A

Thesis Report

on

"BER AND PAPR ANALYSIS OF 8X8 MIMO OFDM SYSTEM USING SLM TECHNIQUE"

Submitted towards the partial fulfillment of requirement for the award of degree of

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CERTIFICATE

I Anurag Sharma, hereby certify that the work which is presented in this thesis entitled **"BER AND PAPR ANALYSIS OF 8X8 MIMO OFDM SYSTEM USING SLM TECHNIQUE"** in partial fulfillment of requirements for the award of degree of Master of Engineering in Electronics and Communication from Thapar University, Patiala, is an authentic record of my own work carried under the supervision of **Ankush Kansal**.

The matter presented in this thesis has not been submitted in any other University/Institute for the award of Master of Engineering.

Anurag
(Anurag Sharma) 15/07/2013

Signature of Student

This is certified that the above statement made by the candidate is correct to the best of my knowledge

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Place: TU, Patiala, India

(ANURAG SHARMA)

ABSTRACT

Increased spectral efficiency and improved link reliability are major challenges in future wireless communications system design. The radio channel constitutes a hostile propagation medium, which suffers from fading and interference from other users. With the evolution of the wireless system the demand for high speed data services have been increasing day by day, which is impossible to be achieve by the conventional serial data transmission system without trade-off between high speed data services and QOS without increasing the band width of the system. So both the options are inconvenient, as one never demands the degradation of the service quality and secondly the need for extra spectrum in a limited spectrum scenario. In order to overcome this problem new parallel data transmission system was proposed, which is known as OFDM system. The performance of OFDM system can further be improved by using multiple antennas at transmitting and receiving side to provide spatial diversity.

Multiple antennas can be used at the transmitter and receiver, an arrangement called a MIMO system. A MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multipath scattering environment. Recently, there have been a lot of interests in combining the OFDM systems with the multiple-input multiple-output (MIMO) technique. These systems are known as MIMO-OFDM systems. MIMO-OFDM system has been currently recognized as one of the most competitive technology for 4G mobile wireless systems. The combination of OFDM and MIMO seems to be very promising when aiming at the design of very high-rate wireless mobile systems. While multiple antennas at the transmitter and receiver elevate channel capacity, i.e. the achievable transmission rate, OFDM converts the wideband frequency selective radio channel into a set of parallel flat-fading channels, thus simplifying signal processing required at the receiver. The main drawback of MIMO-OFDM system is high peak-to-average power ratio (PAPR) for large number of sub-carriers, which result in many restrictions for practical applications. Coding, phase rotation and clipping are among many PAPR reduction schemes that have been proposed to overcome this problem. In this thesis, BER and PAPR of 8x8 MIMO OFDM system is calculated and the PAPR is reduced using SLM(Selected Mapping) Technique.

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1.1 INTRODUCTION

The third generation (3G) mobile communication systems have became popular all around the world. But, its services cannot provide a very big dynamic range of data rates, nor can it meet the requirements of a variety of business types. Besides, voice transportation in 3G still relies on circuit switching technology, which is the same method as used in second-generation (2G) communication systems, rather than pure Internet Protocol (IP) approach. Thus, based on consideration listed above, many countries have already carried out research on the next completely evolutionary fourth generation (4G) communication systems which provide a comprehensive and secure IP solution where voice, data, and multimedia can be offered to users at anytime, wherever the user wants with higher data rates than previous generations [1]. Since bandwidth resource in 4G mobile communications [2] is still scarce, in order to improve spectrum efficiency [3] and achieve as high as 100Mbps wireless transmission rate, it requires more advanced techniques to be employed. The limitation of modulation schemes in existing communication systems has become an obstruction in further increasing the data rate. Hence, next generation mobile communication systems need more sophisticated modulation scheme and information transmission structure. Multiple input multiple outputs (MIMO) and orthogonal frequency division multiplexing (OFDM) have therefore been adopted due to their superior performance. They promise to become key high-speed wireless communication technologies [4] and combining them can provide wireless industry evolution from 3G to 4G system.

