

**PERFORMANCE ANALYSIS OF CYCLIC PREFIX FREE STBC
ENCODED MIMO-OFDM SYSTEM USING OBLIQUE
PROJECTION TECHNIQUE**

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

of

MASTER OF ENGINEERING

In

Wireless Communication Engineering

Submitted By

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(Established under the section 3 of UGC Act, 1956)

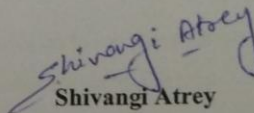
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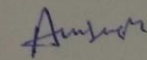
I, Shivangi Atrey hereby declare that the work presented in this thesis entitled "Performance Analysis of Cyclic Prefix Free STBC Encoded MIMO-OFDM system using Oblique Projection Technique" in partial fulfillment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Engineering Department, Thapar University, Patiala is an authentic record of work carried out under supervision of Dr. Ankush Kansal (Assistance 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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ACKNOWLEDGEMENT

Words are not enough to thank my guide I take this opportunity to acknowledge the guidance and encouragement of my guide **Dr. Ankush Kansal**, Assistant Professor, Electronics and Communication Engineering Department, Thapar University, Patiala. I have been inspired by his meticulousness, his attention to detail and his energetic application to any problem. I value his concern and support at all times, good and bad.

I am also thankful to **Dr. Alpana Agarwal**, Head, Electronics and Communication Engineering Department, for providing us with the adequate infrastructure in carrying the work.

I am also thankful to **Dr. Hem Dutt Joshi**, P.G. Coordinator, Electronics and Communication Engineering Department, for the motivation and inspiration that triggered me for the thesis.

Finally, I would like to extend my gratitude to all those persons who directly or indirectly helped me in the process and contributed towards this work.

Above all I thank the Almighty God who is being with me and showers his blessings and grace towards me in all walks of my life.

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ABSTRACT

In today's era demand related to multimedia services are increasing rapidly. On the other hand, bandwidth is a scarce resource. So, the technologies which possess bandwidth efficiency are adopted to overcome this problem. This necessity of achieving high data rate and bandwidth efficiency draws attention towards Orthogonal Frequency Division Multiplexing (OFDM). To provide spatial diversity, multiple antennas at both transmitter and receiver are used, which further enhances the performance of OFDM system. An arrangement of multiple antennas at both transmitter and receiver is known as Multiple Input and Multiple Output (MIMO). MIMO together with OFDM is the recently proposed technique for next generation wireless systems. Although, this combination has many merits, but it has some disadvantages too like Inter Carrier Interference (ICI) and computational complexity. According to available literature, the conventional MIMO-OFDM system uses CP (Cyclic Prefix). CP is an overhead on the transmitted signal which is used to remove Inter-Symbol Interference (ISI). It should be noted that the length of CP will be greater than the delay spread. If this condition is not followed then ISI will also remain with ICI.

This thesis considers CP free MIMO-OFDM model in two steps, firstly, frequency domain (FD) using decision feedback equalizer (DFE) with oblique projection (OB) to reduce the effect of ICI and ISI. Secondly, to decrease the number of computations V-BLAST with QR-decomposition (QRD) has been proposed.

From the simulation results, it has been observed that the bit error rates performance for proposed OB FD-DFE-ZF technique under AWGN and Rayleigh fading wireless channel is better as compare to other model like ZF-OFDM, MMSE-OFDM and OFDM with CP. Moreover CP free ZF technique has better achievable rate than the other techniques like CP based ZF, CP free MMSE and CP based MMSE.

From the results of V-BLAST technique, it has been observed that the number of complex multiplications will be very much less in the proposed system as compared to the conventional CP based MIMO-OFDM system.

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LIST OF ABBREVIATIONS

MIMO	Multiple Input Multiple Output
SNR	Signal to Noise Ratio
SD	Spatial Diversity
OFDM	Orthogonal Frequency Division Multiplexing
RF	Radio Frequency
FDD	Frequency Division Duplex
TDD	Time Division Duplex
ISI	Inter-symbol Interference
ICI	Inter-carrier Interference
CP	Cyclic Prefix
STC	Space Time Coding
STBC	Space Time Block Coding
OFDMA	Orthogonal Frequency Division Multiple Access
IBI	Inter-block Interference
IFFT	Inverse Fast Fourier Transform
S/P	Serial to Parallel
P/S	Parallel to Serial
BER	Bit Error Rate
SISO	Single Input Single Output
SE	Spectral Efficiency
EE	Energy Efficiency
CSI	Channel state Information
ZF	Zero Forcing
MMSE	Minimum Mean Square Error
ASK	Amplitude Shift Keying
PAPR	Peak to Average Power
SLM	Selective Mapping
CFO	Carrier Frequency Offset
SFO	Structure Field Offset
MSE	Mean Square Error

ML	Maximum Likelihood
QoS	Quality of Service
I/Q	In-phase/Quadrature phase
BPSK	Binary Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QOSTBC	Quadrature Orthogonal Space Time Block Coding
4G	4 th Generations
SFBC	Space Frequency Block Coding
IAR	Iterative Amplitude Reconstruction
OB	Oblique Projection
AR	Autoregressive
SIMO	Single Input Multiple Output
SCMA	Sparse Code Multiple Access
LDPC	Low Density Parity Check
FD-DFE	Frequency Domain Decision Feedback Equalizer
V-BLAST	Vertical-Bell Laboratories Layered Space-Time
QPSK	Quadrature Phase Shift Keying
AWGN	Additive white Gaussian noise
BS	Base Station
QRD	QR-Decomposition
SBCE	Semi-blind Channel Estimator
MAP	Maximum a posterior
EM	Expectation Maximization
QRA	Quantitative Risk Assessment
CARI	Cross-antenna Rotation and Inversion
AS	Antenna Selection
IM	Index Modulation
DPS/DPB	Dynamic point selection/Dynamic point Blanking
DFIG	Doubly Fed Induction Generator
QRA	Quantitative Risk Assessments

CHAPTER-1

INTRODUCTION

1.1 Preamble

Different diversity mode makes the radio communication more flexible with varying channels. These include frequency diversity, time diversity and spatial diversity. Multiple antennas are used either at transmitter or receiver end in spatial diversity [1]. Multiple antenna systems are defined as Multiple Input Multiple Output (MIMO) system and are usually indicated as $M_T \times M_R$, where M_T is the number of transmit antennas and M_R is the number of receiver antennas. In this technology multiple antennas are used to enhance the data rate in wireless system. Due to which spectral efficiency also increases [2].

A MIMO arrangement has two main modes which are defined as diversity coding and spatial multiplexing. Diversity coding is used to increase link reliability in presence of fading condition [3]. Whereas in spatial multiplexing several copies of same data are transmitted over multiple antennas, in order to increase the spectral efficiency rather than link reliability [4].

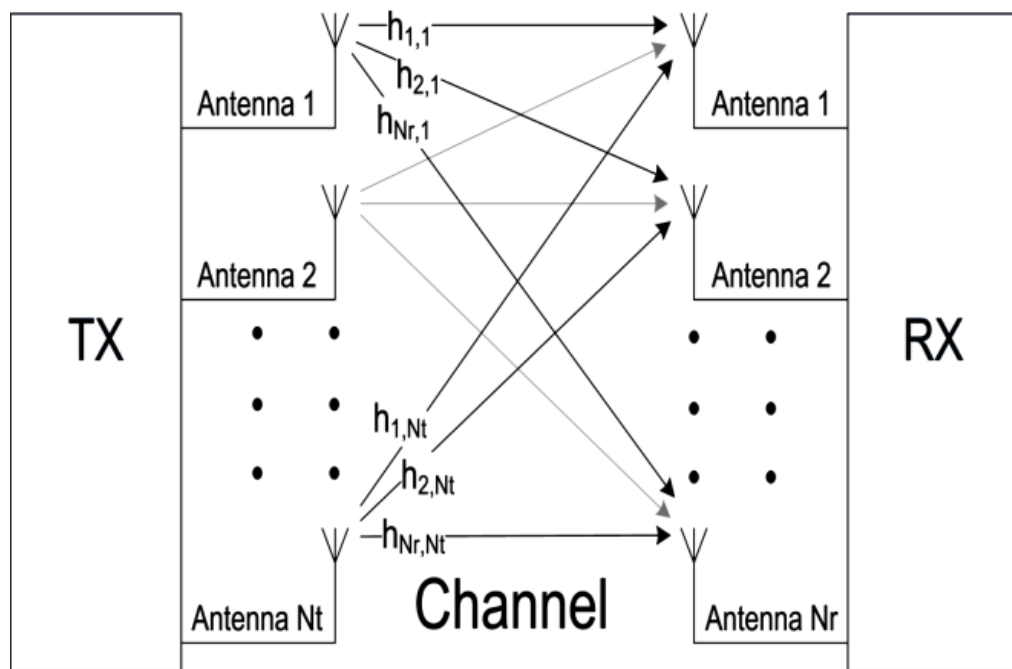


Fig.1.1 MIMO System Model

1.1.1 Advantages of MIMO

There are various advantages of Multi-antenna systems are discussed below:

- **Array gain:-**Array gain is also known as power gain of signals which are transmitted using multiple antennas. Antenna array gain improves the SNR at receiver side considering impairments. The array gain is categorized into two types average power of signal's combine to individual average power of signal and diversity gain compare to outage probability level [5].
- **Spatial Diversity Gain:-**The main aim of spatial diversity is to improve the error performance of the system. This can be achieved on the basis of diversity gain. Multiple copies of signal sent across different fading channels, the effect of fading on these copies will fluctuate. During this process one copy of signal will suffer the least fading as compare to others. Due to this, probability of receiving the transmitted signal increases and it improves reliability of the system [6]. In Fig.1.1 spatial diversity is 4.

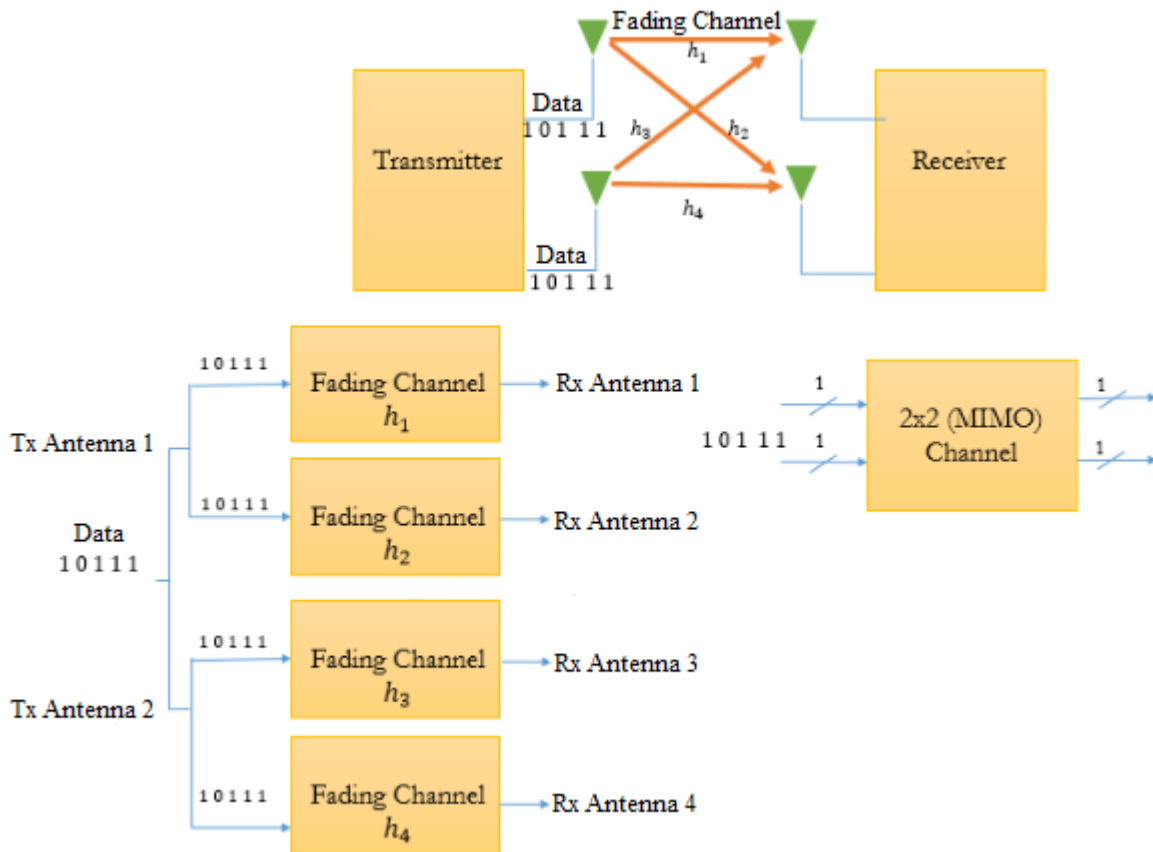


Fig1.2 Spatial diversity [6]

- Spatial multiplexing:-In transmit diversity, data is send via different channels which are independent from each other by placing them on different transmit antennas. Whereas spatial multiplexing technique in MIMO is used to transmit each bit of data on different channels via multiple antennas. Due to which the space dimension is multiplexed more than one time and hence provides more data capacity [7].

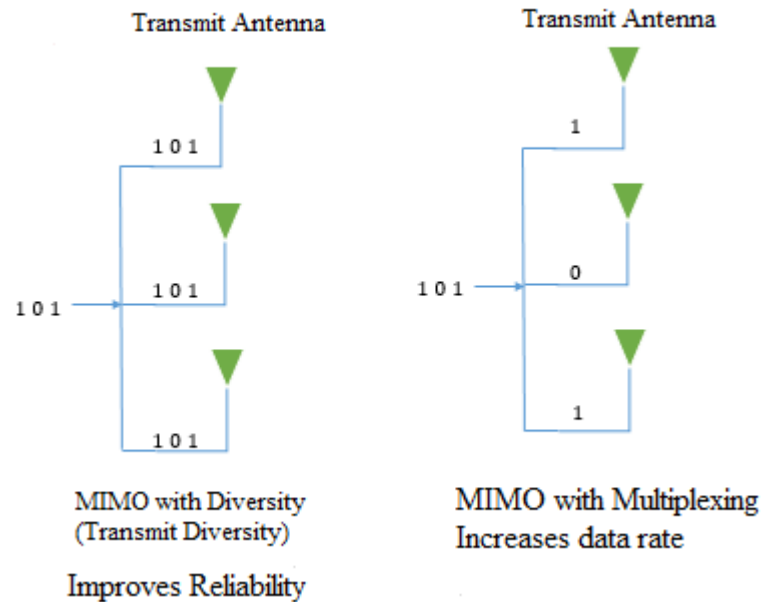


Fig.1.3 Diversity and Multiplexing

- Interference reduction:-In wireless channels, frequency reuse concept is applicable due to which the interference will appear. In communication system, performance will be degraded by the interference. To reduce the interference, there is only one way which is, using multiple antennas in the system in wireless channel. It separates the signal with different spatial copies. Each signal is clearly denoted their own path through which it can travel along with the wireless medium. Channel State Information should be known by the transmitter and receiver to reduce the interference [8].

1.2 OFDM

In today's era demand related to multimedia services are increasing rapidly. On the other hand bandwidth is a scarce resource. So, the technologies which possess bandwidth efficiency are adopted to overcome this problem. This necessity of achieving high data rate and bandwidth efficiency draws attention towards OFDM. In wireless systems if the impulse response of channel is longer than the symbol duration due to the dispersive fading of the wireless channel, the received signal will be distorted and suffers from inter symbol interference (ISI). OFDM is one of the best solutions in case of ISI mitigation. OFDM (Orthogonal frequency division multiplexing) is multicarrier modulation technique in which data is transmitted at very high rate by mitigating the multipath distortions and hence increases the bandwidth efficiency. In other words, it efficiently uses the available channel bandwidth by dividing it into sub channel bandwidths by following the principle of orthogonality as shown in Fig.1.4(b) [9].

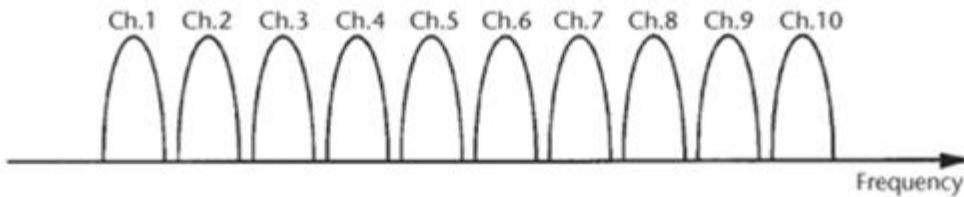


Fig.1.4 Conventional multicarrier technique [9]

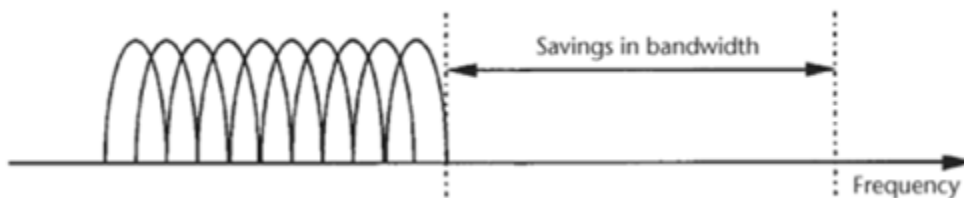


Fig.1.5 Orthogonal multicarrier technique [9]

1.2.1 Orthogonality Principle

In OFDM signals FDM subcarriers are closely separated to each other. Due to this, subcarrier interference occurs except at frequencies which are spaced orthogonally. At orthogonal frequencies, the subcarriers overlap with each other i.e. undesirable effects between the sub-

channels are eliminated. Due to this, the design of transmitter and receiver is simplified to great extent.

Mathematically, the orthogonality principle of two signals can be represented as [10],

$$\frac{1}{T} \int_{t_1}^{t_1+T} f_x(t) \times f_y(t) dt = 0 \text{ if } x \neq y \quad (1.1)$$

where $f_x(t)$ and $f_y(t)$ are signals over interval $[t_1, t_1 + T]$. Here T represents time period of signal.

