 4) is expressed as the standard Alamouti STBC [10]:

$$Z = \begin{bmatrix} X_{12} & X_{34} \\ X_{34} & X_{12} \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ x_3 & x_4 & x_1 & x_2 \\ -x_4^* & x_3^* & -x_2^* & x_1^* \end{bmatrix} \tag{3.10}$$

3.3 QUASI ORTHOGONAL – STBC WITH DOUBLE – QR DECOMPOSITION

The QO-STBC signal Z can be a M-ary phase shift modulated or M-ary quadrature amplitude modulated signal of length N. So unlike $N_T = 2$ case, the QO-STBC involves $N_T > 2$ antenna spaces. Now assuming $N_R = 1$ case, and combining QO-STBC signal with channel, the relation between transmitted and received signal can be written as:

$$\begin{bmatrix} y_1 \\ y_2^* \\ y_3 \\ y_4^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \\ n_3 \\ n_4^* \end{bmatrix} \tag{3.11}$$

$$\text{i.e. } \boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{n} \tag{3.12}$$

where $h_i = [h_1\ h_2\ h_3\ h_4]^T$, and $i = 1,..,4$ denote channel coefficients from transmitting antenna to receiver antenna. $\boldsymbol{H}$ is equivalent detection/channel matrix. At receiver side, first QR decomposition is performed in a way that it reduces the detection matrix to the following form

$$\boldsymbol{H} = \boldsymbol{Q_1 R_1} = \begin{bmatrix} r_1 & 0 & r_3 & 0 \\ 0 & r_1 & 0 & r_3 \\ 0 & 0 & r_2 & 0 \\ 0 & 0 & 0 & r_2 \end{bmatrix} \tag{3.13}$$

where $\boldsymbol{R_1}$ is an upper triangular matrix and $\boldsymbol{Q_1}$ is an unitary matrix.

When $N_R = 1$, channel matrix $\boldsymbol{H}$ in equation (3.12) can be written explicitly as

$$H = \begin{bmatrix} h_{1,1} & h_{2,1} & h_{3,1} & h_{4,1} \\ h_{2,1}^* & -h_{1,1}^* & h_{4,1}^* & -h_{3,1}^* \\ h_{3,1} & h_{4,1} & h_{1,1} & h_{2,1} \\ h_{4,1}^* & -h_{3,1}^* & h_{2,1}^* & -h_{1,1}^* \end{bmatrix} \tag{3.14}$$

Entries of ***R*** can be obtained by using following operations [14, 37]:

$$R_{1,1} = \left\| h_1 \right\| = \sqrt{\left|h_{1,1}\right|^2 + \left|h_{2,1}\right|^2 + \left|h_{3,1}\right|^2 + \left|h_{4,1}\right|^2} \tag{3.15}$$

$$R_{1,2} = \frac{1}{R_{1,1}} h_1^H h_2 = 0 \tag{3.16}$$

$$R_{1,3} = \frac{1}{R_{1,1}} h_1^H h_3 = \frac{2\,\mathrm{Re}\left\{h_{1,1}^* h_{3,1} + h_{2,1}^* h_{4,1}\right\}}{R_{1,1}} \tag{3.17}$$

$$R_{1,4} = \frac{1}{R_{1,1}} h_1^H h_4 = 0 \tag{3.18}$$

$$R_{2,2} = \left\| h_2 \right\| = \sqrt{\left|h_{1,1}\right|^2 + \left|h_{2,1}\right|^2 + \left|h_{3,1}\right|^2 + \left|h_{4,1}\right|^2} \tag{3.19}$$

$$R_{2,3} = \frac{1}{R_{2,2}} h_2^H h_3 = 0 \tag{3.20}$$

$$R_{2,4} = \frac{1}{R_{2,2}} h_2^H h_4 = \frac{2\,\mathrm{Re}\left\{h_{1,1}^* h_{3,1} + h_{2,1}^* h_{4,1}\right\}}{R_{2,2}} \tag{3.21}$$

$$R_{3,3} = \sqrt{h_3^H h_3 + R_{1,3}^2 - \left(h_3^H h_1' + \left(h_1'\right)^H h_3\right)} \tag{3.22}$$

$$R_{3,4} = \frac{1}{R_{3,3}} \left(h_3^H h_4 - \frac{R_{1,3}^*}{R_{1,1}} h_1^H h_4 \right) = 0 \tag{3.23}$$

$$R_{4,4} = \sqrt{h_4^H h_4 + R_{2,4}^2 - \left(h_4^H h_2' + \left(h_2'\right)^H h_4\right)} \tag{3.24}$$

where $h_1' = \left(\frac{R_{1,3}}{R_{1,1}}\right) h_1$ and $h_2' = \left(\frac{R_{2,4}}{R_{2,2}}\right) h_2$. The entries of ***R*** confirm the form of ***R*** in equation (3.13). Further, on evaluating we get $R_{1,1} = R_{2,2}$ and $R_{1,3} = R_{2,4}$. Now further multiplying both the sides of (3.12) with Q_1^H, we get