1.2 Wireless

Wireless [5] is a medium in which electromagnetic waves carry the signal over part or the entire communication path. The term is usually used in the telecommunications industry to refer to telecommunications systems (e.g. radio transmitters and receivers, remote controls etc.) which use some form of energy to transfer information without the use of wires. This implies the transfer of information between two or more points that are not connected by an electrical conductor. Some wireless technologies use electromagnetic wireless telecommunications, such as radio [6]. It consists of various types of fixed, mobile, and portable applications, including cellular telephones, personal digital assistants (PDAs). It can be divided into:

- Wireless at fixed location - The operation of wireless devices or systems in homes and offices, and in particular, equipment connected to the Internet via modems.
- Wireless in mobile applications - The use of wireless devices or systems on high speed moving vehicles like automotive cell phone and PCS (personal communications services)
- Wireless for portable applications - The operation of handheld, battery-powered wireless devices or systems outside the premises or vehicle come under this category.
- Infrared wireless - The use of devices that convey data via IR (infrared) radiation is called Infrared wireless. This is employed in certain limited-range communications and control systems.

1.3 MODULATION

Modulation [7] is the process of varying one or more features of a carrier signal, with a message signal which contains information to be transmitted. It is the process of conveying a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. Modulation of a sine waveform is used to transform a baseband message signal into a pass band signal. In radio communications, the public switched telephone network [8], electrical signals can only be transferred over a limited pass band frequency spectrum. A device that performing modulation is known as a modulator and a device that performs the inverse operation of modulation is known as a demodulator [9]. A modem is a device that can do both the operations of modulation and demodulation. Digital modulation transfers a digital bit stream over an analog band pass channel, for example over the public switched telephone network or over a limited radio frequency band. Analog modulation transfers an analog baseband signal, an audio or TV signal, over an analog band pass channel at a different frequency. Both these modulation facilitate frequency division multiplexing (FDM)[10], in which several low pass information signals are transferred simultaneously over the same shared physical medium, using separate pass band channels.

1.3.1 BPSK Modulation Technique

BPSK [11] uses two phases which are separated by 180° and therefore also termed as 2-PSK as shown in fig1. This modulation is the most robust of all the PSKs. BPSK is functionally equivalent to 2-QAM modulation.

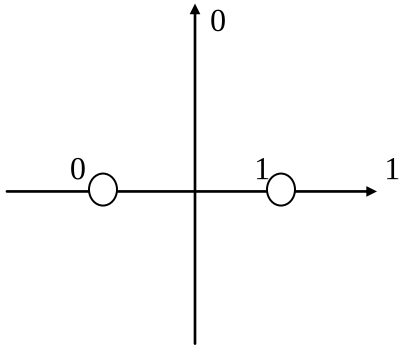

Figure1: Constellation diagram for BPSK [12]

1.3.2 Mathematics for BPSK

BPSK can be written as:

$$S_n(t) = \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_c t + \pi(1-n)), n = 0,1 \quad (1.1)$$

where E_b = Energy per bit, , $n =$ bits per symbol, $T_b =$ Bit duration, f_c is the carrier frequency.

This gives two phases, 0 and π. For binary ‘0’ and ‘1’ this can be written as:

$$S_0(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \pi) = -\sqrt{\frac{2E_b}{T_b}} cos(2\pi f_c t), \; for\, binary\, 0 \quad (1.2)$$

$$S_1(t) = -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t), \; for\ binary\ 1 \quad (1.3)$$

The signal-space of BPSK can be represented by the single basis function:

$$\emptyset\,(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \quad (1.4)$$

where 1 is represented by "$\sqrt{E_b}\emptyset\,(t)$" and 0 is represented by "$-\sqrt{E_b}\emptyset\,(t)$".

Bit error rate

The bit error rate of BPSK in AWGN can be calculated as [13]

$$\boldsymbol{P_b = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)}$$

or

$$\boldsymbol{P_b = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b}{N_0}}\right)} \tag{1.5}$$

where $\boldsymbol{\frac{N_0}{2}} =$ Noise power spectral density (W/Hz). This is also called Symbol error rate as there is only one bit per symbol.

1.3.3 QPSK modulation Technique

QPSK is known as quadrature phase shift keying, quadriphase PSK, 4-PSK, or 4-QAM. The modulated radio waves of QPSK and 4-QAM are same. QPSK uses four points on the constellation diagram, equispaced around a circle. QPSK [14] can encode two bits per symbol with four phases as shown in the Fig 2.