1.2.2 ICI and ISI in OFDM system

A) Inter Carrier Interference:-

In OFDM, all the carriers are overlapped to each other because of the orthogonality property. When subcarriers loose the orthogonal property then there will be existence of ICI in the system [11].

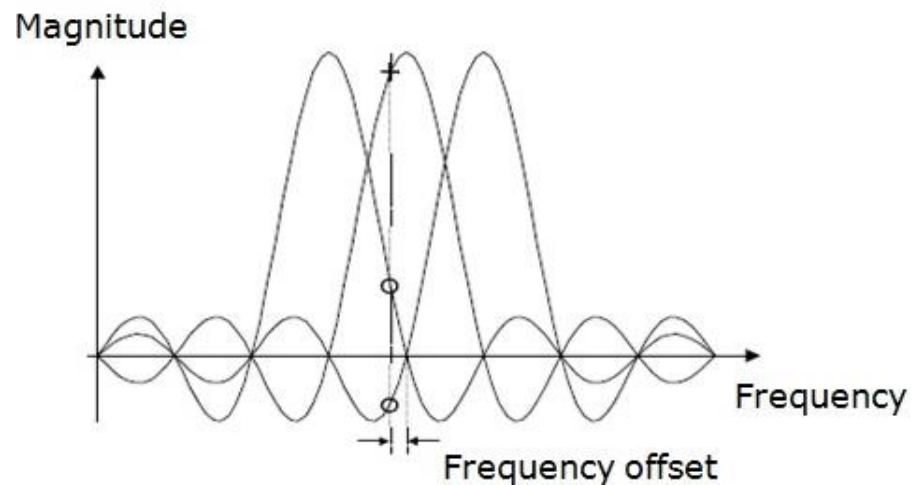


Fig.1.6 Inter-carrier Interference [11]

There are two main points for originate of ICI in the system.

1. When delay spread exceeds from the cyclic prefix interval.
2. Frequency offset exists at receiver side.

B) Inter Symbol Interference:-

ISI usually generated when subcarrier is transmitted in multipath fading channel. In this channel, there are multiple copies of carriers transmitted in different time interval. This interference occurs when two carriers overlap each other. Then one OFDM carrier will be affected by another OFDM carrier. So, this will destroy the symbol information before reaching to receiver [11].

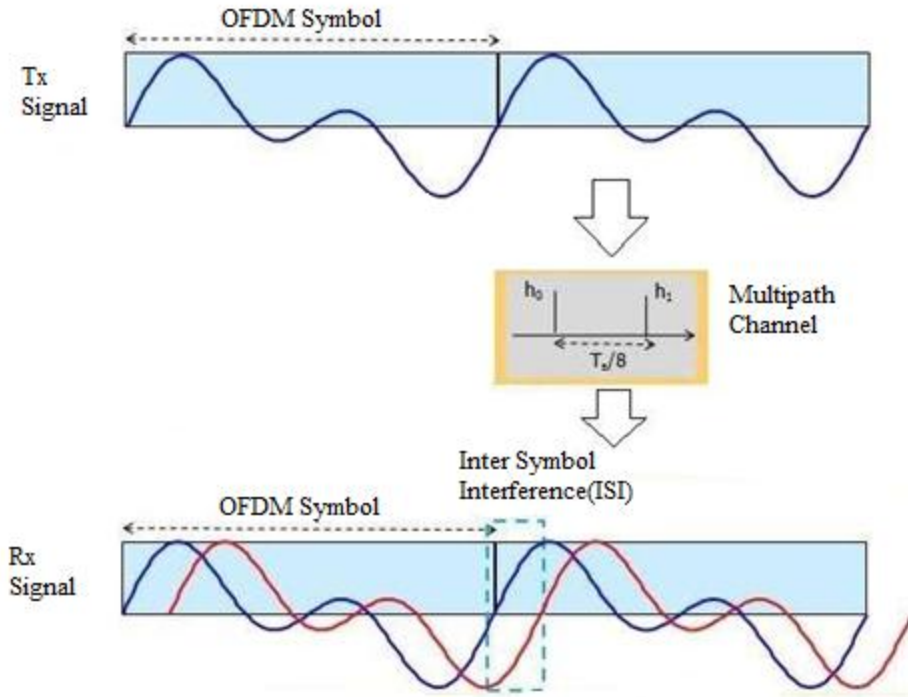


Fig.1.7 Inter-symbol Interference [11]

1.2.3 Addition of Guard band

ISI exists due to delay spread of multipath channel. To remove ISI between consecutive OFDM symbols guard interval is used. By the insertion of guard band, ICI is produced because rapid change of waveform of highest spectral component. The guard interval can be used in different ways such as cyclic extension and zero padding. Cyclic extension can be extended in two ways such as cyclic prefix and cyclic suffix [12].

1.2.4 Role of CP in OFDM

If we introduce the end part of symbol waveform in starting of the symbol as a guard period and repeat it after every symbol waveform, then this cyclic extension of waveform is known as cyclic prefix. Cyclic Prefix acts as a buffer in OFDM system in which it stores the previous information. This prefix will prevent the ISI in OFDM systems. The length of CP must be always greater than the delay spread because it will maintain the principle of orthogonality among sub carriers. If the length of CP is less than delay spread then it will lead to ISI [13].

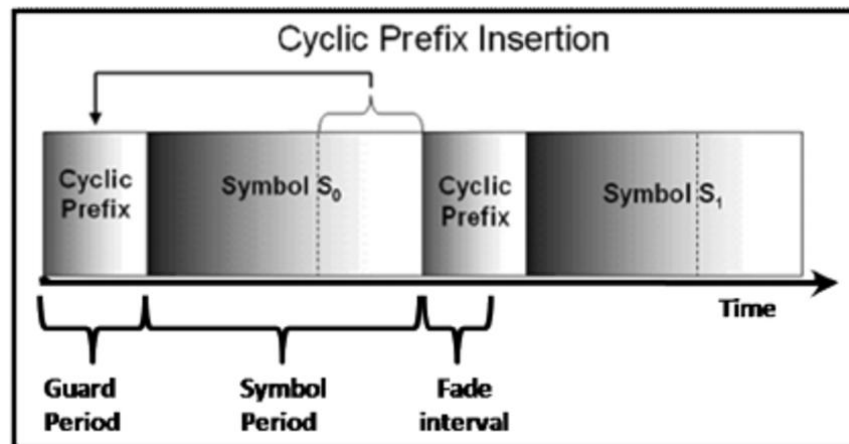


Fig.1.8 Cyclic Prefix in OFDM [13]

1.2.5 Disadvantage of OFDM

Although OFDM system offers many advantages in advance wireless systems but it also has some disadvantages, some of them are discussed below:

- High PAPR (Peak to Average Power Ratio): Due to the high peak to average power ratio There is very much difficulty in implementation of ADC and DAC.
- It is very responsive to Doppler Shift.
- Requirement of efficient synchronization.
- Efficiency of OFDM system decreases by the use of cyclic prefix [13].

1.3 MIMO-OFDM

In wireless system to provide high quality of service and high data rate with limited resources is the key challenge. Recent developments in MIMO techniques promise a significant boost in performance for OFDM system. So, the combination of both OFDM technology and MIMO system plays a vital role in fulfilling the above requirements for next generation mobile and fixed wireless system. OFDM is the multi-carrier modulation in which there is transformation of frequency selective channel into large number of individual frequency non-selective narrow band channels which is best suited for MIMO, which requires non-selective frequency characteristics at each channel. When OFDM signal is transmitted through number of antennas to achieve high transmission gain, then it is known as MIMO-OFDM system. Therefore a MIMO system with the characteristics of OFDM is capable to achieve spectral efficiency to high extent. [14].

1.3.1 System Model of MIMO-OFDM

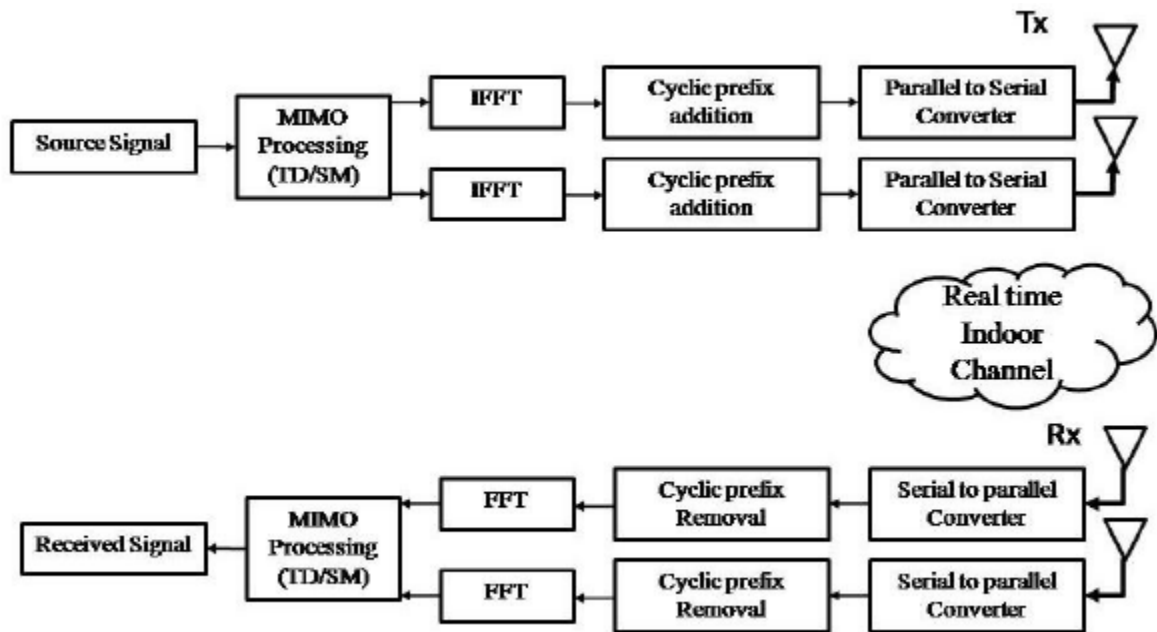


Fig.1.9 MIMO-OFDM System Model [14]

In this system model, there are N number of transmit and M number of receive antenna present. Each antenna are producing the OFDM signal after the inverse Fast Fourier Transform (IFFT) and the signal can be distinguish by the Fast Fourier Transform (FFT).

After receiving the MIMO-OFDM symbol and on applying the FFT at the n^{th} subcarrier and m^{th} OFDM carrier, can be represented as [15],

$$R_i[n, m] = \sum_{j=1}^N H_{i,j}[n, m]A_j[n, m] + W_i[n, m] \quad (1.2)$$

where $i=1,2,\dots,M$ i^{th} receiving antenna j^{th} transmitting antenna.

$W_i[n, m]$ and $A_j[n, m]$ is the Gaussian noise and transmitted data symbol respectively. The resultant signal of $R_i[n, m]$ is in the frequency domain. $H_{i,j}[n, m]$ is the coefficient of the channel in frequency domain. In this, it has been assumed that there is static channel impulse response.

The channel symbol duration $T_{channel}=T+T'$, where T is duration of OFDM symbol and T' is duration of cyclic prefix symbol.

We get the received symbol from all the antennas, given by [15]:

$$R_i[n, m] = H[n, m]A[n, m] + W_i[n, m] \quad (1.3)$$

where,
$$A[n, m] = [A_1[n, m] A_2[n, m] \dots \dots A_N[n, m]]^T \quad (1.4)$$

and
$$R[n, m] = [R_1[n, m] R_2[n, m] \dots \dots R_N[n, m]]^T \quad (1.5)$$

1.4 STBC

Space Time Block Coding (STBC) is one of the capable spatial diversity techniques which depend upon Alamouti code. Signals which have multiple numbers of copies are transmitted across number of transmitting antennas with the use of STBC coding [16]. The codes in STBC are orthogonal and can achieve full transmit diversity specified by number of transmitting antennas. These codes are complex version of Alamouti space time codes. STBC was developed to achieve maximum diversity order for given number of transmit and receive antennas, keeping the fact of limitation of having linear decoding algorithm. This property of STBC makes it different from other techniques. Encoding of STBC is given below [17].

1.4.1 Encoding of STBC

Alamouti code block is given below in Fig. 1.9, where s_1 and s_2 are two modulated symbols. During transmission, source sends a block of two symbols to the modulator. Then, the two modulated symbols are encoded by the Alamouti space time encoder, where two modulated symbols s_1 and s_2 creates encoding matrix \mathbf{A} . The mapping of these symbols is done to two transmitting antennas in two time slots [18]. The encoding matrix is as shown below in Fig 1.9

$$\mathbf{A} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad (1.6)$$

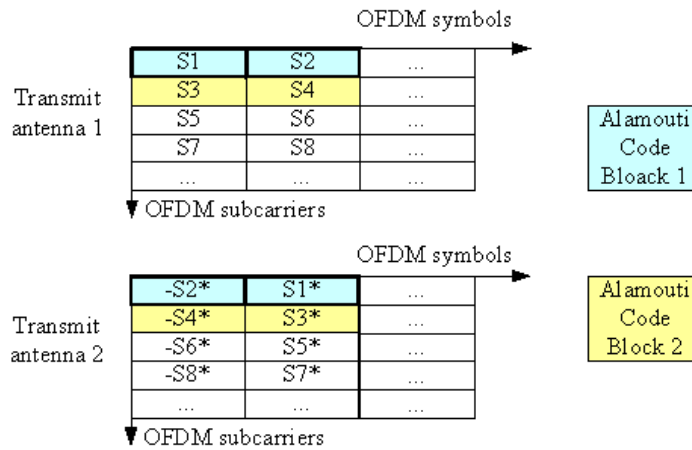


Fig.1.10 STBC encoding [19]

In support of STBC, a couple of symbols, s_1 and s_2 , are encoded into four variants, $s_1, s_2, -s_2^*$, and s_1^* . A similar concept of STBC is followed when number of modulated symbols increased as shown in Fig.1.9.

1.5 STBC-OFDM

Combination of antenna diversity and space time block coding together possesses an attractive feature of high data rate transmission for wireless systems. In OFDM based systems ISI and ICI are two main impairments on which system performance depends [20]. ISI is caused due to temporal channel dispersion and ICI results from temporal channel variation. ISI may be removed with the help of adequate cyclic prefix (CP) but ICI will not mitigate easily. So, STBC-

OFDM is a convenient scheme which helps to decrease ICI in the system, however the receiver complexity increases. Therefore STBC-OFDM attains diversity gain while considering frequency selective fading channels. Alamouti space-time coding is valid on blocks of data symbols rather than individual symbols. Two data vectors $X(i)$ and $X(i+1)$ are taken by Space-time encoder and transmits these two vectors as shown in eq. below [21-22].

$$\begin{bmatrix} X(i) \\ X(i+1) \end{bmatrix} = \begin{bmatrix} X(i) & -X^*(i+1) \\ X(i+1) & X^*(i) \end{bmatrix} \quad (1.7)$$

At the transmitter:

$$X = [X(1), X(2), X(3), \dots, X(N)]^T \quad (1.8)$$

$$X_1 = [0, X(1), X(2), \dots, X(N/4), 0, X(16), X(17), \dots, X(N/2)]^T \quad (1.9)$$

$$X_2 = [0, X((N/2)+1), X((N/2)+2), \dots, X(S), 0, X(S+1), X(S+2), \dots, X(N)]^T \quad (1.10)$$

where $S = N/2 + N/4$,

After applying IFFT to X_1 and X_2 data vectors are converted to time domain. Where x_1 and x_2 are mentioned as IFFT outputs. x_1 and X_{t1} , x_2 and X_{t2} are converted to a serial sequence, as shown below:

$$x_9 = [X_{t1}, x_1], \text{ and } x_{10} = [X_{t2}, x_2].$$

where X_{t1} and X_{t2} are defined as training sequences, and is explained as shown in Fig.1.10 [23].

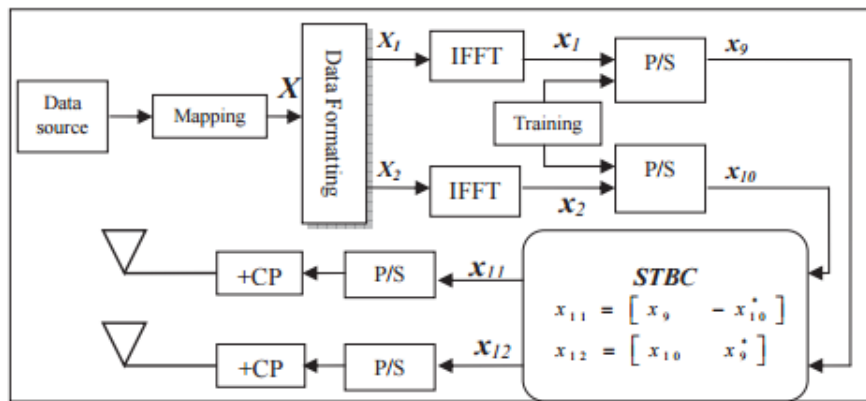


Fig.1.11 STBC-OFDM Transmitter [23]

1.6 Organization of Thesis

The thesis divide into five chapters, those chapter's summary are described here;

Chapter 1: This chapter describes the description of MIMO, OFDM, STBC & space time block coding with multiple inputs multiple outputs orthogonal frequency division multiplexing.

Chapter 2: In this chapter various type of research papers which are related to the thesis topic, gaps occur during research, objectives of thesis and methodology have been discussed.

Chapter 3: This chapter consists of all algorithm of the system & all analytical equations related to QR-factorization algorithm & oblique projection which we have applied in the MIMO-OFDM with or without CP with space time block coding domain.

Chapter 4: Results & Discussions, in this chapter all simulation results have been presented, we propose the MIMO-OFDM system model with or without CP apply the oblique projection technique in frequency domain consisting decision feedback equalizer. According to this simulation we have been implemented BER v/s SNR plot as well as calculated the achievable rate. We also simulate and calculate the number of computations occurring in the system with linear equalizers.