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} r_1 & 0 & r_3 & 0 \\ 0 & r_1 & 0 & r_3 \\ 0 & 0 & r_2 & 0 \\ 0 & 0 & 0 & r_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \tag{3.25}$$

$$\text{i.e. } \hat{\boldsymbol{y}} = \boldsymbol{R_1 x} + \hat{\boldsymbol{n}} \tag{3.26}$$

For performing QR decomposition for the second time as in [14], $\boldsymbol{H}$ and $\boldsymbol{x}$ can be rewritten as:

$$H'x' = \begin{bmatrix} h_4 & h_3 & h_2 & h_1 \\ -h_3^* & h_4^* & -h_1^* & h_2^* \\ h_2 & h_1 & h_4 & h_3 \\ -h_1^* & h_2^* & -h_3^* & h_4^* \end{bmatrix} \begin{bmatrix} x_4 \\ x_3 \\ x_2 \\ x_1 \end{bmatrix} \tag{3.27}$$

$$\text{i.e. } \boldsymbol{y'} = \boldsymbol{H'x'} + \boldsymbol{n} \tag{3.28}$$

using QR decomposition, $\boldsymbol{H'}$ can be represented as

$$\boldsymbol{H'} = \boldsymbol{Q_2 R_2} = \begin{bmatrix} r_4 & 0 & r_6 & 0 \\ 0 & r_4 & 0 & r_6 \\ 0 & 0 & r_5 & 0 \\ 0 & 0 & 0 & r_5 \end{bmatrix} \tag{3.29}$$

Now again multiplying both the sides of (3.28) with Q_2^H, we obtain

$$\begin{bmatrix} y'_1 \\ y'_2 \\ y'_3 \\ y'_4 \end{bmatrix} = \begin{bmatrix} r_4 & 0 & r_6 & 0 \\ 0 & r_4 & 0 & r_6 \\ 0 & 0 & r_5 & 0 \\ 0 & 0 & 0 & r_5 \end{bmatrix} \begin{bmatrix} x_4 \\ x_3 \\ x_2 \\ x_1 \end{bmatrix} + \begin{bmatrix} n'_1 \\ n'_2 \\ n'_3 \\ n'_4 \end{bmatrix} \tag{3.30}$$

$$\text{i.e. } \widehat{\boldsymbol{y}'} = \boldsymbol{R_2}\boldsymbol{x}' + \widehat{\boldsymbol{n}'} \tag{3.31}$$

Now merging 3rd, 4th rows of (3.19) and 3rd, 4th rows of (3.14) into the following form:

$$\begin{bmatrix} y'_4 \\ y'_3 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} r_5 & 0 & 0 & 0 \\ 0 & r_5 & 0 & 0 \\ 0 & 0 & r_2 & 0 \\ 0 & 0 & 0 & r_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} n'_4 \\ n'_3 \\ n_3 \\ n_4 \end{bmatrix} \tag{3.32}$$

So in equation (3.32) a channel matrix with only diagonal elements is achieved. Hence an interference free detection matrix is obtained. Further the symbols sent can be recovered using linear detection methods like ZF equalizer at the receiver side

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3.4 TWDP FADING CHANNEL

Fading channel is the medium amid transmitter and receiver which plays an important role in signal estimation at the receiver. The fading channel used in evaluation of the system in this thesis is TWDP. TWDP stands for Two-Wave with Diffuse Power. This channel model assumes that the signal received has relatively two strong multipath components i.e. unlike Rayleigh which has no LOS path and Rician which has one LOS path component; TWDP has two LOS path components. The mathematical TWDP fading model is expressed as [17]

$$V = V_1 e^{i\theta_1} + V_2 e^{i\theta_2} + V_{dif} \tag{3.33}$$

where $\tilde{V}$ is the signal received, V_1, V_2 the amplitudes of two LOS components and θ_1, θ_2 represent the phases of those two components. The CSI for each channel is presumed to be known at the receiver. As no exact closed form representation of TWDP fading was there, so a group of pdfs were derived in [38] which estimate the TWDP pdf.

One of the most widely recognized strategies for portraying a fading channel is the utilization of a probability density function (pdf), which depicts the likelihood of the quality and strength of the signal received. The state of the pdf decides the execution of receiver placed wirelessly even when interference and noise are present. So the pdf of TWDP as approximated in [17] is defined as:

$$p(r) \approx \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2} - K \right) \sum_{i=1}^{M} a_i D\left(\frac{r}{\sigma}; K; \Delta \cos \frac{\pi(i-1)}{2M-1} \right) \tag{3.34}$$

where

$$K = \frac{V_1^2 + V_2^2}{2\sigma^2}, \quad \Delta = \frac{2V_1V_2}{V_1^2 + V_2^2} \tag{3.35}$$

$$D(x;K;\alpha) = \frac{e^{\alpha K}}{2} I_0\left(x\sqrt{2K(1-\alpha)} \right) + \frac{-e^{\alpha K}}{2} I_0\left(x\sqrt{2K(1+\alpha)} \right) \tag{3.36}$$