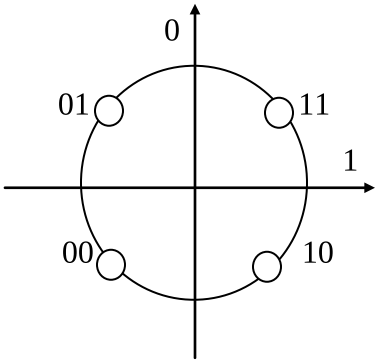

Figure2: Constellation diagram for QPSK

QPSK transmits twice the data rate in a given bandwidth compared to BPSK at the same BER.

1.3.4 Mathematics for QPSK

The symbols in the constellation diagram can be considered in terms of the sine and cosine waves:

$$S_n(t) = \sqrt{\frac{2E_s}{T_s}}\cos(2\pi f_c t + (2n-1)\frac{\pi}{4}),\ n = 1,2,3,4. \tag{1.6}$$

where $E_s =$ Energy per symbol = $nE_b, T_s =$ Symbol duration, $f_c$is the carrier frequency, $n =$ bits per symbol.QPSK has four phases π/4, 3π/4, 5π/4 and 7π/4.

This results in a two-dimensional signal space with unit basis functions

$$\emptyset_1\ (t)\ = \sqrt{\frac{2}{T_s}}\cos(2\pi f_c t) \tag{1.7}$$

$$\emptyset_2\ (t)\ = \sqrt{\frac{2}{T_s}}\sin(2\pi f_c t) \tag{1.8}$$

The first basis function is used as the in-phase component of the signal and the second as the quadrature component of the signal. The signal constellation consists of the 4 signal-space points $(\pm\sqrt{E_s/2}, \pm\sqrt{E_s/2})$.

Bit error rate

The in-phase component of the carrier is modulated using the even or odd bits, while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier. The probability of bit-error for QPSK is the same as for BPSK:

$$P_b = Q(\sqrt{\frac{2E_b}{N_0}}) \tag{1.9}$$

where $P_b =$ Probability of bit-error. The symbol error rate is given by:

$$P_s = 1 - (1 - P_b)^2 \tag{1.10}$$

where P_s =Probability of symbol-error

$$= 2Q\left(\sqrt{\frac{E_s}{N_0}}\right) - \left[Q\left(\sqrt{\frac{E_s}{N_0}}\right)\right]^2 \tag{1.11}$$

If the signal-to-noise ratio is high the probability of symbol error can be given by:

$$P_s = 2Q\left(\sqrt{\frac{E_s}{N_0}}\right) \tag{1.12}$$

1.4 Concept of Fading

Fading is change of the attenuation affecting a signal over certain propagation media. The fading varies with time, geographical position or radio frequency, and is considered as a random process. A fading channel is a communication channel comprising fading. It may be either due to multipath propagation, or due to shadowing from obstacles affecting the wave propagation. The transmitters and receivers are surrounded by reflectors in the environment which create multiple paths for the transmitted signal and as a result, the receiver sees the superposition of multiple copies of the transmitted signal, each following a different path. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the transmitter to the receiver. This results in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver. Destructive interference is known as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio. Generally, the fading channel models are used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication.

1.4.1 Selective Fading

Frequency selective fading is a radio propagation anomaly caused by partial cancellation of a radio signal by itself , the signal arrives at the receiver by two different paths, and at least one of the paths is changing (lengthening or shortening). This happens as the various layers in the ionosphere move, separate, and combines. The two paths can both be sky wave or one be ground wave. As the carrier frequency of a signal is varied, the magnitude of the change in amplitude will vary. The separation in frequency is measured by coherence bandwidth after which two signals will experience uncorrelated fading.

- The coherence bandwidth of the channel is larger than the bandwidth of the signal in flat fading. Hence, all frequency components of the signal will experience the same magnitude of fading.
- In frequency-selective fading, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience uncorrelated fading.

Frequency-selective fading channels are dispersive, the signal energy associated with each symbol is spread out in time. This causes transmitted symbols that are adjacent in time to interfere with each other. Equalizers are often deployed in such channels to compensate for the effects of the inter symbol interference.

1.5 OFDM

OFDM [15] is a special form of multicarrier modulation (MCM), where a single data stream is transmitted over a number of lower rate subcarriers. OFDM can be seen as either a modulation technique or a multiplexing technique. Mostly OFDM is used to increase the robustness against frequency selective fading and narrowband interference. In a single carrier system, a single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of subcarriers will be affected. Error correction coding can then be used to correct the few erroneous subcarriers.