Chapter 5: Conclusion & Future scope, in this chapter whole work has been concluded and the future scope of this work has been discussed carried out to fulfill the research work.

CHAPTER 2

LITERATURE REVIEW

MIMO-OFDM system is the most encouraging consolidation of techniques for high data rates and increases the capacity of next generation of wireless communication system. Space time coding lifted the reliability of the wireless links. Hence the combination of these practices makes the potential to organize the ever rising demands of upcoming communication system.

2.1 MIMO

This short note is presented by **Pota et al.** (1996) [1] which is very simple method, to get the state-space representation which was calculated by the transfer function. In this the preliminary part is deal with the frequency domain analysis followed by the state space theory. The transfer function of the SISO system produces the classical frequency domain. So, According to this paper, in the form of increasing the number of antenna as in MIMO system the minimal state realization can be possible. This part of work wants at providing the motivation of evaluating the practices of the realization of the digital computer implementation.

In this document **Lee et al.** (2017) [2] considered that there is only one procedure a MIMO system which occupying the slow-varying large scale-fading failure and channel association in the spatial multiplexing established transmission in Rayleigh fading channel. In this the author planned a structure which has a low complexity and low errors, which proposed method had a collection of broadcast styles for the most favourable EE (Energy Efficiency) and SE (Spectral Efficiency).

This article shows the lookup table having the less complex system as compare to the previous technique. The aim of this paper is to selecting the best transmission mode which is based on the SE and EE. Both efficiencies were focus on the transmission rate and the complexity of the system. In this model the new frame work was proposed in which the error rate is less as compare to conventional system. The complexity evaluation of result was done with the help of lookup tables.

This manuscript is presented by the **Yoo et al.** (2010) [3], in this author proposed a simple linear precoder which consist the MIMO communication system. The selected transmission link which

is in-between the transmitter and the receiver link was identified at the performance of the substream of the SNR of the signal. This whole process went on after the signal will reach by the receiver. There was an assumption that the full CSI (Channel State Information) is available at the transmitter and the receiver side. The new precoding technique was proposed which appropriated for the ZF equalization. The numerical result states that this method offered the lower computational complexity with the help of near-optimal linear protocol.

The advantage of MU-MIMO had been described by the **Ducoing** *et al.* (2016) [4], which have aim of through the constellations the merits evaluated in this scheme. If MIMO system has fully loaded then through this process the number of antennas can be increases with the help of broadly linear zero-forcing receiver. In this technique the M-ASK modulation process involves the diversity gain in spatial domain. With the help of linear forcing receiver the fully loaded MIMO system achieves the near-optimal BER in the initial state. Significantly, this method approaches much improved BER as compare to the maximum likelihood search in MIMO-OFDM.

Nguyen *et al.* (2015) [5] describes the benefits of the dynamic spectrum access with MIMO communication. He prescribes that for growing the dynamic communication traffic we have to combine those two techniques. In a distributed manner the requirement of both two systems optimized with the spectral allocation and the spatial pattern. The few cases is only centralized which have the spectrum dynamics and heterogeneity. Here the aim of author was to achieving exploit the network throughput with facilitating the distributed algorithms.

These schemes mutually assign the opportunistic channels to the different links in addition of combined with to simultaneously optimize with the MIMO pre-coding matrices. After introducing the dynamic spectrum access connection, the channel allocation which is based on the Nash bargaining was satisfied through the distributed algorithms. The result of that allocation is that the demand rates are assured increasing in the number of resources.

The capacity is analyze by the number of antenna in MIMO system. In this document **Long** *et al.* (2015) [6] focuses on the non-asymptotic inequalities for MU-MIMO (Multiuser Multiple Input Multiple Output) system with the finite number of antennas. Firstly, system bounds the ergodic capacity in the MIMO scheme after that the system capacity will be define by its statically bound which is also known as the falling in probability. This is also instantaneous capacity of the system. When the number of antenna will increases then the system goes in the falling-in

probability and instantaneous capacity will become tighter. This scheme get down an interesting fact that there are arbitrary fluctuations occurs due to the instant capacity while we are raising the number of antenna.

ICI (Inter-carrier Interference) is influenced in channel estimation in the occurrence of pilot contamination has a big deal with the MIMO system. In this paper **Yang et al. (2016)** [7] was proposed a technique which is semi-blind channel estimator is based on the subspace matrix. In this scheme the error will be minimizing from channel estimation which is also known as optimum pilot design for the LS-MIMO (Least Square-Multiple Input Multiple Output) system. In this system we were intriguing the benefit of the optimized pilot and data symbols for SBCE which is accomplished by the asymptotic orthogonality of the channel vectors meet in system. Firstly, we concentrate on the optimal pilot properties and then intend these properties with the Zadoff-Chu sequence for this sequence; the SBCE (Semi-blind Channel Estimator) performance was being possibly best. As the result, the ICI was totally eradicated.

Mbaya et al. (2017) [8] describes the emerging technology in the MIMO system which is known as time-domain broadband beamforming, this is the product of the elementary J-orthogonal matrices also consist the lower triangular matrix among the 1's on the diagonal. This is based on the amalgamation of two matrix factorization method: Smith canonical form and LU (Lower-Upper) Gaussian elimination. The outcome of MIMO channel was decreased exactly diagonal, which is following the separate SISO channel considered zero ICI. In accumulation, the results of SISO channels, apart from the final channel, become easy additive noise channel, without ISI. The presentation of the QR-based frequency domain & time-domain with respect to the BER is discussed in this paper. This technique is considering in MIMO system as well as OFDM system and also in the single carrier multiple input multiple output system whereas when there was no CP used in the system. Temporarily QR-based technique requires a CP expansion.

2.2 OFDM

This short note is presented by **Simko et al. (2013)** [9], There are so much current principles for cellular transmission techniques have a lot of flexibility. In this paper, the author showed the scheme which demonstrated the purpose of optimal pilot-symbol patterns. This prototype increases the upper bound and consist the error in channel estimation and ICI. While changing the channel statistics, the pilot symbol have to follow the pattern. For two reasonable systems,

we have to produce the simulation results and show that the adaptive pilot pattern consists of Long Term Evolution standard and make enhancement of the conventional system. The arrangement has utilized adaptive pilot pattern in transmission of the transmitter to receiver. Throughput range should become accomplish upto 85% as compare to the conventional setting.

This paper presents the new family unit of the low density parity check in which **Qu et al.** (2014) [10] proposed the invertible subset LDPC (Low Density Parity Check) code for complexity reduction in OFDM. Peak-to-average power ratio also reduces compare to previous in orthogonal frequency division multiplexing. An IS-low density parity check consist the various amount of disjoint and every invertible subset has the facility to change the applicable codeword of the LDPC code. All IS can be independently to transform the generated code. After the good presentation of error correcting code, the model anticipated with the edge-growth construction algorithm and with the help of Tanner graph we have to validate the efficiency of IS-LDPC. When the codeword has been transmitted by the numerous OFDM bit stream, the complexity of the investigating lower system. In multicarrier communication system, the PAPR (Peak to Average Power) reduction is very much beneficial based on the IS-LDPC codes.

Wang et al. (2014) [11] offered the system in which OFDM with the help of preamble using two long training symbol consist joint acquisition of CFO (Carrier Frequency Offset) and the SFO (Structure Field Offset). The two dimensional exploration was very much comprehensive as compare to the conventional maximum likelihood method. The author planned a low complexity algorithm for closed form ML estimator to conquer this difficulty. In this the estimation the carrier frequency offset was presented in close loop form and then with the help of Taylor series extension, the sampling frequency offset can be expressed and expand in ML estimation algorithm. In this paper, according to the outcomes we could saw that the performance of ML method will be same as conventional but the complexity will be decreases and there is no exhaustion in search.

In this document **Darsena et al.** (2015) [12] described the setback of OFDM system in which FIR equalization consist the impulsive noise at the receiver which creates the non-linearity in the output. The author intended a FIR frequency domain equalizer which was linear also with the helped of frequency redundant. This reduces the ICI which creates the nonlinearity in OFDM system. The Class A Middleton model which mitigates the impulsive noise and give the path to admittance of the error probability in proposed equalizer.

In this manuscript we are concentrating for OFDM and we have to developing the method by which the system's accuracy of frequency offset calculation will be improved. The **Shin et al.** (2015) [13] presented the algorithm of joint impairments in in-phase/quadrature imbalance & carrier frequency offset. The demonstration of the system of the conventional frequency judgment, in this I/Q imbalance has been examined. The main advantage of this scheme is that in this the proposal accomplishes an observation. So, the estimation of CFO was based on the robustness against I/Q imbalance and this calculation was based on the EM (Expectation Maximization)-based acquisition.

In this letter **He et al.** (2017) [14] illustrated a new OFDM technique which is based on the dc-biased optical system. This algorithm is terminating the noise clipping and direct detection with non-linear system. The foremost drawback of this technique is the noise clipping. In this paper, the various methods described for eliminating the clipping noise. Firstly we have to extract the signal then clipped the signal to the noise and after that noise was separated to the signal. This process is purely non-linear. This experiment is proceeding in the optical wireless communication system frequently.

Zaarour et al. (2015) [15] depicted a novel framework fast time-varying channel. In slow time varying channel, OFDM system has been caused due to the narrowband interference. This problem creates in channel estimation in MIMO-OFDM. In fast time-varying channel the algorithm proposed maximum a posterior expectation maximization which is jointly estimated. The unnecessary factor while considering the EM formulation and the estimation factor is noise variance which has to be approximated. A closed form of the MAP algorithm, calculated the noise variance. This channel is known as Kalman smoother. In convenient interference circumstances the analytical calculation was done on the basis of the MSE and BER of the move towards mobility and the satisfactoriness. The effectualness and the robustness can be achieved for this MAP algorithm.

2.3 MIMO-OFDM

In wireless systems, the major role is playing by the energy efficiency. **She et al.** (2015) [16] declared that the obligation of the energy efficiency maximizes due to this the quality of service is improved and this can be progress the probability of violation where the delay bound can be decreases. To save the energy we have to serve the random sources of the wireless channels. In

this one QoS (Quality of Service) exponent can be converted by the multi-state QoS exponents which is characterized by the effective bandwidth and efficient capacity. The multi-state quality of service is reliant to the queue length. To optimize resource allotment we have to propose the MIMO-OFDM. This scheme consist the power allocation and bandwidth with length based. According to this technique, the energy efficiency and the capacity maximizes beneath the QoS limit. In this QRA (Quantitative Risk Assessments) technique with delay bound consist the finite number of antenna achieved. If the delay bound is inflexible then the active policy will be serving QoS provision.

In wireless channel, the impulsive response connecting to transmit and receive antenna which creates the momentous path of the channel delay spread and time-lags in-between two. The channel will be in the region of sparse i.e. multiplied by the number of transmit and receive antenna. **Prasad et al.** (2015) [17] created the groups of channel known as approximately cluster-sparse means every channel having one cluster. In this ideology some cluster consists a very strong constituent and all clusters make a weak element.

This paper proposed the sparse Bayesian learning framework where the time varying channel consists the block fading. This can simulate the algorithm of the data detection, joint channel evaluation in MIMO-OFDM system. If the capacity of matrix is simply incompletely identified then also the algorithm can be proficient for the sparse wireless channel. For joint channel recognition, judgment and following the system has to be imposed to the recursive Kalman filtering & smoothing procedure. We have to propose also low complexity technique which creates the timating gac-sparse channel. In the simulation the benefits can be shows through the MSE and BER of this technique.

In this manuscript, the consideration of the carrier frequency offset in the multiple input multiple output orthogonal frequency division multiplexing system. **Dutta et al.** (2015) [18] consisted the frequency selective fading channel with noise for single and multiuser inputs. This approach estimate the CFO constraint with continuous value rose in the detection theory, in final alphabet received signal the final framework was minimized the BER. After proposed this method the result was much summarized by the conventionally upgraded. For single user, the performance will be degrading in BER and the variance of carrier frequency offset was cleared the error. In this simulation the achievement taken the MIMO-OFDM system which can improve the

complexity and modulation schemes will also enhanced. The minimum error probability can be conceived by that framework which can be estimated by the parameter of the system.

Dweik *et al.* (2015) [19] presented an original scheme which improves the strength of the MIMO-OFDM system. It gives the frequency selective fading channel in which it consists of the block for 2 neighbouring subscribers. In this we can imagine that the period of the codeword, the channel constraints are equal too each other. This can give the additive noise which can comprise the presentation of time-varying channel with the interference due to the channel variation. This technique supports the Walsh-Hadamard transform for short block length and the system's complexity was very much low as compare to the conventional MIMO-OFDM system.

The new blind channel estimation algorithm in MIMO-OFDM system has been proposed by **Zhang** *et al.* (2015) [20]. In this scheme, the author was described the advantage of low order constellation for example BPSK, QPSK etc due to which the signal covariance matrix was followed by the low rank signal. This method can be recognized the channel data from the received blocks which has in small amount of information. Through this we can assemble the cluster of subscriber for signal covariance matrices. After that we have compared the computational complexity and assessment routine. So, the scheme has supply to all the MIMO-OFDM system which can follow the proposed method.

In this paper, **Yiming** *et al.* (2014) [21] described the importance of nonlinear power amplifiers in MIMO-OFDM system. Firstly the SISO system was introduced then for increasing the performance of the system, the model has constructed the non-linear power amplifier in multiple input multiple output OFDM system. From system's operating point, it can simulate a polynomial based function which can receive the receiver's signal to noise ratio. It is depend on an inter modulation product, unique characteristics of that proposed scheme. The asymptotic expression of SNR which have applied to the linear and non-linear phase of the power amplifier. In this, the phase shift keying and QAM can be applied for integral expression of SEP (Signal End Points). From this analysis, the MIMO-OFDM has optimized performance due to the non-linear PAs.

In this letter, MIMO-OFDM system consist the offset selected mapping scheme which is used to mitigate the performance of peak-to-average power in Alamouti scheme. **Jiang** *et al.* (2013) [22].The diverse succession of phase reproduced to their equivalent phase offset at the

transmitter side. To get better the phase rotation, a minimum Euclidian distance at the receiver has been proposed. So, for the side information, the SLM (Selective Mapping) method should not be turn round the bit at the receiver side. This can be performing increase in data rate in the system. The result can be shows that the SLM was a good technique for improving the SNR and reducing the PAPR.

2.4 STBC MIMO-OFDM

Li et al. (2008) [23] illustrated that clipping is the resourceful scheme to mitigate the PAPR in OFDM system. If we introduce clipping in MIMO-OFDM system then the additive noise will not white at all. This paper gives details about the Gaussian approximation by involving the clipping noise representation with fast maximum likelihood algorithm for orthogonal STBC & quasi orthogonal STBC in MIMO-OFDM system. By introducing this technique, the performance was enhanced but decoding complexities were not growing in clipped MIMO-OFDM system. This is the main advantage of this scheme. This model is divided into three sections for this performance. In section one space time coding was establish in MIMO-OFDM system after that in section two the ML decoding technique with OSTBC and QOSTBC introduced in last section the clipping noise model was described in this system.

In 4G wireless broadband communication, for high speed and soaring efficiency we have to introduce MIMO-OFDM system. If we want to talk about MIMO-OFDM then apart from all advantages the one biggest disadvantage is that peak to average power ratio is very large when we transmit the signal on diverse antennas. **Tan et al.** (2005) [24] proposed a scheme which operates on multiple antenna consist the additional degree of freedom that system is known as the cross antenna rotation & inversion. Apart from this, the author have introduced another 2 suboptimal techniques, known as successive suboptimal CARI (Cross-antenna Rotation and Inversion) & random suboptimal. This scheme explains the important improvements based on performance and the complexity of the system reduced from the concurrent selective mapping which is introduced in conventional MIMO-OFDM system.

In this manuscript, **Jung et al.** (2010) [25] recommended for improving the optimization of adaptive modulation in space time coding channel which is superposition based for MIMO-OFDM system. The STBC chooses the same modulation scheme which have in previous, when the transmit antenna consist the different channel situations but in this process decoding problem

occur because different type of modulation consist the same transmit antenna. In this improvement made by choosing the optimal modulation technique while estimating the corresponding channel in selectively space time coding & decoding channel. So, the adaptive modulation could be comprised by the occupied system.

In this document, **Pelekanakis** *et al.* (2011) [26] described the developing for STBC in MIMO-OFDM system into underwater acoustic communication. When the channel statistic modify, the modulation scheme planed for an explicit representation although that specific model was poorly intended and that specific scheme was Rayleigh fading model. In an assortment of channel circumstance, the enhancement done by developing the coded modulation approach.

There are 2 coded modulation schemes which were compared by their terrestrial radio narration in the terms of BER. In those, 1st model is based on the trellis coded modulation which was depending upon the 8-PSK modulation & symbol interleaving. 2nd model illustrates the bit-interleaved coded modulation in this there are various techniques comprise as a bit interleaver, a conventional encoder and 16-QAM signal streams. In 2 circumstances these parameters was measuring as like BER & number of complex multiplication was tested. First model considered the SIMO system with OFDM system and in second model the MIMO technology designed with OFDM followed by $\frac{3}{4}$ -rate STBC. This scheme gives the estimation of Euclidean distance defines the lower error rate and spatial diversity with comparatively high error rate.

As we know the major demerit of the MIMO-OFDM is high PAPR when the signal was transmitted to the transmit antenna. This inconvenience was removed by the amplitude clipping in the system. Although it could be reduces the system performance because of clipping in amplitude and causes distortion. **Kwon** *et al.* (2007) [27] introduced the clipping noise alleviation schemes STBC and SFBC MIMO-OFDM system. A new reconstruction could be given by in optimum equalizer in the system which had derived and proposed to the clipped signals. The evaluated parameter derived the signal will be generated through this technique with moderate computational complexity and the proposed receiver was effectively recovered the signal at the receiver.