I_o is the zeroth-order Bessel function of the 2nd kind and

$$a_i = \frac{2(-1)^i}{(2M-1)(2M-i)!(i-1)!} \int_0^{2M-1} \prod_{\substack{k=1 \\ k \neq i}}^{2M} (u-k+1)du \tag{3.37}$$

In Equation (3.37), M stands for the order of the approximation used in (3.34) and as a rule of thumb, $M \geq \frac{1}{2} K\Delta$ is recommended. The TWDP fading channel and its envelope pdf can give extra knowledge that clarifies various situations. For instance, when the two strong multipath components in TWDP fading are equivalent in terms of strength but contrary in terms of phase when received at receiver, the system can perform worst as it can perform poor than Rayleigh channel. This is noteworthy as the Rayleigh approximations are frequently taken as the most pessimistic scenario in outlining the communication model.

3.5 SPECTRAL EFFICIENCY

Spectrum efficiency cites to the data rate or information rate transmitted under a pre-determined spectrum/bandwidth in a particular communication framework. The trade-off bandwidth vs power is reflected in the tradeoff of the information-theory quantities such as

Spectral Efficiency and SNR. The concept used is to proximate spectral efficiency as a function of SNR in decibels. The terms used are bandwidth *B* (Hz), transmitted power P_s (W), and data rate *R* (b/s). For a practical communication system, the rate *R* should be lower than the capacity C [42], i.e.

$$R < B\log_2\left(1+\frac{P_s}{N_0 B}\right) bits/second \tag{3.38}$$

where N_0 stands for the noise. Normalizing both sides with respect to bandwidth *B*, we get

$$\frac{R}{B} < \log_2\left(1+\frac{P_s}{N_0 B}\right)\frac{R}{B} bits/second/Hz \tag{3.39}$$

Now since symbol to noise ratio is *R* times the bit to noise ratio, i.e.

$$\frac{P_s}{N_0} = R\frac{E_b}{N_0} \tag{3.40}$$

where E_b is the bit energy. Substituting this to (3.39), we get

$$\frac{R}{B} < \log_2\left(1+\frac{R}{B}\frac{E_b}{N_0}\right) bits/second/Hz \tag{3.41}$$

Let spectral efficiency be defined by *r* in bits/second/Hz, so the above equation can be reduced to

$$\frac{E_b}{N_0} > \frac{2^r-1}{r} \tag{3.42}$$

In which when *r* tends to zero, the bit to noise ratio would be

$$\frac{E_b}{N_0} > \lim_{r\to 0}\frac{2^r-1}{r} \tag{3.43}$$

There is no guaranteed feasibility for the absolute solution of equation (3.43), the absolute representation for spectral efficiency with respect to SNR are moderately uncommon.

Luckily, it is likely in the system with lesser spectral efficiency to bypass not just the solution of equation (3.43) which carries non-linearity, however also the computation of capacity.

3.6 ACHIEVABLE RATE

In this section, an expression for achievable rate is defined which is further used to analyse the designed system's performance behaviour. In this work, a realistic system model is designed with different channel fading and then the bounds of achievable rate are put to it. The essential test is attenuation of interference caused, and the ordinary objective is portraying the highest possible achievable rate under the constraint of transmitted power. The work done earlier utilized the worst case dissimilar noise to demonstrate that the imperfect CSI, in a terrible situation, prompts the presentation of AWGN and therefore the achievable rate is bounded by mutual information [46]. The objective here is to maximize the rate achievable of designed QO-STBC-D-QR system in contrast to the conventional QO-STBC system.

For ordinary MIMO system with hardware ruination, there exists a finite ceiling of achievable rate which is autonomous of transmit power and fading scenarios. If the MIMO system considered is large in scale, then the loss in achievable rate relies on the Rician *K*-factor. This achievable rate is defined as [45, 47]

$$AR = 2c_r\left(1-e\right) \tag{3.44}$$

where c_r is the code rate and e stands for the Bit Error Rates of the symbols for respective system.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this section, the performance analysis of proposed system model of MIMO system has been analysed. The analysis is done by taking various metrics, in order to evaluate designed system's performance. The performance is evaluated over different fading channel and then compared for the best results. The signal is encoded using Quasi Orthogonal STBC system before transmission and the reconstruction of signal is done by using zero-forcing decoder at the receiver. The response of proposed system for higher order modulation like 1024-PSK and 1024-QAM has also been presented.

4.1 QO-STBC D-QR SYSTEM

The fundamental QO-STBC D-QR system presented in this thesis is validated by comparing with the results obtained in [14] and hence is bench-marked.