1.6 MIMO

Multiple-input and multiple-output, or MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance. MIMO technology [16] has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. It is one of several forms of smart antenna technology. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) and to achieve a diversity gain that improves the link reliability (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP Long Term Evolution, WiMAX.

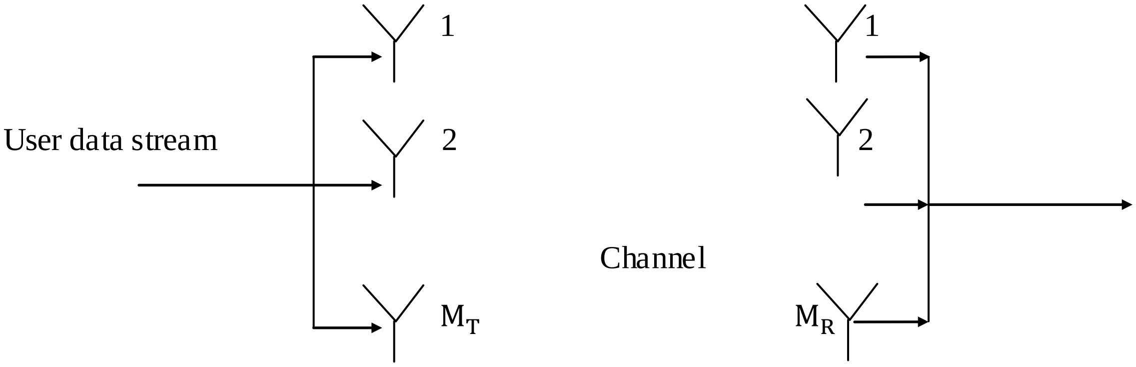

Figure 3: MIMO System

1.7 SISO

SISO is an acronym for single-input and single-output system. It refers to a simple single variable control system with one input and one output. In radio it is the use of only one antenna both in the transmitter and receiver. SISO systems [17] are typically less complex than multiple-input multiple-output (MIMO) systems. Frequency domain techniques for analysis and controller design dominate SISO control system theory. The usual tools for SISO system analysis are Bode, Nyquist, Nichols, and root locus.

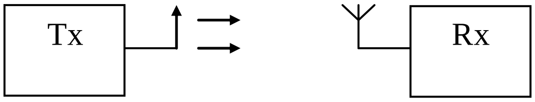

Figure 4: SISO System

1.8 SIMO

Single Input Multiple Output (SIMO) [18] is an antenna technology for wireless communications in which a single antenna at the transmitter and multiple antennas are used at the destination (receiver). The antennas are combined to minimize errors and optimize data speed. SIMO technology has applications in digital television (DTV), wireless local area networks (WLANs), metropolitan area networks (MANs), and mobile communications. An early form of SIMO, known as diversity reception, has been used by military, commercial, amateur, and shortwave radio operators at frequencies below 30 MHz .

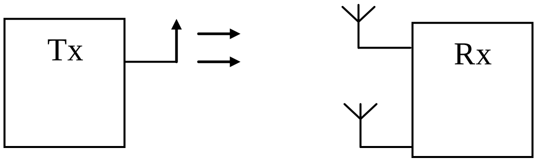

Figure 5: SIMO System

1.9 MISO

Multiple Input Single Output (MISO)[19] is a smart antenna technology that uses multiple transmitters and a single receiver on a wireless device to improve the transmission distance. MISO technology can be applied in areas of Wireless Local Area Networks, Metropolitan

Area Networks and mobile communications. The implementation of MISO would include multiple antennas at the source, or transmitter, and the destination, or receiver, has only one antenna, the antennas are combined to minimize errors and optimize data speed. When an electromagnetic field (EM field) is met with obstructions such as hills, canyons, buildings, and utility wires, the wave fronts are scattered, and thus they take many paths to reach the destination. The late arrival of scattered portions of the signal causes problems such as fading and intermittent reception. In digital communications systems such as wireless Internet, it can cause a reduction in data speed and an increase in the number of errors. The use of two or more antennas, along with the transmission of multiple signals at the source, can reduce the trouble caused by multipath wave propagation.