Kim *et al.* (2009) [28] proposed the technique which were based on the (iterative amplitude reconstruction) IAR firstly in single input single output orthogonal frequency division multiplexing system. This process was based on the clipped signal reconstruction method followed by spatial diversity in space time and space frequency coded systems. This paper also

described on the reduction of the resolution of peak to average power ratio in MIMO-OFDM system.

Iterative amplitude reconstruction method can be easily introduced on the space time block coding orthogonal frequency division multiplexing system but in space frequency block coding systems that technique was not directly applied because the transmitted data sequence was in the frequency domain as various antennas those used the codes which are dependent on the frequency term. To defend this problem we have to introduce a clipped OFDM transmitter based on space time frequency code which reduces the computational complexity just about half of previous SFBC-OFDM. In this technique, the proposed signal would be completely orthogonal to the transmitter and the clipped signal was improved at the receiver.

In this document, **Moon et al.** (2003) [29] investigated how to enhance the performance of next generation wireless local area network system. The MIMO-OFDM is very suitable to that object. According to this the peak to average power was evaluated of the MIMO-OFDM system which is coded by the space time blocks. The approach was considered in the way that the techniques which control the PAPR as partial transmit sequence and selective mapping. In this the value should be degraded by the conventional value & as well as the side information should be same as the previous. If the probability was low and the side information varied and not same as the previous then the performance of the system was degraded and the proposed technique was not suitable of the system and the error was there in encountered side information.

2.5 Oblique Projection

If zero forcing equalizer cascaded with the transmission system then it will work with same as the block-based pre-coder which is used in transmission block system. This helps to calculate the bit error rate (BER). The study was formulated of the two redundancy schemes were cyclic prefix and the trailing zeros. When **Wu et al.** (2007) [30] introduced the oblique projection in the transmission system then ISI was totally eradicated with the property of the OB. Oblique projection is followed by the degree-of freedom in which the ICI will also be equalized. In this the channel state information is only available at the receiver side due to this ISI equalization is cascaded with the proposed equalization which helped to create the optimum block based pre-coder. This is only the reason that bit error rate was minimized for the ISI was totally eliminated and the transmission was become with the power constraint. According to this the cascaded equalizer will be working as a zero forcing equalizer. This proposed work allowed not only

improving the BER performance of the system but it was also mitigate the ISI and ICI and create the space for the sufficient redundancy.

Karlsson *et al.* (1996) [31] introduced the modified Yule-Walker equation in which the noisy autoregressive (AR) process would be done in the noisy system. The system consisting white noise at the transmitter side was multiplexed in the signal process and also in the received signal. So, the system have the channel state information means receiver knew the information at the transmitter side. Oblique projection was followed by the autoregressive parameter in white noise over the q -operator in the algorithm. In fast sampling, the lightly damped low frequency region was covered in the AR process.

Vrhel *et al.* (1997) [32] described calculating form of continuous wavelet transform as in expressive & straightforward method. In this method the system proposed by the oblique projection technique helpful to achieve complexity, filter coefficient with the simple integration & the system which have very low hammering in accuracy in the slightest square approaches. In this method the space was describing by the compactly sustained by the scaling function which is approximated to the oblique projection with P wavelets per octaves. With the help of zero padding filtering & two scale relation, the wavelet templates were prolonged to the bulky in dimension. In the support of the error bounds, the use of oblique projection can be justified by the simplicity of the orthogonal system. The fast recursive algorithm the justification was given to the error bounds which described in one FIR filtering in place of one filter.

In a low rank subspace the oblique projection is the only technique which controls to project the capacity in direction of the subspace. **Behrens** *et al.* (1994) [33] illustrated different schemes for enhancing the signal of the system. This may be include for constructing formulas of OB and their simulation results with desirable range and nullified space. For comprehend their properties, algebra and geometry analysis would be done under the systems limits. In this paper author showed the process to remove the effect damped and un-damped interfering sinusoids, impulse noise & narrow band noise. In some cases the OB would be only solution to protect the signal to various kinds of noises & it would be only the solution of the problems which would be addressed by the system. After elimination impulse noise, one can use the OB to introduced misplaced data. To remove the steer beams & nulls of the data samples is important in array processing so it can be remove by the OB & in communication we can mitigate the ISI with the help of oblique projection.

Tong et al. (2001) [34] demonstrated the simulation of symbol assessment & blind channel in SIMO system. Channel vector & channel input sequence was estimated by the linear estimator, also using the finite sample property. Most important part of system was based on the oblique projection. The order of subtractive holding hold for OB and the detection algorithm take place for unite of joint channel estimation. It can also be useful for multiuser detection. In this channel response and symbols can be jointly calculated by the OB only.

Knockaert et al. (2006) [35] illustrated scheme depend upon reduced order modelling. It depend on the narrow band interval, this technique basically derived from Kautz scheme & this is belongs to frequency pertinent transformation. With the help of oblique projection, we acquire a modified reduced order modelling technique; this was based on general M th-order state space transfer function. The simulating model was more focused on the frequency band as well as it has much efficient reduced order modelling feature which will mitigate the number of complex computations. It can also be divided into the various form one of the singular value decomposition. Main advantage of this scheme was that in one projection matrix, the involvements of two projections occur and the number of column is same as for the one matrix.

Peng et al. (2005) [36] proposed method based on the recursive oblique projector. This type of metrics is divided into two forms orthogonal and oblique projector. Both idempotent and orthogonal is hermitian and OB is not. This orthogonal projector is a special part of OB and application is in adaptive signal processing. This document provided a geometrical interpretation of recursive OB and various examples was presented on the systems performance.

2.6 Computational Complexity in MIMO-OFDM

In wireless network, main focus is to improve the system performance by introducing various techniques. The one is sparse code multiple access system which conveys the multiple various complications produce during broadcasting process. This is one of the best application in multiple input multiple output system. **Du et al.** (2017) [37] proposed the various challenges to convey this scheme in MIMO-OFDM system. One of the biggest tasks was to construct the nominal computational cost in the system when the detectors have near-optimal bit error rate achievement. To fulfil this target, author created sparse code multiple access codeword and a combined graph which has a single graph of multiple input multiple output system channel with sparse graph after that for providing the help of detector a virtual SCMA codebook design in that

combined channel. A new architecture will be proposed according to this process which creates the joint processing algorithm which is based on the passing message. Like this two approaches built which gives joint sparse graph for serial and parallel agendas.

Bouchoucha et al. (2017) [38] illustrated the required transmit beam patterns which discover the correlated waveforms by matrices. This matrices help to design waveform. After that in 2nd step, the covariance matrix can be synthesized and actual waveform can be designed. In this, the problem was occurred when the iterative algorithm optimized by the other methods. But the computational complexity is very much high because of these optimization. In MIMO radar by introducing the discrete-Fourier- transform help to obtain closed form covariance matrix. The finite-alphabet constant envelope waveform will be directly design for this whole procedure which is totally closed form algorithm.

Amadori et al. (2016) [40] proposed that type of antenna selection system in which the users constructive interference was exploited. Matched filter set up in the antenna selection scheme, that precoder gives the better performance of the system. Channel inversion pre-coder is also a good AS technique but it is expensive and complex as compare to MF. Firstly with the help of PSK transmission mould the constructive and destructive interference after introduced the suitable antenna selection technique for this it can be produces the maximum power of the transmission system. It has been analyzed the number of complications produces in the system and on the basis of this estimation we have set the upper bound power of the receiver side. On the basis of throughput transmitted power of the system can be evaluated.

Least square criterion creates the outstanding estimation performance but with very high computational complexity. The number of computations are very much high in this algorithm. **Zhu et al.** (2009) [41] described the issues on the basis of complexity, they used the least square method but at the rate of low complexity. In this paper, new algorithm has been proposed which was based on range measurement. The range of the frequency was restricted and weighted in proficient way. The result is in the closed form of the structure which involves the linking linearization. The structure was same as the previous but with the low complexity.

Sadeghi et al. (2017) [42] prescribed that large-scale antenna system with co-channel groups in their physical layer. One message would be distributed by all the system antennas in one groups, those groups were common to the entire antenna system. Design pre-coding vectors which have

maximum minimum fairness and maintain the quality of service by assuming that the channel state information is available on the base station. By using semi definite relaxation scheme the base station exploits to low complexity. The semi definite relaxation has less number of complexities as compare to $O(N^6)$. To reduce the complexity, author proposed the 2 new algorithms, one is based on the min-max fairness and the other one was quality of service basis. They create the duality from both the technical issues and the simulation model gives the less number of complications with the use of single semi definite relaxation.

There is always flexible trade-off between the spectral effectiveness and error pursuance in multiple input multiple output orthogonal frequency division multiplexing system with IM. This creative practice was gave the energy efficient system in 5G wireless communication networks. **Zheng et al.** (2017) [43] produced the sub-block with strong dependent subcarrier in individual blocks. For fabricating transmitting data adequately with low complexity is very demanding task of the system especially at the receiver side. After producing that scheme, the system was followed two detectors and introduces on them, one is Sequential Monte Carlo which gives the detection in multiple input multiple output orthogonal frequency division multiplexing system index modulation. In 1st detectors the sample of the signal at the sub-block level was design independently and in 2nd detector signal depicts the sample at the subcarrier level after that decreased to the complexity. 2nd detector had the ability to auxiliary coupled to completely Sequential Monte Carlo scheme. But one thing is common in both the detector is that both can accomplish near-optimal error management.

2.7 Achievable Rate in MIMO-OFDM

To handle ICI, one mechanism has been used known as cooperative multipoint transmission which is based on the dynamic point selection & dynamic point blanking scheme. **Wang et al.** (2015) [44] proposed a system in which, the 3 transmission points set already for calculating the bit error rate while this performing non-adaptive & ideal adaptive modulation which includes dynamic point selection & dynamic point blanking scheme. This scheme is very suitable for cooperative multipoint transmission system. By estimating all the values of probability density in DPS/DPB (Dynamic point selection/Dynamic point Blanking) techniques, after this the calculation for non- adaptive & ideal adaptive modulation had been be proposed. So, the bit error rate with respect to the achievable rate for the calculated index was differing from the conventional system.

In this paper the technique have been used the multiple input multiple output orthogonal frequency division multiplexing for power proficient transmission technique, which require frequency division multiplexing scheme. In this transmission the CSI was available at transmitter side but not receiver side. **Liang et al.** (2007) [45] introduced the independent encoding scheme in which the information was sent through the antenna individually and decoded by the receiver itself respectively. This scheme considers the closed loop Vertical Bell Labs layered space time due to this the channel information was coming as a feedback to the transmitter again. Because of this the transmit antenna have been assign to power & achievable rate respectively. Since the low rate feedback was came to the transmitter. So the transmit power was considered to the feedback rate. The simulation results have been close as the CSI known at the transmitter as well as receiver with improved power and achievable rate.

Chen et al. (2012) [46] discussed the performance of the cognitive radio. In this the spectrum sensing implies the effect of the channel due to this the system has been adaptively channelize the primary user. Nakagami- m fading channel gives the time delay in the system where the numbers of various techniques are involving on the different channels. For calculating the achievable rate, use both adaptive modulations discrete as well as continuous. In this the primary user can return of any part of frame at any time when cognitive radio is transmitting the data with the channel state information. According to this channel authorization, SNR & BER gives the range which is completely independent to the primary user so that achievable rate can become also effective for the system.

Kuang et al. (2012) [47] proposed a new STBC MIMO-OFDM technique which is based on the adaptive renovation. The main focus is on the beam forming of the system since at the transmitter the CSI have been considered and to estimate total power & spatial power subjected to the average power limit when the BER is objective. The major difficulty in designing this system is that transmit power & Eigen beams power allotment both were the conventional schemes which was not helping to calculate the SNR of the system. To mitigate this problem, there had been done a modification in proposed technique is that to set an optimum threshold of the SNR of the system & developed a new variable known as effective SNR, this can help to set the threshold level.

Optimization procedure has been described by the **Mazzotti et al.** (2012) [48]. In multiuser technique, the resource allocation technique was taken as the transmission channel. Presume that

the adaptive modulation coding was taken as the downlink announcement link in the system. In this the sum rate maximum difficulty can be control to the dual solution in adaptive modulation through the IP-address video & data communication. The transmission buffer also is limited due to this termination. After this the transmission codes can be transmitted which are based on M -QAM modulation & LDPC codes. These codes are mutually effecting on the scheduler who gives the fairness output and effectual SNR.

Taki et al. (2014) [49] described the interference alignment scheme for those channels which have imperfect channelization of the CSI. In this model a MIMO-OFDM system with IA has been designed when available IA is imperfect at the transmitter side. The space between transmitter & receiver is also having allowed to the imperfect CSI. The channel parameter was satisfied for the power constraint by dynamically optimized to the power setting, modulation & BER weighted sum rate to produce the achievable rate. Transmitter and receiver with access to the interference channel having the CSI which is imperfect to the channelization.

Tang et al. (2016) [50] introduced heuristic dynamic programming model which was representing an adaptive modulation technique on the basis of control power system. In this model, directly spotlight point is doubly fed introduction generator which is based on the static synchronous compensator. In this various properties which are useful for the transmission is high voltage direct current; these properties are going to be helped out to fault recovery problem of DFIG. These methods provide the full derivation on the basis of achievable rate, power optimization & SNR. To achieve more efficient modulation, the goal represents the more state performance which has been generated by the heuristic dynamic programming. In high voltage direct current transmission lines the signal was according to observed power system.

2.8 Research Gaps

From the literature survey following gaps have been observed that:

1. System model of SISO-OFDM and SIMO-OFDM in CP free environment is defined with multipath time varying channel, whereas TD-IBI-DFE techniques cannot be applied directly upon these systems, due to this time-reversal block-wise conjugate encoding will lead to present symbol block [24].

2. In SISO and SIMO with OFDM one cannot apply the decision feedback equalizer with ICI in time domain environment because of time reversal block-wise conjugate encoding. This will lead to represents ISI in the system model [25].
3. The number of transmitting antennas was equal to the number of receiving antennas in MIMO-OFDM system due to this the transmitter antenna were not given the sufficient degree of freedom, as the result of this, there was no separation in-between the desired and undesired signal, So works needs to be done in the direction to have higher number of receiving antennas [26-27].
4. Although using CP in OFDM, ISI will be removed sufficiently but there are so many undesired components which are combining to the desired signals as like ISI and structure noise. This component decreases the signal strength, which needs to be analysed further for improvement of received signal strength [28].
5. In oblique projection large calculations are required. This can be improved by employing the QR-factorization, in this mathematical derivation complexities will be less and result will be more accurate as compare to other technique [29].
6. By using Gram-Schmidt process in QR based factorization the system becomes unstable and due to the numerical complexities, there are various types of error occur so one can use House holder reflection algorithm to create error free and stable environment [30].
7. In V-BLAST technique based MIMO-OFDM, the system complexity was very much high. Due to this there was no real-time scope of application. Using V-BLAST with oblique projection has been given satisfied performance and also decreases the number of computations [31].

2.9 Objectives

The objectives of this thesis are given below;

1. Study of MIMO-OFDM system with cyclic prefix (CP).
2. To employ the STBC encoding technique on MIMO-OFDM system under CP free environment. Also to apply the FD-DFE with oblique projection technique.
3. Performance evaluation of proposed system in terms of BER vs. SNR, Achievable rate and computation complexity.
4. Reduction of computational complexity in V-BLAST MIMO-OFDM system by using Oblique projection technique.

2.10 Methodology

In this manuscript, the system model which is cyclic prefix free single input multiple output orthogonal frequency division multiplexing and SISO-OFDM system expand to the STBC MIMO-OFDM system which consist the multipath time-varying channel surroundings [32]. The inter symbol interference will be develop from encoding of present symbol block which is the drawback of time reversal block-wise conjugate signals, we can't capable to implement the time domain inter block interference decision feedback equalizer methods straightforwardly. To avoid this problem, we introduce a substitute of this technique to employ the decision feedback equalizer in the frequency domain (FD), used on behalf of cyclic prefix free multiple input multiple output orthogonal frequency division multiplexing system consist along with STBC [33]. So the model is symbol block representation it offers the very easy or non-complex mode of distinguishing the received signal symbols at receiver. There will be many term involving in the received signal block as like the preferred symbol block (ICI term) [34], the structured noise (the ISI term) and the environmental noise. Here planned structure, for providing the adequate degree of freedom, the number of receiver antenna should be in excess of the number of transmitter antenna. This assumption has been considered so that at last the outcome will be signal model matrix and the element of structured-noise model matrix to be displacing by each other [35].

This stimulates for achieving non-orthogonal projector as well as the smallest amount of square explanation toward build an original matrix procedure. It is as equal as the oblique projection (OB). The OB is doing abolish the system's unwanted component, as like the structured noise whereas conserving the preferred symbol constituent. Preferably, we would foremost attain an inter symbol interference free signal representation using oblique projection operation and then prevailing symbol block is attempted via using the frequency division decision feedback equalizer. The OB projector in the company of QR-based factorizations is engaged in the direction of accomplish enhanced technically possessions [36].

CHAPTER-3

SYSTEM MODEL

In this chapter, firstly, we describe the system model of CP based MIMO-OFDM. After that the CP-free MIMO-OFDM system model has been proposed. To remove the demerits of previous model, in the next section, MIMO-OFDM system with frequency domain decision feedback equalizer followed by Oblique projection which completely removes the ISI and ICI have been proposed and improved the BER performance. Further, V-Blast technique with MMSE and ZF equalizer with and without CP has been proposed. It is observed that, CP based this model is more complex as compare to CP free model.