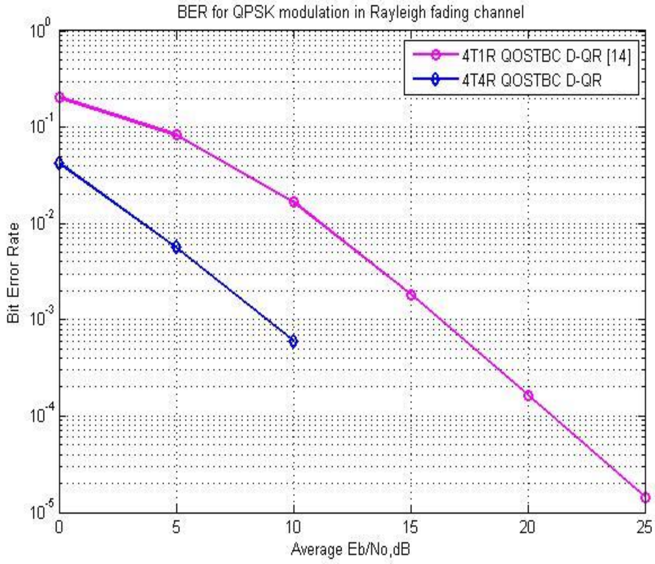

Figure 4.1 BER comparison of QOSTBC D-QR scheme using QPSK modulation over Rayleigh fading channel with [14].

From Figure 4.1, it can be analysed that BER performance of QOSTBC D-QR scheme using QPSK modulation for 4T4R MIMO system is better than 4T1R system proposed in [14]. It is observed that at 5 dB SNR, 0.0056 BER is achieved for system designed in this thesis whilst system in [14] has BER of 0.08251. So performance improvement is observed when 4T4R MIMO system is used instead of 4T1R.

Further in this chapter, the conventional QO-STBC system and this designed QO-STBC D-QR system are compared initially. Then it is extended for different parameters to analyse this designed system more deeply. The performance analysis of BER for the proposed system will be done using QO-STBC with Double-QR decomposition.

4.2 BER ANALYSIS

In this section, the BER of proposed system is presented under different wireless fading channels like AWGN, Rayleigh, Rician and TWDP fading channels and then compared for the best results. Initially, the analysis is done between BER and SNR values for only QPSK modulation to draw the comparison amid different fading channels. After comparing the results of designed system for different fading channels, the best channel in terms of BER performance is chosen for further analysis.

The simulations carried in this section are for 4transmitting and 4 receiving antennas (4T4R) for QO-STBC encoded MIMO system using Double-QR decomposition at the transmitter side and using Zero Forcing equalization at the receiver side for QPSK modulation format under different fading channels.

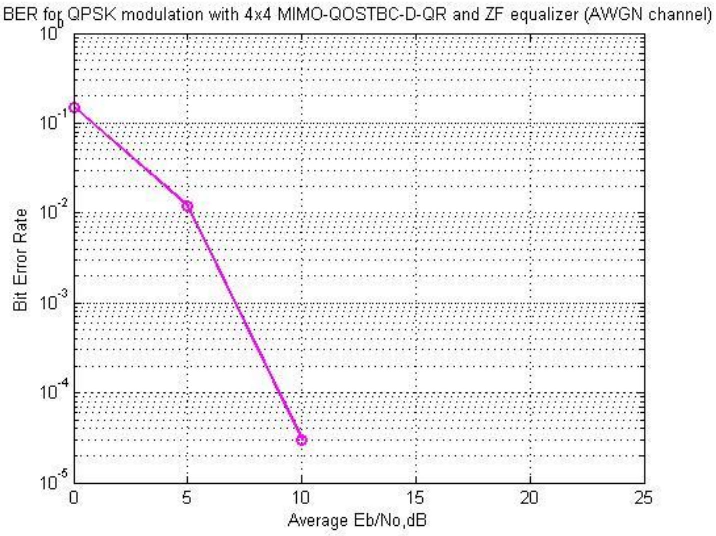

Figure 4.2 BER vs. SNR plot for QO-STBC-D-QR scheme using QPSK modulation scheme over AWGN channel.

The representation of BER vs. SNR plot of MIMO system with QPSK modulation over AWGN channel for 4T4R configuration using QO-STBC D-QR with zero forcing detector is given in Figure 4.2. As can be observed from the Figure 4.2, the designed system imparts SNR of approximately 7dB at BER of 10^{-3} when the channel distortions dealt with is Additive White Gaussian Noise and the detector used is linear. Also it can be validated that a 4T4R system performs better in terms of BER than 4T1R system owing to the space diversity. Further, it is analyzed that higher value of SNR results in the improved system efficiency.

Next, the BER performance of QO-STBC-DQR system compared with the conventional QO-STBC system over Rayleigh channel using QPSK modulation format for respective SNR values and is presented in Figure 4.3.