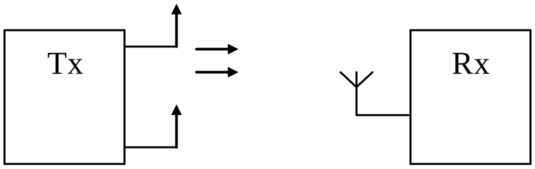

Figure 6: MISO System

1.10 MIMO-OFDM SYSTEM

OFDM & MIMO systems have some drawbacks. OFDM system has disadvantages like frequency error, phase error, synchronization of cyclic prefix. MIMO system has disadvantages like Complexity, Power consumption and Size of the mobile device. Increased component costs within an access point required for its implementation. Moreover OFDM & MIMO separately cannot serve high data rates applications. Multiple-input multiple-output (MIMO) wireless technology in combination with orthogonal frequency division multiplexing (MIMO-OFDM)[20] is an attractive air-interface solution for next-generation wireless local area networks (WLANs), wireless metropolitan area networks and fourth-generation mobile cellular wireless systems. MIMO technology is predominantly used in broadband systems that exhibit frequency-selective fading and, therefore, inter symbol interference (ISI). OFDM modulation turns the frequency-selective channel into a set of parallel flat fading channels and is, hence, an attractive way of coping with ISI. One of the major concerns is Bit error rate. In MIMO OFDM systems the BER is reduced to quite smaller value compared to MIMO or OFDM because of combined properties of MIMO and OFDM.

1.11 PAPR (Peak to Average Power Ratio)

A special characteristic of an OFDM signal is that it consists of a number of independently modulated subcarriers which have different amplitudes and phases. These subcarriers occupy different spectra in the frequency domain and are transmitted at the same time. When those subcarriers are added up coherently, the instantaneous peak power of an OFDM signal will be much bigger than the average power, resulting a large peak-to-average power ratio (PAPR). In the worst case, when the N signals are added with the same phase, they will produce a peak power that is N times the average power. If a nonlinear power amplifier is used to boost OFDM signals, the large peak power brings about its nonlinearity, which creates out-band signal emission and in-band distortion and significantly degrades performance. The peak to average power ratio (PAPR)[21] is a related measure that is defined as the peak amplitude squared giving the peak power divided by the RMS value squared giving the average power[22].

$$PAPR = \frac{|x|_{peak}{}^{2}}{x_{rms}{}^{2}} \tag{1.13}$$

The SLM (Selected Mapping) Technique is a powerful method to reduce the PAPR which is a major problem in OFDM systems. SLM method applies scrambling rotation to all sub-carriers independently. This technique can be applied to any scenarios without restriction on the type of modulation.

Chapter 2

2.1 LITERATURE REVIEW

Shao Lulu *et al.* [23] gave their ideas towards spectrum sensing in cognitive radio. The authors advance collaborative sensing method based on energy detection and OFDM. Simulation and analysis results show that the method can effectively improve detecting spectrum holes probability. Due to the scarcity of the wireless spectrum, it is very important to manage the radio spectrum efficiently. Flexibility would mean that radios could find and adapt to any immediate local spectrum availability. Cognitive radios have been proposed as a mean to implement efficient reuse of the licensed spectrum. Authors gave summary of OFDM technology and cooperative spectrum sensing technology, and expatiates application of OFDM technology in cooperative spectrum sensing.

Analysis of intersymbol and intercarrier interference of OFDM systems on time invariant channels is done by V. D. Nguyen *et al.* [24]. They derived mathematical description of interference and useful power. The simulation results show a good agreement with the theoretical results. Orthogonal Frequency Division Multiplexing (OFDM) is a multi carrier modulation technique, which is well known as the method to prevent the Inter Symbol Interference.

Investigation on the error probability behavior for orthogonal frequency division multiplexing (OFDM) signals distorted by nonlinearities and noise is done by M.R.D Rodrigues *et al.* [25]. They showed that the error probability of nonlinearly distorted OFDM signals does not increase indefinitely with an increase in the number of OFDM sub-channels. The authors investigate by simulation the error probability behavior for nonlinearly distorted OFDM signals with various numbers of sub-channels. The error rate against number of OFDM sub-channels curves for various E_b/N_0 and output back-off (OBO) values, for low E_b/N_0 values the noise contribution to error probability degradation dominates with respect to the nonlinearity contribution and the error rate against number of sub-channels curve is constant. For high Eb/N0 values the nonlinearity contribution to error probability degradation dominates with respect to the noise contribution and it is observed that the error rate against number of sub-channels curve is not constant anymore.