3.1 Cyclic Prefix consisting STBC MIMO-OFDM System

In MIMO-OFDM system, the cyclic prefix (CP) should be longer than the length of channel impulse response (CIR) to avoid the ISI and ICI. So, let us consider the length of CP is larger or equal to the order of $(2N_r)$ receiver multipath channels, where, N_r is the receiver antenna which has two branch diversity schemes that are apply with discrete time baseband representation [37]. Fig. 3.1 shows transmitter and receiver model which is divided into two symbol blocks. At time k , the j^{th} transmit-antenna sends the OFDM symbol block that can be express as,

$$s_j(k) = F^H m_j(k), 1 \leq j \leq 2 \quad (3.1)$$

where, F is an N -point Fast Fourier transform matrix. Let us suppose $s(k)$ and $s(k + 1)$ are the two transmitted symbol block having N -dimensional. By passing through the STBC encoder, the broadcasted data series is given as [38],

$$\dots \dots \begin{bmatrix} s_2^*(k) \\ s_1^*(k) \end{bmatrix} \begin{bmatrix} s_1(k) \\ s_2(k) \end{bmatrix} \begin{bmatrix} -s_2^*(k-1) \\ s_1^*(k-1) \end{bmatrix} \begin{bmatrix} s_1(k-1) \\ s_2(k-1) \end{bmatrix} \dots \dots \quad (3.2)$$

From eq. (3.2), $s_1(k)$ and $s_2(k)$ can be represented as,

$$s_1(k) = s(k) = [s(kN) s(kN + 1) \dots \dots s(kN + N + 1)]^T \quad (3.3)$$

and

$$s_2(k) = s(k+1) = [s((k+1)N)s((k+1)N+1) \dots s((k+1)N+N1)]^T \quad (3.4)$$

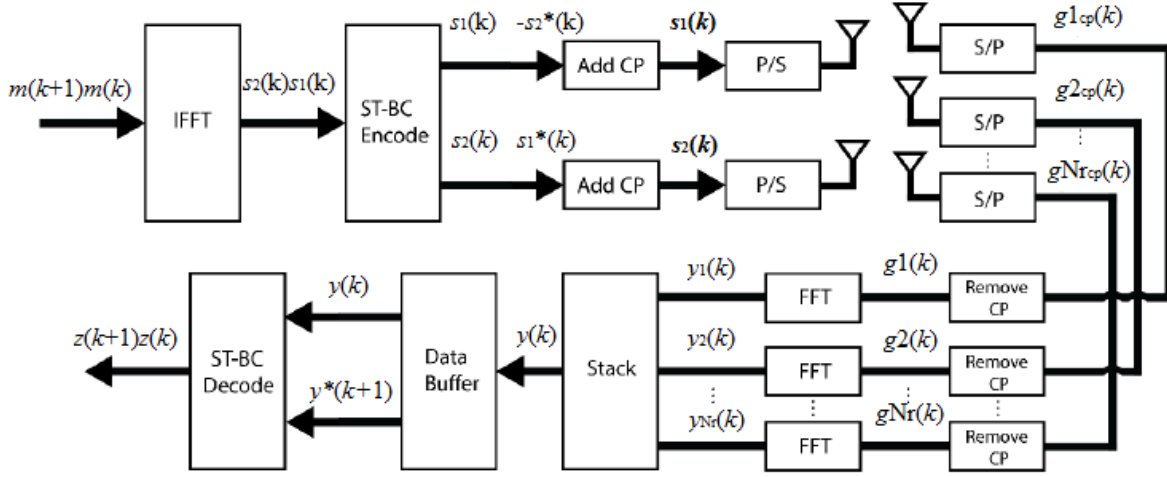


Fig.3.1 MIMO-OFDM system with Cyclic Prefix in Space Time Encoding [39]

At time k and $k+1$, the data vector $[s_1^T(k) \ s_2^T(k)]^T$ and $[-s_2^H(k) \ s_1^H(k)]^T$ is sent to Add CP, respectively, which is the conjugate of data vector $[s_1^T(k) \ s_2^T(k)]^T$ having $2N \times 1$ dimension and so on [39].

Let us consider linear time invariant channel (with Maximum channel order $L=2N_r$) having impulse response denoted as $h_1^{(r,j)}(k) = 0,1\mathbb{C}[0 \ L]$ which is bounded by j th transmit and r th receive antenna. The length of cyclic prefix is inserted into every OFDM symbol block which decreases the channel noise and time varying multipath fading distortion. The OFDM symbol with cyclic prefix can be express as [40],

$$\tilde{s}_j(k) = \gamma F_{cp}^H m_j(k), 1 \leq j \leq 2 \quad (3.5)$$

where, $F_{cp}^H = A_{cp} F^H$, $A_{cp} = [I_{cp}^T I_N^T]^T$, I_{cp} is the $N \times N$ identity matrix with inserted CP, γ is powerless factor defined as $\gamma = \sqrt{\frac{N}{N+D}}$ and D is the last rows of cyclic prefix inserted matrix. Powerless factor is use to preserve the equal power before and after cyclic prefix inclusion. Further, $\tilde{s}_j(k)$ is sent to the consecutive channel. Assume that the transmitter and receiver both are fully synchronized with each other, so, r th antenna receive the data vector which is given as [41],

$$\begin{aligned}
g_{cp}^{(r)} = & \sum_{j=1}^2 H_0^{(r,j)}(k) \tilde{s}_j(k) + \left\{ H_1^{(r,2)}(k-1) F_{cp}^H s_1^*(k-1) - H_1^{(r,1)}(k-1) F_{cp}^H \gamma s_2^*(k-1) \right\} \\
& + n_{cp}^{(r)}(k)
\end{aligned} \tag{3.6}$$

where, $H_0^{(r,j)}(k)$ and $H_1^{(r,j)}(k-1)$ is the upper and lower triangular Toeplitz matrices with $P \times P$ dimensions, respectively and these are represented as,

$$H_0^{(r,j)}(k) = \begin{bmatrix} h_0^{(r,j)}(k) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ h_L^{(r,j)}(k) & \cdots & h_0^{(r,j)}(k) \end{bmatrix} \tag{3.7}$$

$$H_1^{(r,j)}(k-1) = \begin{bmatrix} 0 & \cdots & h_1^{(r,j)}(k-1) \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{bmatrix} \tag{3.8}$$

The first term in eq. (3.6) represents the upper triangular Toeplitz matrices mixed with channel tone matrix also known as desired signal, second term is Inter symbol interference (ISI) and third term is structured noise. By using eq. (3.7) and eq. (3.8), eq. (3.6) can be written as [42].

$$g^{(r)}(k) = \sum_{j=1}^2 I^{(r,j)}(k) \tilde{s}_j(k) + n^{(r)}(k) \tag{3.9}$$

where, $I^{(r,j)}(k)$ is $N \times N$ circulant matrix. After demodulating the time domain received signal, we get the signal in frequency domain that is given as,

$$y^{(r)}(k) = \sum_{j=1}^2 D^{(r,j)}(k) \gamma m_j(k) + v^{(r)}(k) \tag{3.10}$$

where, $D^{(r,j)}(k)$ is $N \times N$ diagonal matrices. Now, we can rewrite eq. (3.10) in $M \times N$ -dimensional form that represents the multichannel system model [43],

$$y(k) = [D_1(k) \ D_2(k)] \begin{bmatrix} \gamma m_1(k) \\ \gamma m_2(k) \end{bmatrix} + v(k) \quad (3.11)$$

Similarly, for $k+1$ time, frequency domain received signal can be express as,

$$y(k+1) = [D_2(k+1) \ -D_1(k+1)] \begin{bmatrix} \gamma m_1^*(k) \\ \gamma m_2^*(k) \end{bmatrix} + v(k+1) \quad (3.12)$$

After combining the STBC decoder, eq. (3.11) and eq. (3.12) can be present in vector matrix form as,

$$\begin{bmatrix} y(k) \\ y^*(k+1) \end{bmatrix} = \begin{bmatrix} D_1(k) & D_2(k) \\ D_2^*(k+1) & -D_1^*(k+1) \end{bmatrix} \begin{bmatrix} \gamma m_1(k) \\ \gamma m_2(k) \end{bmatrix} + \begin{bmatrix} v(k) \\ v^*(k+1) \end{bmatrix} \quad (3.13)$$

Let us consider, the transmitter and receiver both have same CSI, so by using the channel tone matrix with $2N_r N \times 2N$ dimension, we get,

$$\begin{aligned} D^H(k+1) &= \begin{bmatrix} F_r g(k) \\ F_r^* g^*(k+1) \end{bmatrix} \\ &= \begin{bmatrix} \tilde{D}^1(k+1) & \tilde{D}^2(k+1) \\ \tilde{D}^3(k+1) & \tilde{D}^4(k+1) \end{bmatrix} \begin{bmatrix} \gamma m_1(k) \\ \gamma m_2(k) \end{bmatrix} + \tilde{D}^H(k+1) \begin{bmatrix} v(k) \\ v^*(k+1) \end{bmatrix} \end{aligned} \quad (3.14)$$

where, $\tilde{D}^3(k+1)$ and $\tilde{D}^4(k+1)$ both are close to trival matrices. $\tilde{D}^1(k+1)$ and $\tilde{D}^2(k+1)$ shows M-fold diversity gain at the receiver. Here, we have assumed that channel is slowly faded from k to $k+1$. In CP based case we consider $2N_r$ fold frequency domain analysis [44].

3.2 Cyclic Prefix free STBC MIMO-OFDM System

This scheme consists of OFDM block signal without cyclic prefix. So, the received signal vector in time domain at r th receiving antenna is [45],

$$\begin{aligned}
g^{(r)}(k) &= \sum_{j=1}^2 H_0^{(r,j)}(k) F^H m_j(k) \\
&\quad + \left(\left\{ H_1^{(r,1)}(k-1) F^H m_1^*(k-1) - H_1^{(r,2)}(k-1) F^H m_2^*(k-1) \right\} \right. \\
&\quad \left. + n^{(r)}(k) \right)
\end{aligned} \tag{3.15}$$

where, $H_0^{(r,j)}(k)$ is an upper triangular Toeplitz matrix and $H_1^{(r,j)}(k-1)$ is a lower triangular matrix. In eq.(3.15), the first term is the mixture of upper triangular Toeplitz matrix and channel tone matrix also known as desired signal, second term is ISI and third term is structured noise which is also known as white Gaussian noise (AWGN) vector. On expanding eq.(3.15), we get,

$$\begin{aligned}
g^{(r)}(k) &= \sum_{j=1}^2 \left(H_0^{(r,j)}(k) + H_0^{(r,j)}(k) \right) F^H m_j(k) - \sum_{j=1}^2 H_0^{(r,j)}(k) F^H m_j(k) + \\
&\quad \left(\left\{ H_1^{(r,1)}(k-1) F^H m_1^*(k-1) - H_1^{(r,2)}(k-1) F^H m_2^*(k-1) \right\} \right. \\
&\quad \left. + n^{(r)}(k) \right)
\end{aligned} \tag{3.16}$$

Here we assumed that both the transmitter and receiver are synchronized to each other and CSI is known at both side. By taking the Fast Fourier Transform of eq.(3.16), we get,

$$\begin{aligned}
y^{(r)}(k) &= \\
&\quad \sum_{j=1}^2 \left(D^{(r,j)}(k) m_j(k) \right) - \sum_{j=1}^2 \left(F H_1^{(r,j)}(k) F^H m_j(k) \right) + \\
&\quad \left(F H_1^{(r,2)}(k-1) F^H m_1^*(k-1) - F H_1^{(r,1)}(k-1) F^H m_2^*(k-1) \right) \\
&\quad + v^{(r)}(k)
\end{aligned} \tag{3.17}$$

where, $v^{(r)}(k) = F n^{(r)}(k)$. First term shows the channel tone matrix combined with the desired signal. Now, we can form multichannel system model with $N_r \times N_t$ dimensional which can be represented as [46],

$$y(k) = D(k) \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} - F_{N_r} H_1(k) F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} + F_{N_r} H_1(k-1) F_2^H \begin{bmatrix} -m_2^*(k) \\ m_1^*(k) \end{bmatrix} + v(k) \tag{3.18}$$

where, $D(k) = [D_1(k) \quad D_2(k)]^T$ and $F_{N_r} = F * I_{N_r \times N_r}$ is Kronecker Product.

Similarly, at time $k+1$, for $M \times N$ -dimensional system,

$$y(k+1) = D(k+1) \begin{bmatrix} -m_2^*(k) \\ m_1^*(k) \end{bmatrix} - F_{N_r} H_1(k+1) F_2^H \begin{bmatrix} -m_2^*(k) \\ m_1^*(k) \end{bmatrix} + F_{N_r} H_1(k) F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} + v(k+1) \quad (3.19)$$

In eq.(3.19), $F_{N_r} H_1(k+1) F_2^H$ and $F_{N_r} H_1(k) F_2^H$ represents $H_{ICI}(k)$ and $H_{ISI}(k+1)$ respectively. By multiplying signal at time k and $k+1$, and arrange it into a real-valued auxiliary matrix with dimension of $(2N \times 2N)$, we get [47],

$$J = \begin{bmatrix} O_{N \times N} & -I_{N \times N} \\ I_{N \times N} & O_{N \times N} \end{bmatrix} \quad (3.20)$$

Now both eq.(3.18) and eq.(3.19) can be represent in vector form as,

$$\begin{bmatrix} y(k) \\ y^*(k+1) \end{bmatrix} = \begin{bmatrix} s_1(k) \\ s_2(k) \end{bmatrix} + \begin{bmatrix} D(k) \\ D^*(k+1) \end{bmatrix} \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} + \begin{bmatrix} v(k) \\ v^*(k+1) \end{bmatrix} + \begin{bmatrix} H_{ICI}(k) \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \\ H_{ICI}(k+1) J \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \end{bmatrix} + \begin{bmatrix} H_{ISI}(k-1) J \begin{bmatrix} m_1^*(k-1) \\ m_2^*(k-1) \end{bmatrix} \\ H_{ISI}^*(k) \begin{bmatrix} m_1^*(k) \\ m_2^*(k) \end{bmatrix} \end{bmatrix} \quad (3.21)$$

where, $\begin{bmatrix} v(k) \\ v^*(k+1) \end{bmatrix}$ is AWGN noise, $\begin{bmatrix} H_{ICI}(k) \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \\ H_{ICI}(k+1) J \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \end{bmatrix}$ denotes ICI term and

$\begin{bmatrix} H_{ISI}(k-1) J \begin{bmatrix} m_1^*(k-1) \\ m_2^*(k-1) \end{bmatrix} \\ H_{ISI}^*(k) \begin{bmatrix} m_1^*(k) \\ m_2^*(k) \end{bmatrix} \end{bmatrix}$ is the mathematical form of Inter Symbol Interference of the system

model [48].

Now, it can be concluded that without using cyclic prefix in MIMO-OFDM system, the interference occurs in the received signal and decoder output is not perfect. To mitigate this interference, an equalizer introduces in system that reduce ISI and also restoring the signal with additional gain [49].

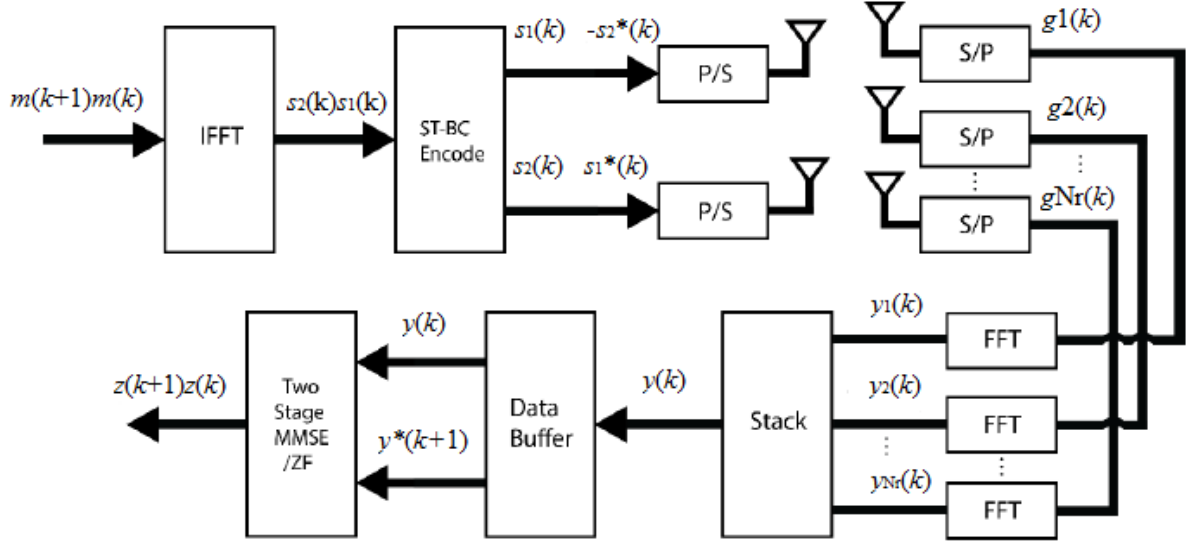


Fig.3.2 MIMO-OFDM system CP free STBC Encoded System [50]

3.3 Performance Analysis of OFDM System with CP-free STBC by using the Oblique Projection Technique

3.3.1 The Concept of Oblique Projection Technique

By expanding eq.(3.16) in vector form with $N_r \times N$ dimensional multichannel system [53], we get,

$$\begin{aligned}
 g^{(r)}(k) &= \begin{bmatrix} H_0^{(1,1)}(k) & \cdots & H_0^{(1,2)}(k) \\ \vdots & \ddots & \vdots \\ H_0^{(r,1)}(k) & \cdots & H_0^{(r,2)}(k) \end{bmatrix} F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \\
 &+ \begin{bmatrix} H_1^{(1,1)}(k-1) & \cdots & H_1^{(1,2)}(k-1) \\ \vdots & \ddots & \vdots \\ H_1^{(r,1)}(k-1) & \cdots & H_1^{(r,2)}(k-1) \end{bmatrix} F_2^H \begin{bmatrix} -m_2^*(k-1) \\ m_1^*(k-1) \end{bmatrix} \\
 &+ \begin{bmatrix} n^{(1)}(k) \\ \vdots \\ n^{(r)}(k) \end{bmatrix} \tag{3.22}
 \end{aligned}$$