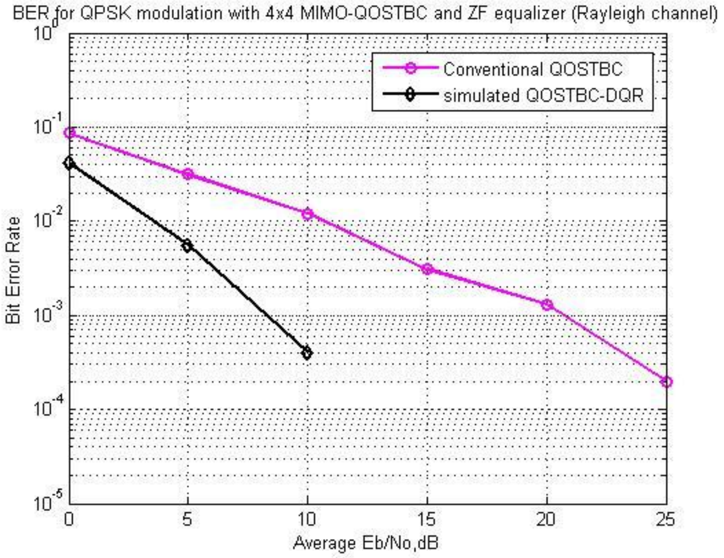

Figure 4.3 BER vs SNR plot for conventional QO-STBC and QO-STBC-DQR scheme using QPSK modulation scheme over Rayleigh channel.

The evaluation of BER of MIMO system over Rayleigh channel is done by using QO-STBC coding method in Figure 4.3 and it ascertains that the QO-STBC-DQR scheme in comparison to conventional QO-STBC system causes increase in the coding gain. Also the result converges slowly when channel under consideration is Rayleigh approximation in contrast to the quick convergence for the case of AWGN as in Figure 4.2. The designed system imparts SNR of approximately 8.2dB at BER of 10^{-3} when the system is operated in Rayleigh channel modeling and the linear detector is Zero-forcing equalizer.

Figure 4.4 depicts the BER plot of QO-STBC-DQR system contrasted to the conventional QO-STBC system operated in Rician channel for QPSK modulation format with 4T4R antenna configurations by utilizing zero forcing detector for respective SNR values.

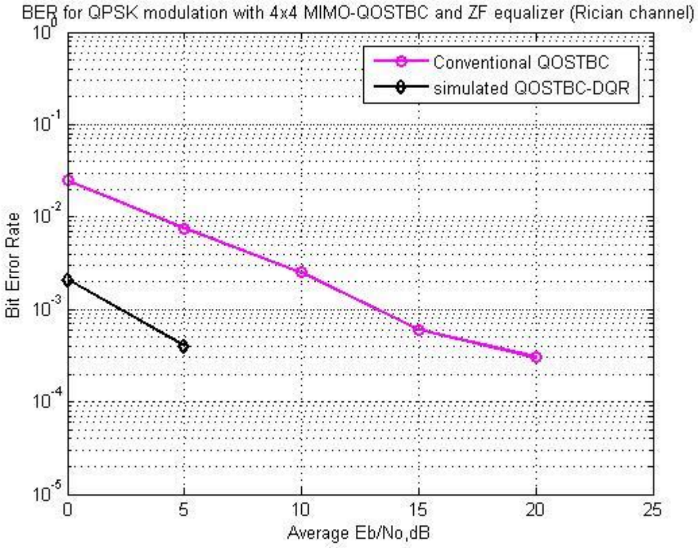

Figure 4.4 BER vs. SNR plot for conventional QO-STBC and QO-STBC-DQR scheme using QPSK modulation scheme over Rician channel.

It can be interpreted from Figure 4.4 that the QO-STBC-DQR scheme in comparison to conventional QO-STBC system over Rician channel causes further increase in the coding gain when compared with the same system operated in Rayleigh channel approximation. The result converges even quickly for Rician channel. SNR of approximately 2.5dB is observed at BER of 10^{-3} i.e. around 5.7dB improvement is seen. This owes to the LOS component considered for Rician channel.

Figure 4.5 displays performance comparison of QO-STBC-DQR system compared with the conventional QO-STBC system in terms of BER and operated in TWDP fading channel for QPSK modulation format for respective SNR values. The detection for the system is done using linear detector namely, zero-forcing equalizer.

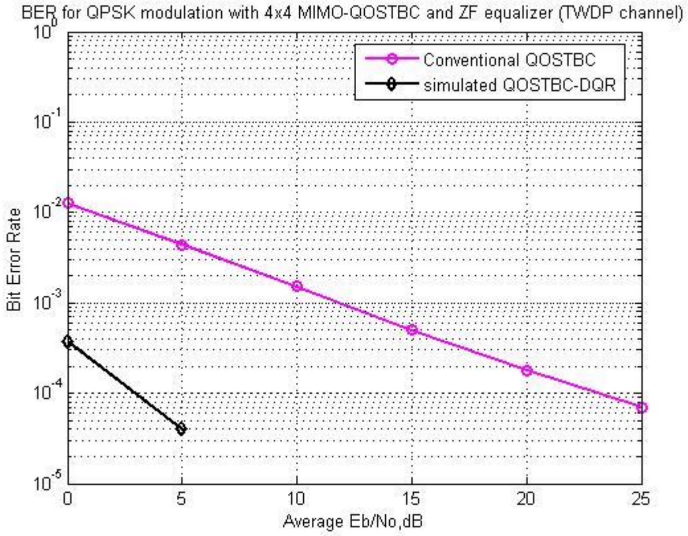

Figure 4.5 BER vs. SNR plot for conventional QO-STBC and QO-STBC-DQR scheme using QPSK modulation scheme over TWDP channel.