Spread Spectrum (SS)-OFDM analysis for PAPR reduction is proposed by Hiroshi Kaiho [26] *et al.* The results of computer simulation showed that authors' proposal with a large roll-off factor can reduce PAPR effectively compared to that of conventional OFDM and CI/OFDM, the complexity is greatly reduced compared to OSSR-OFDM. There is a little degradation in BER performance and no out-of-band emissions. This proposal can achieve good BER performance in non linear channel.

A proposal on how the widely accepted IEEE 802.11a/g systems as well as the emerging IEEE 802.11n system might be extended to support the dynamic OFDM in a single-user (point-to-point) setting has been proposed by James Gross *et al.* [27]. The presented approach guarantees backward compatibility to legacy devices. They addressed these issues by presenting a) a set of protocol modifications required to incorporate dynamic OFDM in 802.11a/g/n; and b) a performance evaluation of the suggested extension. Although 802.11n already includes advanced MAC and PHY features i.e., frame aggregation and MIMO transmissions, their performance evaluation demonstrates that a further improvement is achievable by incorporating dynamic OFDM.

P. Vainikainen *et al.* [28] discussed the antenna configurations in small mobile terminals for MIMO (multiple-in-multiple-out) systems. They presented some visions how all these antenna configurations might be realized in the very limited space available in the mobile terminal. They described the measurement Based Antenna Test-bed (MEBAT) for the evaluation of mobile terminal antennas for MIMO systems. The method combines data from a measured directional channel library and the radiation patterns of antennas under test.

Investigation on the characteristics of propagation channels between high-speed trains and fixed base stations for multimedia communications links using Orthogonal Frequency Division Multiplexing (OFDM) is done by Sandra Knorzer *et al.* [29] To model the system behavior realistically, impulse responses of the transmission channels are generated by a ray-tracing tool. Typical environments along a railway track are taken into account as well as the train motion. Mobile station antennas with different patterns are included in the simulation model and the results are compared and assessed with respect to characteristic channel parameters.

Helmult Bolcskei *et al.* [30] provides an overview on the basics of MIMO-OFDM technology and focuses on space-frequency signaling, receiver design, multiuser systems, and hardware implementation aspects. Multiple input multiple-output (MIMO) wireless technology seems to meet the demands by offering increased spectral efficiency through spatial multiplexing gain, and improved link reliability due to antenna diversity gain. MIMO technology is used in broadband systems that exhibit frequency-selective fading and, therefore, intersymbol interference (ISI). OFDM modulation turns the frequency-selective channel into a set of parallel flat fading channels and is, hence, an attractive way of coping with ISI.

Construction of a simple MIMO-OFDM wireless communication system based on the analysis of the technical principles and the system models of the MIMO technology and the OFDM technology has been done by Jiang Xuehua *et al.* [31]. The system combines the MIMO system and the OFDM system together, space-time coding is done in the transmitter firstly, the signal is launched after OFDM modulated, and the process of the receiver is the inverse process of the transmitter. Result showed that the MIMO-OFDM wireless communication system has better performance when the antenna number is very large and the other conditions are identical, but the system performance will reduce if the carrier number increases. The performance is simulated using MATLAB. The simulation showed that the system has good performance when there are more antennas especially the number of the receiver antennas is greater than that of the transmitter antennas and the other conditions are the same. But, the increase of the carrier number can decrease the system performance, because the interference between each sub-carrier can increase when the number of the carrier number increase.

Introduction about MIMO technology is given by Zhang Ke *et al.* [32], they pointed out that the combination of OFDM and MIMO seems to be very promising when aiming at the design of very high-rate wireless mobile systems. Secondly, they described the application of

OFDM and outline the block diagrams of an OFDM modulator and demodulator and a MIMO-OFDM system. Authors provided several methods for combining the different diversity at the receiver, analyzed the performances of diversity in OFDM-MIMO system with simulation results.

Exploration of various physical layer research challenges in MIMO-OFDM system design, including physical channel measurements and modeling, analog beam forming techniques using adaptive antenna arrays, space–time techniques for MIMO-OFDM, error control coding techniques, OFDM preamble and packet design, and signal processing algorithms used for performing time and frequency synchronization, channel estimation, and channel tracking in MIMO-OFDM systems is proposed by Gordon L. Stuber *et al.* [33]. They also considered a software radio implementation of MIMO-OFDM.