The auxiliary matrices $H_0(k), H_1(k-1)$ represents signal-model matrix with dimension $(MN \times 2N)$ and $n(k)$ represents structured-noise matrix with dimension $(MN \times 1)$ formless interference correspondingly. Similarly, at time $(k+1)$, [54], we get,

$$\begin{aligned}
g^{(r)}(k+1) = & \begin{bmatrix} H_0^{(1,1)}(k+1) & \dots & H_0^{(1,2)}(k+1) \\ \vdots & \ddots & \vdots \\ H_0^{(r,1)}(k+1) & \dots & H_0^{(r,2)}(k+1) \end{bmatrix} F_2^H \begin{bmatrix} m_1(k+1) \\ m_2(k) \end{bmatrix} \\
& + \begin{bmatrix} H_1^{(1,1)}(k) & \dots & H_1^{(1,2)}(k) \\ \vdots & \ddots & \vdots \\ H_1^{(r,1)}(k) & \dots & H_1^{(r,2)}(k) \end{bmatrix} F_2^H \begin{bmatrix} -m_2^*(k) \\ m_1^*(k) \end{bmatrix} \\
& + \begin{bmatrix} n^{(1)}(k+1) \\ \vdots \\ n^{(r)}(k+1) \end{bmatrix}
\end{aligned} \tag{3.23}$$

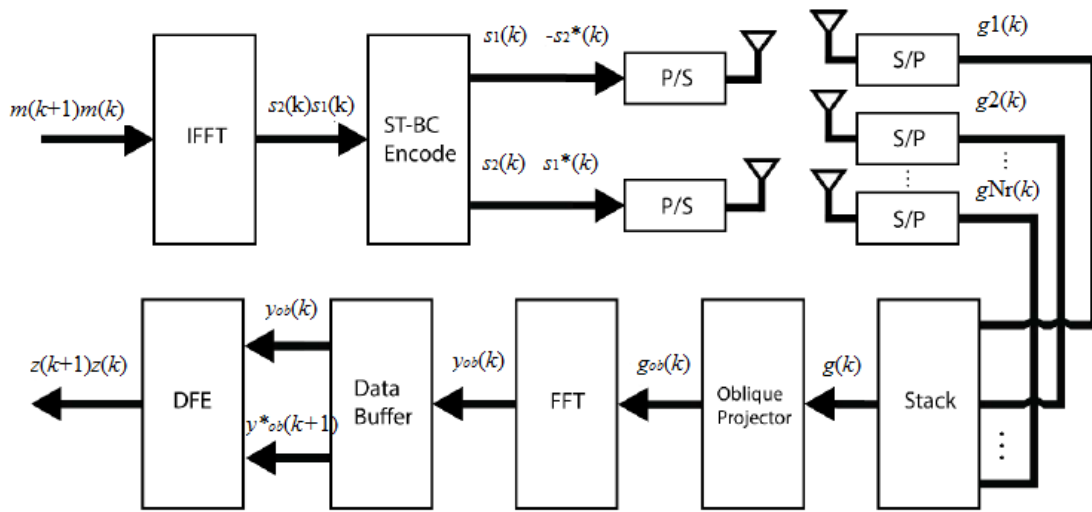


Fig.3.3 System Block of MIMO-OFDM CP-free STBC transceiver with Oblique Projection [52]

The signal multiplied and arranged with similar appearance for proposed decoder which has a real-valued auxiliary matrix with dimension of $(2N \times 2N)$.

In eq.(3.22) and eq.(3.23), the model of multichannel system represent $\langle H_1(k-1) \rangle$ as a structured noise subspace, $\langle H_0(k) \rangle$ as the signal subspace and $n(k)$ as the unstructured noise vector. The channel matrix $H_1(k-1)$ is the cause of inter symbol interference along with the two successive transmitted symbol blocks, and $H_0(k)$ contains the ICI components that have preferred symbol blocks [56]. MIMO-OFDM scheme is well planned with two-branch diversity method that consist of r th receiver antenna, channel matrix $H_0(k)$ with column rank $2N$ and the structured noise matrix $H_1(k-1)$ with column rank $(2 \times L)$

This assumption is valid only when the transmitting and receiving antennas for all the $2m$ sub-channel are uncorrelated to each other. It is observed that the column matrices $H_1(k-1)$ and $H_0(k)$ are linearly independent if and only if $MN \geq 2N + 2L$ for $M \geq 3$. The signal subspace $\langle H_0(k) \rangle$ and structure noise subspace $\langle H_1(k-1) \rangle$ are displace with each other as given [53], it means the 3-way disintegration of Euclidean MN -space is,

$$\langle H_0(k) \rangle \oplus \langle H_1(k-1) \rangle \oplus \{ \langle H_1(k-1) \rangle \cup \langle H_0(k) \rangle \}^\perp = \mathcal{C}^{MN} \quad (3.24)$$

Now, we have to define an ISI-free model which is based on equation (3.22). Firstly, we have to create an innovative matrix $H_L(k-1)$ that is developed by the last L columns of $H_1(k-1)$. $H_1(k-1)$ and $H_L(k-1)$ both the channel matrices have the same linear subspace of $\langle H_0(k) \rangle$.

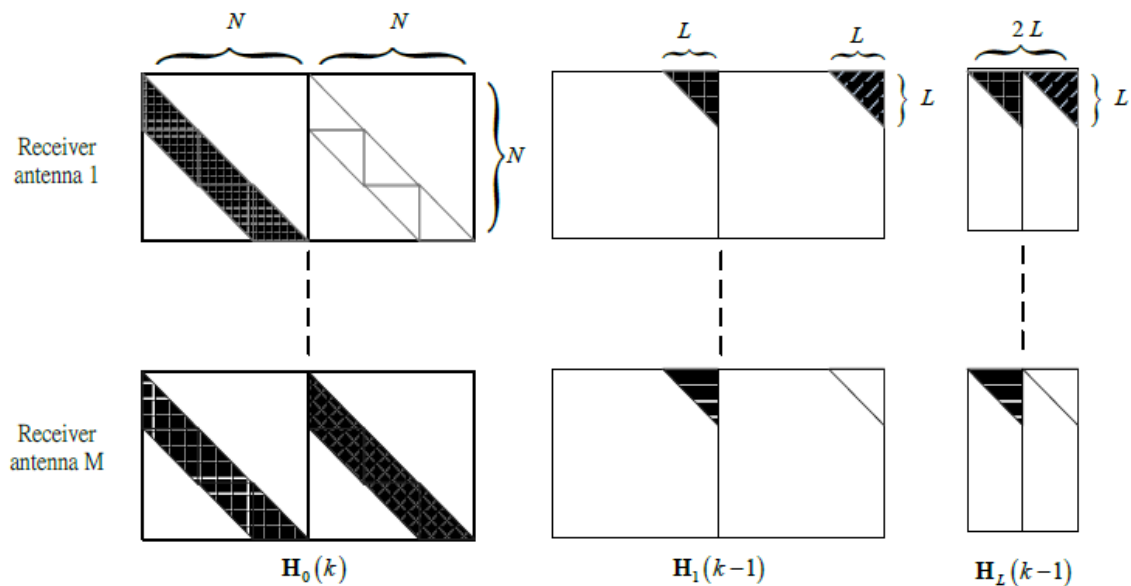


Fig.3.4 Structures of matrices $H_0(k)$, $H_1(k-1)$ and $H_L(k-1)$ [54]

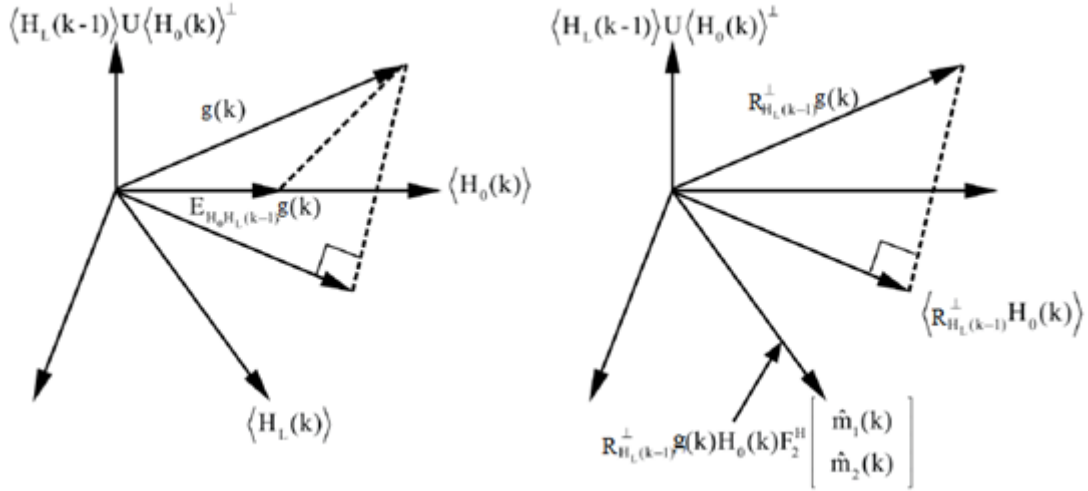


Fig.3.5 Euclidean space 3 way resolution and it's Orthogonal Projection of $R_{H_L(k-1)}^\perp g(k)$

During the outcome of eq.(3.24), the three-way Euclidean space can be defined by the eq.(3.22). Assume that $R_{H_L(k-1)}^\perp$ is orthogonal projection complement of $H_L(k-1)$ having the dimensions $(MN \times MN)$. By multiplying $R_{H_L(k-1)}^\perp$ in eq.(3.22) on both sides and removing the term $H_L(k-1)$, we get the least-square solution as [55],

$$R_{H_L(k-1)}^\perp g(k) = R_{H_L(k-1)}^\perp H_0(k) F_2^H \begin{bmatrix} \widehat{m}_1(k) \\ \widehat{m}_2(k) \end{bmatrix} + R_{H_L(k-1)}^\perp n(k) \quad (3.25)$$

From Fig.3.5, eq.(3.25) becomes,

$$R_{H_L(k-1)}^\perp g(k) \approx R_{H_L(k-1)}^\perp H_0(k) F_2^H \begin{bmatrix} \widehat{m}_1(k) \\ \widehat{m}_2(k) \end{bmatrix} \quad (3.26)$$

By multiplying $(R_{H_L(k-1)}^\perp H_0(k))^H$ in eq.(3.26) on both side, eq.(3.26) can be express as,

$$\begin{aligned} & (R_{H_L(k-1)}^\perp H_0(k))^H R_{H_L(k-1)}^\perp g(k) \\ &= (R_{H_L(k-1)}^\perp H_0(k))^H R_{H_L(k-1)}^\perp H_0(k) F_2^H \begin{bmatrix} \widehat{m}_1(k) \\ \widehat{m}_2(k) \end{bmatrix} \end{aligned} \quad (3.27)$$

$R_{H_L(k-1)}^\perp H_0(k)$ is full column rank matrix, $\left(R_{H_L(k-1)}^\perp H_0(k)\right)^H R_{H_L(k-1)}^\perp H_0(k)$ is invertible matrix, the estimation of LS (Least Square) for most wanted symbol block of MIMO-OFDM is given as[56],

$$\begin{aligned} & \left(\left(R_{H_L(k-1)}^\perp H_0(k) \right)^H R_{H_L(k-1)}^\perp H_0(k) \right)^{-1} \left(R_{H_L(k-1)}^\perp H_0(k) \right)^H R_{H_L(k-1)}^\perp g(k) \\ & = F_2^H \begin{bmatrix} \widehat{m}_1(k) \\ \widehat{m}_2(k) \end{bmatrix} \end{aligned} \quad (3.28)$$

or

$$\left(H_0(k) \left(H_0^H(k) R_{H_L(k-1)}^\perp H_0(k) \right) \right)^{-1} H_0^H(k) R_{H_L(k-1)}^\perp g(k) = F_2^H \begin{bmatrix} \widehat{m}_1(k) \\ \widehat{m}_2(k) \end{bmatrix} \quad (3.29)$$

By multiplying the $H_0(k)$ on both side in eq.(3.28) because in STBC system need to exploit to present additional diversity on behalf of reducing the consequences for channel fading, hence we get,

$$\begin{aligned} & H_0(k) \left(H_0(k) \left(H_0^H(k) R_{H_L(k-1)}^\perp H_0(k) \right) \right)^{-1} H_0^H(k) R_{H_L(k-1)}^\perp g(k) \\ & = H_0(k) F_2^H \begin{bmatrix} \widehat{m}_1(k) \\ \widehat{m}_2(k) \end{bmatrix} \end{aligned} \quad (3.30)$$

or

$$\left(E_{H_0(k)H_L(k-1)} \right) g(k) = H_0(k) F_2^H \begin{bmatrix} \widehat{m}_1(k) \\ \widehat{m}_2(k) \end{bmatrix} \quad (3.31)$$

where $E_{H_0(k)H_L(k-1)}$ shows the projection operator [57].

In eq.(3.32) right hand side is $\langle H_0(k) \rangle$ which is the signal subspace without ISI data subsequent to the oblique projector.

$$E_{H_0(k)H_L(k-1)} g(k) \subseteq \langle H_0(k) \rangle \quad (3.32)$$

The oblique projection (OB) related to $r(k+1)$ is given as,

$$\begin{aligned}
& E_{H_0(k+1)H_L(k)} \\
& = H_0(k+1) \left(H_0^H(k) R_{H_L(k-1)}^\perp H_0(k) \right)^{-1} H_0^H(k) \\
& + 1) R_{H_L(k)}^\perp
\end{aligned} \tag{3.33}$$

Eq.(3.28) and eq.(3.29) represents the property of oblique projection. Oblique projection is used to remove the effect of ISI from the received signal symbol blocks which is given in eq.(3.22) [58].

3.3.2 Frequency-Domain Decision Feedback Equalizer with Oblique Projection

By applying the oblique projection operator $E_{H_0(k)H_L(k-1)}$, the structured noise can be removed while the channel matrix term remains undisturbed, i.e.

$$\begin{aligned}
g_{ob}(k) & = E_{H_0(k)H_L(k-1)} g(k) \\
& = H_0(k) F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} + E_{H_0(k)H_L(k-1)} n(k)
\end{aligned} \tag{3.34}$$

In frequency domain, eq.(3.34) can be express as,

$$\begin{aligned}
g_{ob}(k) & = F_2^H E_{H_0(k)H_L(k-1)} g(k) \\
& = (H_0(k) + H_1(k)) F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} - H_1(k) F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \\
& + F_2^H E_{H_0(k)H_L(k-1)} n(k)
\end{aligned} \tag{3.35}$$

Taking the FFT on both sides, we get,

$$\begin{aligned}
O_{ob}(k) & = F_r g_{ob}(k) \\
& = F_r (H_0(k) + H_1(k)) F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} - F_r H_1(k) F_2^H \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \\
& + F_r E_{H_0(k)H_L(k-1)} n(k)
\end{aligned} \tag{3.36}$$

where, $F_r(H_0(K) + H_1(k))F_2^H$ is auxiliary matrix denoted as $D(k)$ and $F_r E_{H_0(k)H_L(k-1)} n(k)$ is noise vector denoted as $v(k)$. Auxiliary matrices with $MN \times 2N$ can be distinct as [59],

$$D(k) = [D_1(k) \quad D_1(k)] \quad (3.37)$$

where, $D_i(k) = [D^{(1,i)T}(k) \dots D^{(M,i)T}(k)]^T$, for $1 \leq i \leq 2$ and $1 \leq r \leq M$ and $D^{(r,j)}(k) = F \left(H_0^{(r,j)}(k) + H_1^{(r,j)}(k) \right) F^H$ is diagonal matrix with the n th diagonal entries. Now we have to elaborate the n th subscriber of the r th receiving and j th transmitting antenna [60].

By using oblique projector given in eq.(3.33) and apply it to in eq.(3.20). So, we get the loaded frequency domain multiple acknowledged signal-vectors,

$$\begin{aligned} & \begin{bmatrix} O(k) \\ O^*(k+1) \end{bmatrix} \\ &= \begin{bmatrix} D(k) \\ D^*(k+1)J \end{bmatrix} \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} - \begin{bmatrix} F_r H_1(k) F_2^H \\ F_r^* H_1^*(k+1) F_2^T J \end{bmatrix} \begin{bmatrix} m_1(k) \\ m_2(k) \end{bmatrix} \\ &+ \begin{bmatrix} v(k) \\ v^*(k+1) \end{bmatrix} \end{aligned} \quad (3.38)$$

where, $\begin{bmatrix} F_M H_1(k) F_2^H \\ F_M^* H_1^*(k+1) F_2^T J \end{bmatrix}$ is $H_{ICI}(k+1)$. The first term on right hand side of eq.(3.38) is mixture of the preferred tone-by-tone signals and channel tone matrix and second term is inter carrier interference (ICI) that destroy the channel regularly. To remove ICI, the degrees of freedom should be sufficient at receiving antenna [61].