QO-STBC-D-QR scheme in comparison to conventional QO-STBC system causes increase in the coding gain as can be observed in Figure 4.5. Also it is analyzed that in TWDP channel the same system performs better than in Rayleigh and Rician channel. So the best results among all channels are obtained when TWDP channel is considered. The result of the Figure 4.5 converges quickest of all the previous figures. Thus TWDP channel approximation proves out to result the best compared to others.

Wireless Fading Channel	SNR Values (in dB)
Additive White Gaussian Noise	7
Rayleigh Channel	10
Rician Channel	5
Two Wave with Diffuse Power	1

Table 4.1 SNR values at $10^{-3.4}$ BER for various fading channels in 4T4R MIMO QOSTBC D-QR system using QPSK modulation.

Table 4.1 depicts the SNR values of the QO-STBC D-QR system at $10^{-3.4}$ BER for only QPSK modulation but over four different channels, which indicates that for Rayleigh channel SNR is 10dB, for Rician channel it is 5dB and for TWDP channel it is 1dB. Hence an improvement of 9dB from Rayleigh and 4dB from Rician is observed for TEDP channel.

Table 4.1 shows that among all fading channels, TWDP fading channel results in the better BER performance.

4.3 MODULATION SCHEME COMPARISON

In this section, further comparison between M-PSK and M-QAM for different values of M such as 8, 16, 32, 64, 128, 256, 512 and 1024, for a QO-STBC-D-QR system for 4X4 MIMO system under TWDP fading in terms of BER for different SNR values is presented. Figure 4.6 shows the performance of QO-STBC-DQR system for 4X4 MIMO system in TWDP channel for M-PSK modulation format with M = 8, 16, 32, 64, 128, 256, 512 and 1024-PSK in terms of BER.

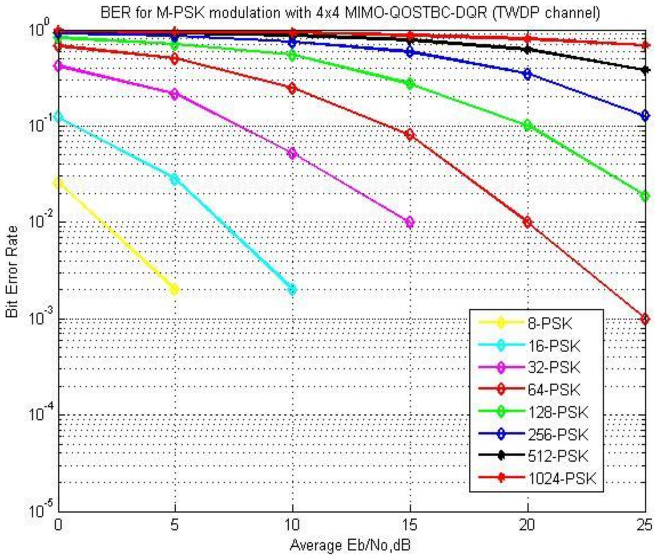

Figure 4.6 BER vs. SNR plot for 4X4 MIMO QO-STBC-DQR scheme using M-PSK modulation scheme with M=8, 16, 32, 64, 128, 256, 512 and 1024 under TWDP channel.

It is analyzed from Figure 4.6, the QO-STBC-DQR scheme in TWDP channel shows decrease in the coding gain as the M is increased in M-PSK modulation. The graphs are plotted by increasing the modulation level from 8-PSK to 1024-PSK, which provides the variations in the signal received and its recovery depending upon the increased modulation level. Increasing M implies more number of bits can be transmitted per symbol thus increasing the data rate and efficiency at the expense of Inter-Symbol interference which is then compensated by using QO-STBC-D-QR system as it provides an interference-free detection matrix.

Figure 4.7 presents the BER performance of QO-STBC-D-QR system for 4T4R MIMO system in TWDP channel for M-QAM modulation format with M = 8, 16, 32, 64, 128, 256, 512 and 1024-QAM at respective values of SNR and using zero-forcing equalizer at the receiver.