Chao-Cheng Tu *et al.* [34] proposed a novel subspace-based blind channel-estimation algorithm with reduced time averaging, as obtained by exploiting the frequency correlation among adjacent subcarriers in MIMO orthogonal frequency-division multiplexing (OFDM) systems. Simulation results showed that the proposed approach outperforms other previously proposed methods within a reasonable averaging time over a Third-Generation Partnership Project (3GPP) spatial channel model.

Time varying channels will degrade the performance of orthogonal frequency division multiplexing (OFDM) due to the inter channel interference (ICI). Won-Gyu Song and Jong-Tae Lim [35] proposed the channel estimation for multiple input multiple output MIMO-OFDM with time varying channels based on the grouped and equi-spaced pilot tones. Authors approximated the time varying channels to the polynomials and proposed the detection method for the OFDM with ICI.

An analytical expression of signal to noise plus interference ratio (SNIR) and average probability of error in MIMO-OFDM system over Nakagami-m fading channel is derived by S. R. Sabuj *et al.* [36]. It is found that the SNIR of MIMO-OFDM system decreases while increasing normalized frequency offset. To increase the fading parameter m, the bit error rate (BER) performance for Nakagami-m fading channel has been reduced.

Evaluation of bit error rate (BER) performance of the MIMO OFDM-CDMA system, in case of Rician frequency selective fading, using computer simulation is proposed by Ugljesa Urosevic[37]. The assumed system uses space-time block coding applied to two, three and four transmit antennas and has arbitrary number of receive antennas. Channel estimation is performed by implementing pilot sequences at each transmit antenna. The results are compared with BER results of the competitive OFDM-CDMA down link system with threshold detection combining (optimum TDC). The results showed that the presented system provides lower BER, even when less sub carriers are used for transmitting single data symbol, than its competitive solution.

Pei-Yun Tsai *et al.* [38] presented a MIMO-OFDM baseband transceiver design for indoor gigabit wireless communication systems. The proposed system uses 5 GHz carrier frequency with bandwidth up to 160 MHz Both the transmitter and the receiver support 4 antennas. At the receiver, we design symbol timing detector, carrier frequency offset first acquisition and subsequent tracking mechanisms, channel estimation and MIMO detection. Simulation results showed that the proposed symbol timing detection algorithm is more precise than the conventional algorithm.

Investigation on the estimation of channel at high frequencies with conventional Least Square (LS) and Minimum Mean Square (MMSE) estimation algorithms which is carried out through Mat lab simulation is analyzed by C. Poongodi *et al.* [39]. The bit-error rate (BER) of multilevel quardrature amplitude modulation (M-QAM) in flat Rayleigh fading channel is also analyzed. The performance of MIMO OFDM is evaluated on the basis of Bit Error Rate (BER) and Mean Square Error (MSE) level.

Orthogonal frequency division multiplexing (OFDM) for MIMO channels (MIMO-OFDM) for wideband transmission to mitigate inter symbol interference and enhance system capacity is given by Ye (Geoffrey) Li *et al.* [40]. The MIMO-OFDM system uses two independent space-time codes for two sets of two transmit antennas. At the receiver, the independent space-time codes are decoded using pre-whitening followed by maximum likelihood (ML) decoding or ML decoding based on successive interference cancellation.

Manel Collados *et al.* [41] discussed the packet error rate (PER) performance of multiple-input multiple-output (MIMO) wireless systems. Author focused his discussion on communication systems based on the IEEE 802.1 ldg standard. In particular, we study the performance of spatial multiplexing systems with joint encoding at the transmitter and linear detection at the receiver. We show that spatial multiplexing systems based on minimum mean square error (MMSE) or zero forcing (ZF) demultiplexing benefit greatly from antenna subset selection. These results agree with recent analytical results showing the equivalence in diversity order between a full system (all receive antennas) and a system with antenna selection.

Presentation on a MIMO-OFDM based broadband power line communication (BPLC) with maximum ratio combining is proposed by Jeonghwa Yoo *et al.* [42]. Authors evaluated the proposed MIMO-OFDM over BPLC channels, with or without cross-talk between antenna paths. The suggested maximum ratio combining (MRC) scheme effectively combines both multiple antenna diversity gain and multipath fading diversity gain over 3-phase (2´2 MIMO, outdoor) or single-phase (SISO, indoor) power line channels. Simulation results prove the performance advantage of the proposed scheme, whether or not cross-talk exists, over existing schemes.