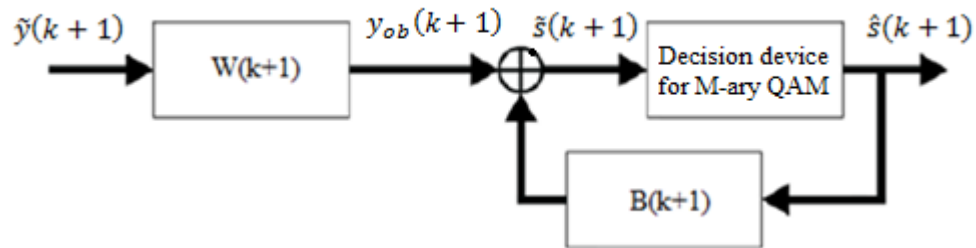


Fig.3.6 Block diagram for Decision Feedback Equalizer in frequency-domain [62]

According eq.(3.37), we suggest a fresh FD decision feedback equalizer being compact with the inter carrier interference term of (3.37); below hypothesis to faultless channel state information is

accessible at the receiver. Fig. 3.6 represents the structure of decision feedback equalizer (DFE) that contains forward filter represented by matrix $W(k+1)$ having length $(2N \times 2MN - 2L)$, feedback filter represented by matrix $B(k+1)$ and decision making device with dimensions $2N \times 2N$. From Fig.3.6, the output of forward filter is,

$$\begin{aligned} y_{ob}(k+1) &= W(k+1)\tilde{y}(k+1) \\ &= W(k+1)\Gamma^H(k+1) \begin{bmatrix} D(k) \\ D^*(k+1)J \end{bmatrix} \begin{bmatrix} s_1(k) \\ s_2(k) \end{bmatrix} \\ &\quad + W(k+1)\tilde{v}(k+1) \end{aligned} \quad (3.39)$$

where, $\tilde{y}(k+1) = \Gamma^H(k+1) \begin{bmatrix} y(k) \\ y^*(k+1) \end{bmatrix}$, $\Gamma(k+1) = \begin{bmatrix} \Gamma_1(k+1) \\ \Gamma_2(k+1) \end{bmatrix}$ and $\Psi(k+1) = \Gamma^H(k+1) \begin{bmatrix} D(k) \\ D^*(k+1)J \end{bmatrix}$

Both matrix $\Gamma_1(k+1)$ and $\Gamma_2(k+1)$ have the same dimension of $(MN \times 2MN - 2L)$. Weight matrix in FD Decision Feedback Equalizer $B(k+1)$ and $W(k+1)$ are presented as,

$$B(k+1) = U(k+1) - I_{2N \times 2N} \quad (3.40)$$

$$W(k+1) = D_m^{-1}(k+1)U^{-H}(k+1)\Psi^H(k+1)\sigma_n^{-2} \quad (3.41)$$

where, $U(k+1)$ is an upper triangular matrix. In this matrix, diagonal terms are unity. STBC technique improves the diagonal terms of matrices $\Psi^H(k+1)\sigma_n^{-2}\Psi(k+1)$ [63].

With the help of eq.(3.40) and eq.(3.41), the desired result can be obtained as,

$$\hat{y}(k) = [\widehat{s^T}(k) \quad \widehat{s^T}(k+1)]^T = [\widehat{s^T}(k) \quad \widehat{s^T}(k)]^T \quad (3.42)$$

3.4 V-BLAST Technique for MIMO-OFDM followed by QR-factorization algorithm

Vertical Bell Laboratories Layered Space-Time (V-BLAST) is an algorithm technique that uses multiple paths to send independent signals to the receiver, thus the data rate increases by using this technique. V-BLAST technique can be divided into two different schemes, first is open loop and second is close loop V-BLAST. Both schemes are different to each other depending on the

basis of effective channel equalization. In closed loop V-BLAST technique, a feedback channel is inserted between transmitting and receiving antenna that inform to transmitter about optimize transmit power, rate and assigned transmit antenna for each data stream at different OFDM tones. Fig.3.7 represents the block diagram of close loop V-BLAST MIMO-OFDM [64].

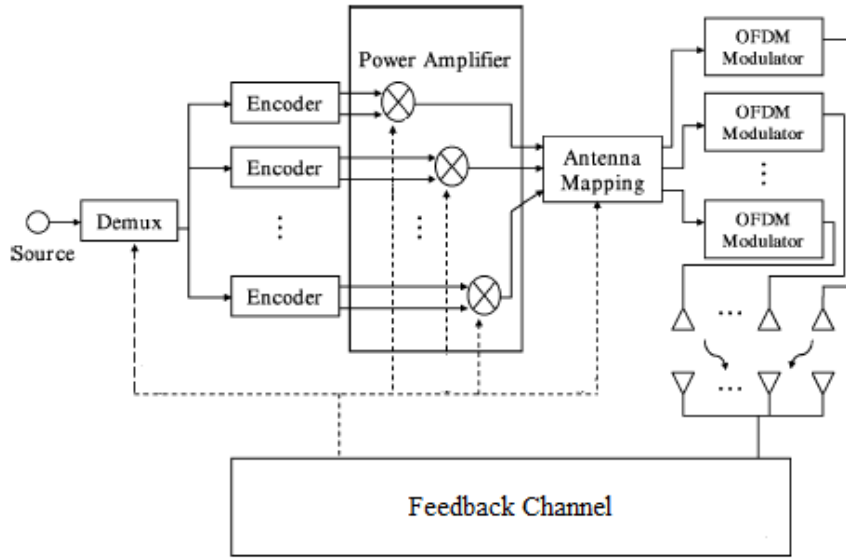


Fig.3.7 Block diagram of close loop V-BLAST MIMO-OFDM. [64]

All the information regarding this model is given below,

- Demultiplexer: In demultiplexer, all information bits of each transmission block (target rate R) are first divided into M data stream, where $M = \min(M_r, M_t)$. Each data stream should have rate which is r_j/r , $j=1, 2, \dots, m$ where r_j is j^{th} data stream rate.
- Encoder: Encoder converts the data stream into another form through the channel coding and modulation technique. Each and every data stream are separated by the S repeatedly K -tuples [65].

For every j^{th} data tributary, the pointer allocated n^{th} -OFDM symbols that is given by,

$$x_{g,j}(n), g = 1, 2 \dots K, n = 1, 2 \dots S \quad (3.43)$$

- Power Amplifier: In power amplifier, $x_{g,j}(n)$ is amplified with respect to its allocated data stream and tone position at each OFDM symbols. For the j^{th} data stream, the signal

is defined as $x_{g,j}(n), n = 1, 2, \dots, S$ and every g th stream is enlarged according to $q_{g,j}$. The output of power amplifier is given as [66];

$$\tilde{x}_{g,j}(n) = q_{g,j} \times x_{g,j}(n) \quad (3.44)$$

- **Antenna Mapping:** Antenna Mapping synchronizes the demultiplexer through receiving antenna. In this, each element of $\tilde{x}_g(n)$ are correspondingly mapped to its transmitting antenna. Let $\tilde{x}_g(n) \triangleq [\tilde{x}_{g,1}(n), \dots, \tilde{x}_{g,m}(n)]^T$ and the mapped antenna at tone g are specified by the vector $\gamma_g = [\gamma_{g,1}, \gamma_{g,2}, \dots, \gamma_{g,m}] \subseteq \{1, 2, \dots, m_t\}$. $\gamma_{g,1}$ represents the transmit antenna at tone g for carrying the 1st data stream. Now we can calculate $m \times m_t$ matrix G^{γ_g} as follows:

$$G^{\gamma_g}_{i,j} = \begin{cases} 1, & \gamma_{g,i} = j \\ 0, & \text{otherwise} \end{cases} \quad (3.45)$$

So, the output after antenna mapping can be represented as,

$$y_g(n) = G^{\gamma_g} * \tilde{x}_g(n) \quad (3.46)$$

where, $y_g(n)$ is transmitted signal vector [67].

- **OFDM Modulator:** It modulates the signal with respect to the QPSK technique into the n th OFDM symbol which is radiate by the i th transmit antenna, $i=1, 2, \dots, m_t$ [67].

$$y_g(n) \triangleq [y_{g,1}(n), \dots, y_{g,m_t}(n)]^T \cdot \{y_{1,i}(n), \dots, y_{K,i}(n)\} \quad (3.47)$$

M data stream, with transmission rate r_1, r_2, \dots, r_M , separately transmitted through the horizontal encoding. Because there is no assignment of any data and the value of r_j is zero for all values of 'g' so the close loop V-BLAST system randomly get used to number of data stream. In general, all antenna's are active if single transmit antenna is assign towards its one data stream for one tone excluding allocate to the other data stream for another tone. Other toggled transmit antenna

haven't assign to data stream. According to this theory, we have defined three main parameters in close loop MIMO-OFDM system [68].

1. Target rate assignment.
2. Power assignment through the power amplifier.
3. Transmit antenna allocation.

So, the each and every data stream can be decoded through the multiuser detection technique. It can be either MMSE based or ZF based. The receiver formation of this system is different from the transmission system process. In this thesis, MMSE and ZF both decoding technique are considered. V-BLAST close loop MIMO-OFDM system, based on the MMSE technique achieve the capacity of Gaussian multiple access channel and it is optimal for the proposed system. Moreover, the proposed system has high computational complexity when the number of transmitting and receiving antenna is huge. So, it is so much difficult to create the practical modulation & coding parameter into the feedback optimization. Although, the ZF based V-BLAST receiver is not so much complicated as compare to MMSE based.

Successive parameterized decoding is based on the ZF by the set of projection vectors at special OFDM tones for each data stream given by [68],

$$b_{g,j}^{\gamma_g} \in \mathbb{C}^{i \times 1}, g = 1, \dots, K, j = 1, \dots, m \quad (3.48)$$

where, $b_{g,j}^{\gamma_g}$ is depend on the parameter γ_g , which is defined by the data stream of separate OFDM channel allocate by the transmit antenna. γ_g is the QR-factorization for the channel matrix at tone 'g'. So this can be expressed as [68],

$$H_g * G^{\gamma_g} = B^{\gamma_g} * C^{\gamma_g} * I^{\gamma_g} \quad (3.49)$$

where, $B^{\gamma_g} \in \mathbb{F}^{i \times m}$ assures $(B^{\gamma_g})^\dagger B^{\gamma_g} = C^{\gamma_g}$ has an $m \times m$ diagonal matrix and $I^{\gamma_g} \in \mathbb{F}^{m \times m}$ is a monic lower triangular matrix. In ZF algorithm firstly concern to the projection vector of the received signal which is given as,

$$\tilde{y}_g(n) = (B^{\gamma_g})^\dagger * v_g(n) \quad (3.50)$$

$$= (B^{Y_g})^\dagger * H_g * y_g(n) + \tilde{u}_g(n) \quad (3.51)$$

where,

$$\tilde{u}_g(n) = (B^{Y_g})^\dagger * u_g(n) \quad (3.52)$$

From eq.(3.48) and eq.(3.49), eq.(3.51) can be written as,

$$\tilde{y}_g(n) = C^{Y_g} * I^{Y_g} * \tilde{x}_g(n) + \tilde{u}_g(n) \quad (3.53)$$

Suppose, eq.(3.51) has data stream decoding order from 1 to m . The j th data stream from 1 to $(j-1)$, so, we can define that the matrix is off-diagonal and lower triangular. The data stream which is not decoded yet can be removing by the ZF algorithm from the projection vector [22]. Here we have noted that, performing channel matrix consist of data stream size $(i \times m)$ which has the decoded data stream. This stream completely eliminates the noise from the other $(m-1)$ stream after proposing the ZF based algorithm [69]. The j th data stream can be described by the channel gains which is denoted as $d_{g,j}^{Y_g}$ and this is acquired by,

$$C^{Y_g} \triangleq \text{Diag} \left(\left[\sqrt{d_{g,1}^{Y_g}}, d_{g,2}^{Y_g}, \dots, d_{g,m}^{Y_g} \right] \right) \quad (3.54)$$

In ‘ S ’ OFDM symbol periods, the successive decoding with the delay can be given which is frequently small in number.

Achievable rate of each data stream which has a set of antenna mapping and power assignment can be calculated by,

$$r_j(\{Y_g\}) = \frac{1}{2K} \sum_{g=1}^K \log_2 \left(1 + \frac{d_{g,j}^{Y_g} * q_{g,j}}{r} \right) \quad (3.55)$$

r_j is calculated in bits/sec/Hz. So we have to introduce $\frac{1}{2}$ in front of achievable rate. The gaps between all data stream are assumed to be equal and the capacity of signalling is non-ideal for remaining channel. So, power obligation to the different data streams for same OFDM tone will be connect to the channel equalization. The calculation rate at each data stream of the signal in OFDM for every tone will be exact rate [69].

3.4.1 QR-Decomposition Algorithm

Let, B is a real $(i \times j)$ matrix, where, $(i > j)$ and the rank of B is r . Here, the B may be decomposed into the product given as,

$$B = QR \quad (3.56)$$

Here, R is upper triangular matrix which is $(j \times j)$ & Q is an orthogonal matrix which is $(i \times j)$.

where,

$$Q^T Q = I_j \quad (3.57)$$

This algorithm can be proposed the Schmidt orthogonalization process. This algorithm process will be generalized only when the value of Q should be represented in the explicit form. So, this algorithm consist the n number of steps. We have considered the m th step is,

$$kQ_1, \dots, kQ_{k-1} \quad (3.58)$$

Now we have to evaluate the projection by using the $k B_m$,

$$q_{nm} kQ_n \text{ with } q_{nm} := kQ_n^T kB_m \quad (3.59)$$

Then, the vector formation is,

$$a_m = kB_m - \sum_{n=1}^{m-1} q_{nm} kQ_n \quad (3.60)$$

All the vectors are orthogonal; consequently we get [70],

$$kQ_m := \frac{a_m}{\|a_m\|} \quad (3.61)$$

So, all the mathematical procedure we can derive through the algorithm, this algorithm defines the QR decomposition method proposed with Household-Transformation process consist in the MIMO-OFDM system [70].

Household-Transformation process is more stable as compare to Schmidt orthogonalization process in QR-decomposition then the transformation of Q is defined as,

$$Q^T = A_n A_{n-1} \dots \dots A_1 \quad (3.62)$$

$$Q = (A_n \dots \dots A_1)^T = A_1^T A_2^T \dots \dots A_j^T = A_1 A_2 \dots \dots A_j \quad (3.63)$$

Here, A_n are symmetric. In this process the system is perfectly orthogonal with the MIMO-OFDM system.

CHAPTER-4

RESULTS & DISCUSSION

In this segment, Bit-error-rate and computational complexity of STBC MIMO-OFDM system has been simulated and discussed by using two different methods one is FD-DFE followed by oblique projection and another is V-BLAST with QR-factorization algorithm.

4.1 BER vs. SNR

The comparison of STBC MIMO-OFDM system with CP or without CP using different equalizers has been analyzed in Fig.4.1.

Number of transmitting antennas	2
Number of receiving antennas	3
Number of Multiple paths	4
Number of subcarriers	32
Fading Channel	Rayleigh Fading Channel

Table 4.1 Parameters specification related to SNR vs. BER

4.1.1 Analysis: Performance Comparison of OB FD- DFE with other technique

Fig. 4.1 depicts the plot of BER as the function of SNR (dB) for ZF, MMSE, OB FD-DFE-ZE and CP technique using MIMO-OFDM system. It has been observed that by applying equalizing schemes MMSE and ZF in MIMO-OFDM system with cyclic prefix achieve higher BER as compare to the system with oblique projection frequency domain decision feedback equalizer. In results it has been shown that proposed cyclic prefix free system is better than all due to reduced ISI and ICI.

TECHNIQUE	SNR at 0.01 BER in dB
OB FD DFE-ZF OFDM	4.33
OFDM with CP	5
MMSE OFDM	14
ZF OFDM	16

Table 4.2 SNR values for different techniques at 0.01 BER

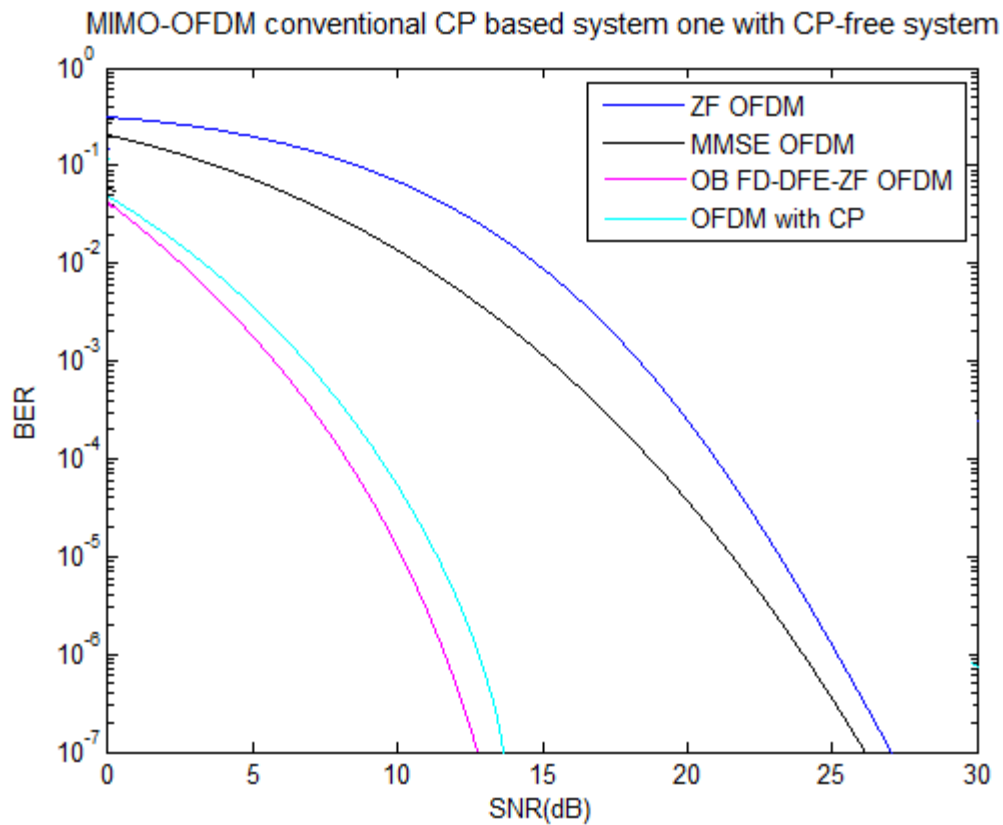


Fig.4.1 Performance comparison of the proposed Cyclic Prefix free STBC MIMO-OFDM scheme with conventional CP-based system with channel order $L=4$

From the Fig.4.1, it is observed that the BER of OB FD-DFE-ZF is almost same as BER of CP based technique. Moreover, OB FD-DFE-ZF technique has better BER performance as compare to other techniques. Also, we obtain the lowest bit error probability for OB FD-DFE-ZE technique and highest one for ZF technique for fixed SNR values as presented in Fig.4.1.

4.2 Achievable Rate vs. SNR

Fig.4.2 shows the Achievable Information rate versus SNR. The achievable rate measured according to,

$$F_k = F_k^{UB} = \log_2 \left(1 + \frac{M}{\sigma_v^2} \right) \quad (4.1)$$

The above rate can be achieved in the Rayleigh Fading channel and without counting any cyclic prefix overhead.