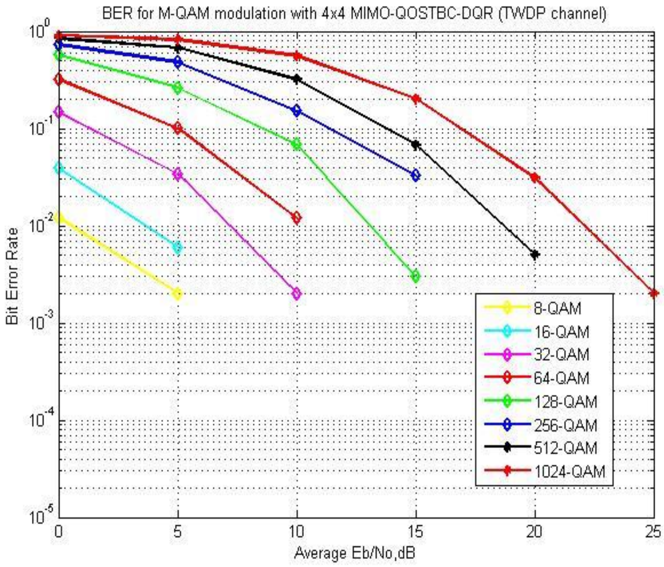

Figure 4.7 BER vs. SNR plot for 4X4 MIMO QO-STBC-DQR scheme using M-QAM modulation scheme with M=8, 16, 32, 64, 128, 256, 512 and 1024 under TWDP channel.

From Figure 4.7, it is observed that the QO-STBC-DQR scheme in TWDP channel shows decrease in the coding gain as the M is increased in M-QAM modulation. The graphs are plotted by increasing the value of M from 8-QAM to 1024-QAM. When close analysis is done, it gets clear that the system efficiency is reduced with higher level of modulation. For instance, at 10^{-2} BER 16-QAM shows SNR of approximately 4 dB whereas 32-QAM shows SNR of approximately 7 dB at the same BER, thus as M is increased to 32 the performance worsens.

Modulation Technique	**BER values for various M values under TWDP channel at 5dB SNR**							
	M=8	**M=16**	**M=32**	**M=64**	**M=128**	**M=256**	**M=512**	**M=1024**
MPSK	0.002	0.028	0.216	0.507	0.704	0.861	0.908	0.956
MQAM	0.002	0.006	0.034	0.101	0.261	0.48	0.678	0.822

Table 4.2 BER values at 5dB SNR for various values of M in 4T4R MIMO QOSTBC D-QR system using MPSK and MQAM modulation.

It can be inferred from Table 4.2 that 32-PSK has 5dB SNR at the BER of 0.216 whilst for 32-QAM, 0.034 BER is achieved at same SNR which proves that M-QAM scheme performs better in contrast to M-PSK scheme. Also it can be observed that as modulation level increases, systems performance degrades in terms of BER which means that a 16-PSK or 16-QAM performs better than 32-PSK or 32-QAM respectively.

4.4 ANALYSIS ON SPECTRAL EFFICIENCY

Now, after analyzing that for designed system, best wireless fading channel is TWDP and that the lower level modulation i.e. QPSK is best among higher M-PSK formats, the spectral efficiency of QO-STBC-D-QR system operated in the TWDP channel for QPSK modulation format at different values of SNR is presented in Figure 4.8. This parameter is studied to answer how efficient the designed system spectrally is.

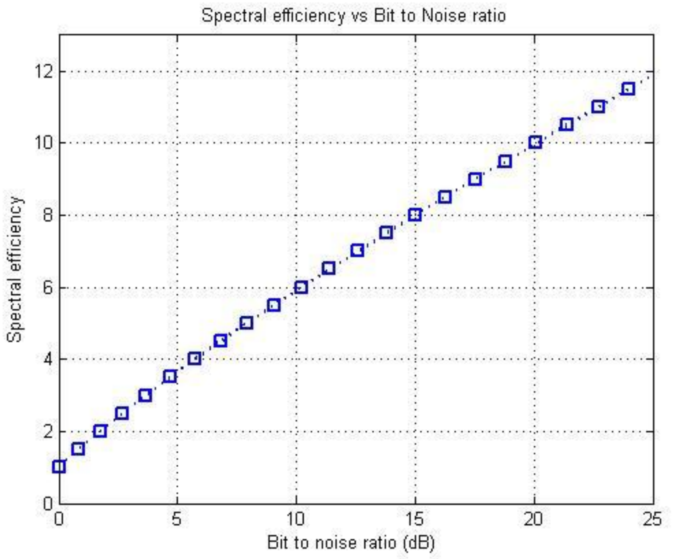

Figure 4.8 Spectral efficiency vs. Signal to Noise ratio plot for QO-STBC D-QR scheme using QPSK modulation.

For higher SNR range, spectral efficiency varies approximately linearly and for lower it is slightly non-linear as depicted by Figure 4.8. So as the SNR increases, spectral efficiency also increases. When compared with results of [43], which are for 4X1 STBC-MIMO system, this system shows higher spectral efficiency owing to increased receiver antennas and to this QO-STBC-D-QR scheme used.