Number of transmitting antennas	2
Number of receiving antennas	3
Number of Multiple paths	4
Number of subcarriers	32
Fading Channel	Rayleigh Fading Channel
Number of terminals	10
Noise Immunity	-10dB(SNR at the input of the BS antennas)

Table 4.3 Parameters specification related to Achievable rate vs. SNR

4.2.1 Analysis: Analysis: Performance Comparison of OB FD- DFE CP free with other technique

Fig.4.2 represents the plot of Achievable rate (bit/sec/Hz) as the function of SNR(dB). It has been observed that the value of achievable rate with respect to signal to noise ratio will be increases when we are using oblique projection in ZF and MMSE equalization.

TECHNIQUE	Achievable Rate at 5dB SNR in bits/sec/Hz
MIMO-OFDM without CP,ZF	2.8
MIMO-OFDM with CP,ZF	2.2
MIMO-OFDM without CP,MMSE	2
MIMO-OFDM with CP,MMSE	1.2

Table 4.4 Achievable Rate values for different combination of techniques at 5dB SNR

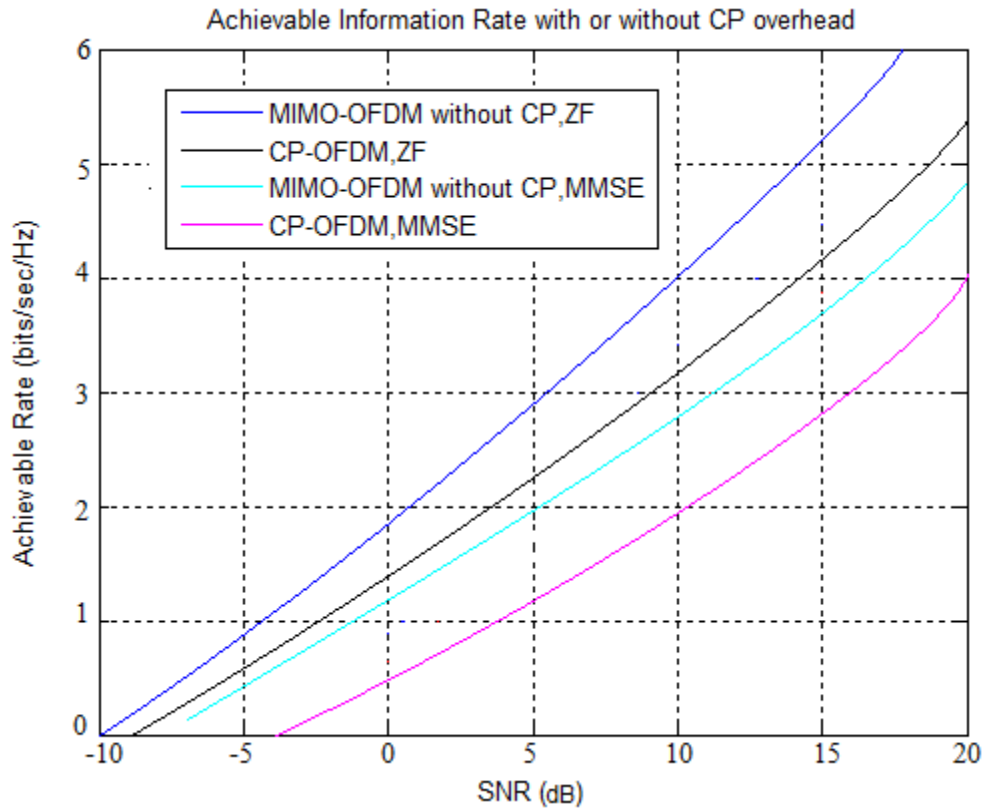


Fig.4.2 Achievable rate of the MIMO-OFDM system without CP with the MMSE and ZF equalizers as well as that of the CP-OFDM with MMSE and ZF detector

From Fig.4.2 it is observed that the achievable rate is highest for ZF without CP technique and lowest for CP-MMSE technique, moreover, MMSE without CP technique contains higher achievable rate as compared to MMSE with CP technique for fixed SNR values.

4.3 Computation Complexity vs. Number of Antennas

In this section, computational complexity of STBC-MIMO-OFDM system has been analyzed by changing number of base stations. It can be expected that the complexity of the system will be

increases in the first round of iteration. Introducing V-BLAST technique with oblique projector, the number of complications will be decreases and system performs with low complexity. Due to this the value of ISI and ICI will be negotiable as compare to conventional OFDM.

Number of Multiple paths	4
Number of subcarriers	32
Fading Channel	Frequency Selective Rayleigh Fading Channel
Noise	AWGN
CP	16
RMS delay Spread	25ns
Sampling Frequency	1/80MH
Noise Immunity	-10dB

Table 4.5 Parameters specification related to Computational complexity

4.3.1 Analysis: Number of computation comparison with CP based and CP-free

(A) Computational complexity vs. Number of base station antenna

Fig.4.3 (a) depicts the plot of number of complex multiplication as the fuction of number of base satation antenna.The number of complex multiplications increases due to the presence of number of antennas in the MIMO-OFDM system with CP and without CP in linear equalizer scenario. In Fig.4.3(a) we are varying the number of receiving antenna and the number of transmitting antenna is constant. Table 4.6(a) shows the values of the results according to Fig.4.3(a).

TECHNIQUE	Complex Multiplications when number of BS antennas are 30
MIMO-OFDM without CP,ZF	3.9
MIMO-OFDM with CP,ZF	5.1
MIMO-OFDM without CP,MMSE	2.88
MIMO-OFDM with CP,MMSE	2.4

Table 4.6(a) Number of Complex multiplication values when BS antenna is varying

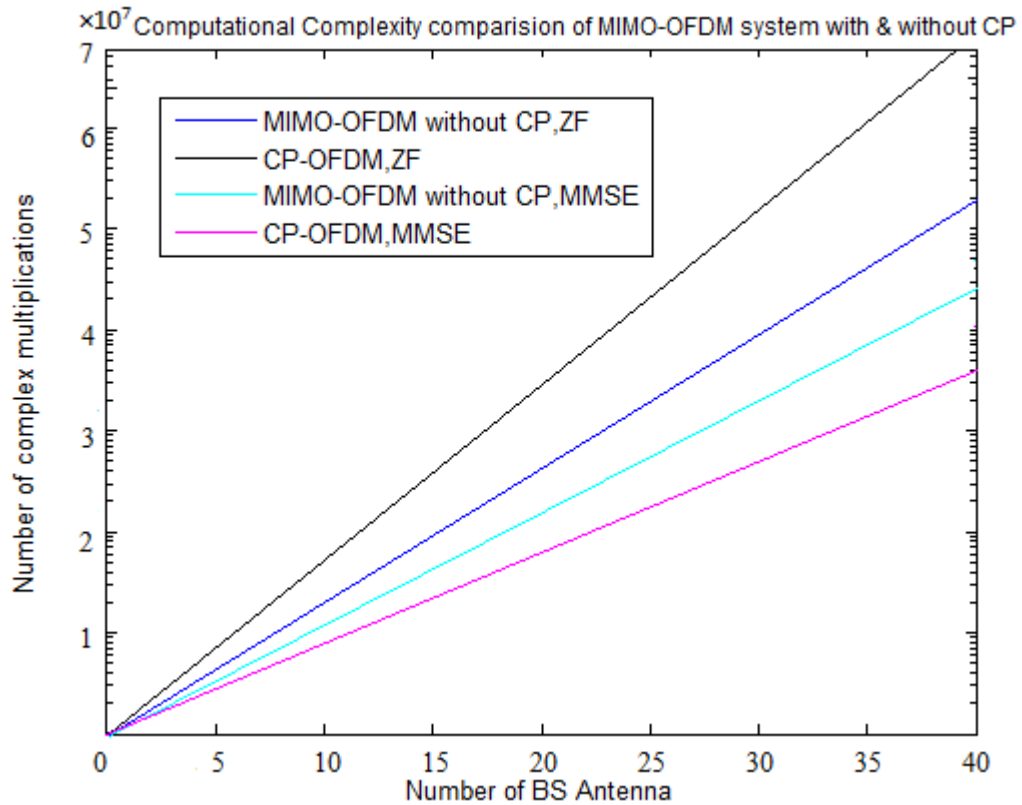


Fig.4.3(a) Computational complexity comparison of MIMO-OFDM without CP with MMSE and ZF techniques against CP-OFDM with MMSE and ZF equalizations, number of base station antenna is varied and the number of receiving antenna is fixed

From Fig.4.3(a), it is observed that MMSE without CP technique has minimum number of complex multiplication as compare to ZF without CP and ZF with CP technique for fixed number of BS antenna.

(B) Computational complexity vs. Number of receiving antenna

Fig.4.3(b), receiving antenna suppose to be fixed and varying transmitting antenna. There is a 74% complexity when we use CP based conventional OFDM system while if we take receiving antenna is 12 and apply QR-factorization then complexity is reduced to 57.3% approximately. The computational cost of proposed model is reducing rapidly when we vary the number of receiving antenna. Table 4.6(b) shows the values of the results according to Fig.4.3(b) .

TECHNIQUE	Complex Multiplications when number of Receiving antenna are 30
MIMO-OFDM without CP,ZF	0.75
MIMO-OFDM with CP,ZF	1.2
MIMO-OFDM without CP,MMSE	0.2
MIMO-OFDM with CP,MMSE	0.05

Table 4.6(b) Number of Complex multiplication values when receiving antenna is varying

From Fig.4.3(b), it is observed that, CP free MMSE technique has minimum number of complex multiplication as compare to ZF with and without CP technique for fixed number of receiving antenna. More over, CP free ZF technique has minimum number of complex multiplications as compare to ZF with CP technique. Further, Fig.4.3(b) represents that, on increasing the number of receiving antenna, the number of complex multiplication gets slightly increases which has better performance as compare to plot presented in Fig.4.3 (a).

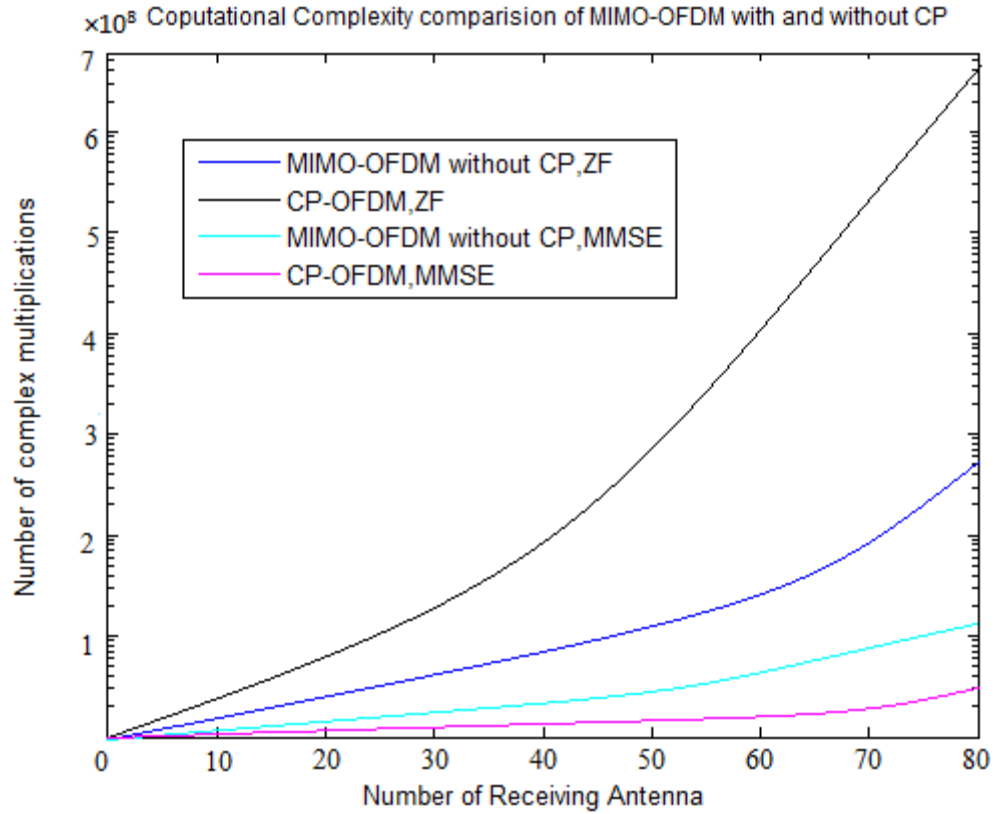


Fig.4.3(b) Computational complexity comparison of MIMO-OFDM without CP with MMSE and ZF techniques against CP-OFDM with MMSE and ZF equalizations,number of receiving antenna is varied while the transmit antenna is fixed

MMSE and ZF detectors have the two parts one is with cyclic prefix OFDM and another is CP-free OFDM in the MIMO system. Both parts have their own detector at the receiver side in channel estimation; here we talk about the complexity minimization of each part. We have commenced the number of complex multiplications which have to execute in the MMRC and ZF CP-OFDM and CP-free OFDM.

PROCEDURE	Number of Complex Multiplications
MMSE	$\frac{1}{2}RN_t n \log_2 n + RN_t n N_r$
ZF	$\frac{1}{2}RN_t n \log_2 n + RN_t n N_r + \frac{3}{2}N_t n N_r + \frac{1}{3}n N_r$

Table 4.7 Computational Complexity in the CP-OFDM System

Table 4.7 presents the conventional CP-OFDM with the MMRC and ZF exist at the receiver side. In MMRC 1st and 2nd both terms are represent the alteration of time to frequency complexity. In the ZF the 3rd and the 4th terms are due to the simplification of ZF coalescing matrices.

PROCEDURE	Number of Complex Multiplications
MMSE	$\frac{1}{2} \frac{RN_t n}{m - M + 1} m \log_2 m + \frac{RN_t n N_r m}{m - M + 1} + \frac{1}{2} \frac{RN_r n}{m - M + 1} m \log_2 m$ $+ \frac{1}{2} RN_r n \log_2 n$
ZF	$\frac{N_r(N_r + 1)}{2} N_t m + \frac{N_r(N_r + 1)}{4} m \log_2 m + \frac{1}{2} N_r n \log_2 n$ $+ \frac{1}{3} n N_r + Rn N_r$

Table 4.8 Computational Complexity in the CP-free-OFDM System with QRD Algorithm

Here R is the number of OFDM symbols. Table 4.8 shows in MMSE the first 3 term shows linear equalizer combining by using the fast-convolution with implementation of QR decomposition (QRD) algorithm. The 4th term occurs because of the matrix inversion in OFDM. In ZF, the first 2 terms are due to the channel responses using the FFT. The 3rd terms because of the channel coefficient of the system and last two terms due to the calculation of the estimation of OFDM in frequency fading channel.

CHAPTER-5

CONCLUSION & FUTURE SCOPE

5.1 Conclusion

In this thesis, two techniques have been proposed, FD (Frequency Domain) Decision feedback equalizer and V-BLAST with QR-decomposition based on CP free STBC MIMO OFDM system. The presented results can be performed in well known standard software package like Matlab and Mathematica. The results based on these two techniques are novel and never reported in literature. It is noted that, in MIMO-OFDM system, by increasing the number of transmitting and receiving antennas ICI, Computational complexity and structured noise gets increased. Due to these demerits the performance of the system gets reduced. Henceforth, to improve the system performance, two techniques have been proposed, first is oblique projection using decision feedback equalizer in frequency domain and second is V-BLAST using QR-decomposition.

FD (Frequency Domain) Decision feedback equalizer based system model, which is connected through the OB, consists of 2 transmitting and 3 receiving antennas because the number of subscribers N is characteristically greater than channel order L . Hence it has been established that the selection of $M \geq 3$ the degrees of freedom is adequate to convince the situation, ($MN \geq 2N + 2L$), because of ICI. From the results achieved, it is observed that BER is less for OB FD-DFE-ZF technique as compared to other models like ZF OFDM, MMSE OFDM and OFDM with CP. In other words, we have obtained minimum BER by proposing the technique as compared to conventional techniques proposed in previous literature for fixed average SNR. Moreover, by increasing the SNR (dB), the achievable rate gets increased. We have obtained an achievable rate of 2.8 for CP free ZF technique which is better than conventional techniques like CP based ZF, CP free MMSE and CP based MMSE.

V-BLAST technique followed by QR-factorization algorithm in linear equalizer channel estimation reduces the number of complex multiplications. In this technique, the detection order is opposite to the transmitted signal. Due to this, the speed of the system increases and complexity is reduced. In the simulation results, it has been observed that for a fixed number of transmitting antennas (for e.g. $N_t=30$), the number of complex multiplications is 3.9 for ZF and 2.88 for MMSE decoder and for a fixed number of receiving antennas (for e.g. $N_r=30$), the number of complex multiplications is 0.75 for ZF and 0.2 for MMSE. Thus it can be concluded that, on varying the

number of receiving antenna, we have obtained less computational complexity as compare to by varying the number of transmitting antenna.

5.2 Future Scope

In this study, different problems of CP-free MIMO-OFDM system have been considered and suitable solutions have been provided. As it is an established fact that research is never ending process, a foundation of new process always waiting. Therefore, following works are the open research problem in this thesis.

- In future, we can use PAPR reduction method in CP-free MIMO-OFDM model.
- We can use the different estimation process or fading technique to improve the achievable rate performance.
- As we know that the effect of mutual coupling will change the spatial correlation, so in future the performance analysis of MIMO-OFDM system under the antenna mutual coupling can be performed.

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LIST OF PUBLICATIONS

- [1] Atrey S and Kansal A (2017).Performance Analysis of OFDM System with CP-Free STBC by using the Oblique Projection Technique, *International Journal of Sensor, Wireless Communication and Control communicated.*
- [2] Atrey S and Kansal A (2017).Computational Complexity reduction in MIMO-OFDM system with QR-factorization algorithm, *Wireless Networks, the Journal of Mobile Communication, Computation and Information communicated.*

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