4.5 COMPARISON ON THE BASIS OF ACHIEVABLE RATE

This section further analyzes the achievable rate metric by comparing conventional QO-STBC and designed QO-STBC-D-QR system as depicted in Figure 4.9 for 4T4R antenna configuration using zero-forcing equalizer. The fading channel under consideration for this analysis is TWDP fading model and the modulation used is QPSK.

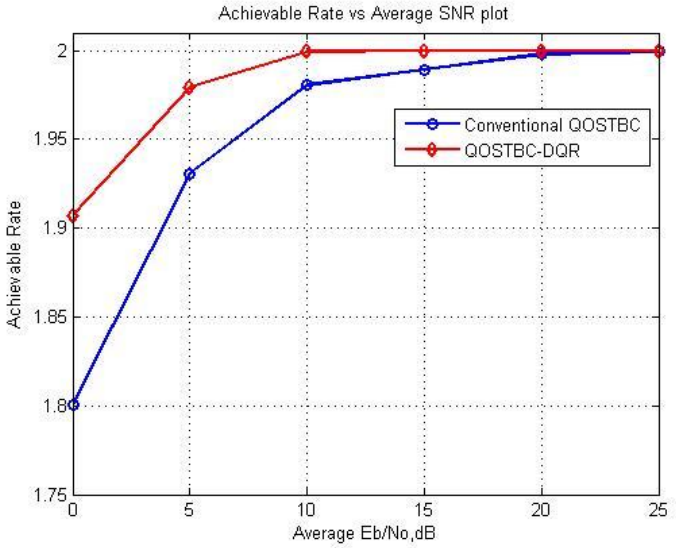

Figure 4.9 Achievable rate vs. SNR for 4T4R MIMO system.

In Figure 4.9, it is observed that achievable rate of this QO-STBC-D-QR scheme is higher than the conventional system. For a particular achievable rate, the new method utilizes approximately 3dB SNR and conventional uses approximately 7dB, thus making the QO-STBC-D-QR better than the conventional. Further it is observed that there exist rate ceilings at high SNR owing to the interference constraint thus confirming the system to be realistic as rate ceilings exists for the real time systems only [45, 46].

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In this thesis work, the performance of a MIMO system using QO-STBC-D-QR decomposition over TWDP channel for M-ary Phase Shift Keying and M-ary Quadrature Amplitude Modulation formats with Zero Forcing detector is presented. This implementation is done using M-PSK and M-QAM in which values of M = 8, 16, 32, 64, 128, 256, 512 and 1024 are used in order to enhance the rates of transmission of data and the efficiency of the system. The space time block codes used for the transmission are Quasi-orthogonal space time block code. The signal is then modulated and arranged in the form of QO-STBC detection matrix. Now, since this detection matrix has non-diagonal elements in it which cause interference, so to eliminate this double-QR decomposition is used in a particular way. The QOSBTC encoded form of the signal is decoded at the receiver using zero-forcing detector. It is shown in the results that QO-STBC-D-QR system for a said modulation technique, operated in AWGN, Rayleigh, Rician and TWDP fading channel model, results best when the channel used is TWDP fading model as compared to conventional MIMO system. So the result converges quickest for TWDP channel implying that for a given SNR, lowest BER is achieved. Also it is proved that the designed QO-STBC-D-QR system performs better than the conventional QO-STBC system for a said MIMO system. It can also be concluded observing from the work done before and work done in this that the increase in the count of antennas in a MIMO system results in the better BER performance; for simulations in this work, 4X4 MIMO system is used. Further it is inferred from the results that the BER performance of 8-PSK and 16-PSK modulation format is better than the BER performance of 32-PSK, and so on up to 1024-PSK modulation level. Similarly, the BER performance of 8-QAM and 16-QAM modulation format is better than the BER performance of 32-QAM, and so on up to 1024-QAM modulation level, i.e. an increase in the modulation level degrades the system performance. Comparing the results obtained from M-PSK and M-QAM modulation formats, for a given value of M, the BER performance of QAM is better than that of PSK. Further it is observed that spectral efficiency of the designed system is higher when compared with the existing systems owing to the increase in count of receiver antennas and to the D-QR system used. Further, on comparing QO-STBC-D-QR system with the conventional QO-STBC system in terms of achievable rates for a said SNR, it is ascertained that the QO-STBC-D-QR system is better than the conventional system. Therefore, the overall result discussed in this thesis is that there is an inverse relationship between the BER and the SNR values; and the count of receiver antennas and the BER along with the SNR; and direct relationship amid spectral efficiency and achievable rate.

5.2 FUTURE SCOPE

In future, this work can be extended to analyse the performance of MIMO system using QO-STBC-D-QR scheme by applying rotation along with the other high rate space-time block codes. Work can be done by incorporating this system to the image transmission and with different receiver architectures over different fading channels. Spatial multiplexing can be used further to enhance the performance. The work can also be extended to ameliorate the reconstruction performance of the image using different detectors like MMSE, ML etc. Designed system can be implemented by boosting the count of antennas at both transmitting and receiving end, with a view to enhance the system performance. Different algorithms can also be utilized for better recovery.

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