Guo Rui *et al.* [43] presented error rates of multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) signals on frequency selective Nakagami-m fading channels. The author analyzed that for frequency-selective fading Nakagami-m channels, the magnitudes of the channel frequency responses approximate to be Nakagami-m distribution random variables (RVs), but the fading and mean power parameters are different from the counterparts in the time domain. Based on this result, the performance of a MIMO-OFDM system with space-time block code(STBC) diversity at the transmit antennas and maximum ratio combining (MRC) diversity at the receive antennas over Nakagami-m fading channels is analytically evaluated.

Shruti Trivedi *et al.* [44] analyzed Bit Error Rate (BER) using BPSK modulation and then optimum modulation is analyzed. Multiple transmit and receive can be used to form multiple input multiple-output (MIMO) channels to increase the capacity and data rate. The advantage of employing multiple antennas is to get reliable performance through diversity and the achievable higher data rate through spatial multiplexing. In MIMO system the same information can be transmitted and received from multiple antennas simultaneously since the fading for each link between a pair of transmit and receive antennas can usually be considered to be independent, the probability that the information is detected accurately is higher.

Yuro Lee[45] proposed a new MIMO receiver algorithm for 8x8 MIMO system based on hybrid detection to reduced computational complexity for Giga-bps data transmission. The proposed MIMO detector, Multi-rate QR-MDD consists of MDD (Multi-Dimensional Detector), DSC (Decision Symbol Cancellation) and WZF (Weighted Zero Forcing) where the transmit streams are divided into two groups. The first group is transmitted using lower modulation level and lower code rate and the MDD algorithms is used for demodulation and decoding, while the second group is transmitted using higher modulation order and higher code rate and the WZF algorithms is used. Once the first group is decoded, they are cancelled out form received signal for demodulation and decoding of the second group. The error performance is slightly worse performance than that of MLD (Maximum Likelihood Detection). And computational complexity viewpoint of the required number of real multiplications is approximately 2 times the complexity level of WZF.

A description of the testbed, detailing the testbed architecture, algorithms interest and hardware components is given by Yang Lan [46]. The authors also presented measurement results and show the impact of spatial correlation on system performance. An 8×8 field programmable gate arrays (FGPA)-based MIMO-orthogonal frequency division multiplexing (OFDM) real-time transmission testbed has been developed by the DOCOMO Beijing Labs

(DBL) in a typical indoor environment. Author aim was: 1) to validate the functionality of MIMO and OFDM technologies; 2) to verify the receiver detection algorithm, orthogonal grouping-based near optimal detection algorithm (OGNO), proposed for high order MIMO systems.

MIMO-OFDM has become a promising candidate for high performance 4G broadband wireless communications. But one main disadvantage of MIMO-OFDM is the high peak-to-average power ratio (PAPR) of the transmitter's output signal on different antennas. The selected mapping (SLM) approach provides good performance for PAPR reduction, but applying separately on each antenna this method doesn't benefit additional degrees of freedom providing by the use of multiple antennas. Jarboui Slaheddine *et al.* [47] proposed a more efficient solution using SLM in combination with sub band Permutation.

One of main problems of Orthogonal Frequency Division Multiplexing (OFDM) is its high Peak-to-Average Power Ratio (PAPR) which seriously limits power efficiency of High Power Amplifier (HPA). Byung Moo Leewe *et al.* [48] presented PAPR reduction technique of V-BLAST based MIMO-OFDM system. Author used the Selected Mapping (SLM) technique as a PAPR reduction technique since it does not cause any signal distortion. As a special protection for Side Information (SI) of SLM technique, author proposed SI power allocation technique. Simulation results show that proposed technique gives significantly better BER performance than ordinary SLM technique for MIMO OFDM systems.

SFBC MIMO-OFDM system inherits from OFDM systems the drawback of high peak-to-average power ratio (PAPR) of the transmitted signal. The selected mapping (SLM) method is a major scheme for PAPR reduction. But computational complexity of the traditional SLM scheme is relatively high since it requires a number of inverse fast Fourier transforms (IFFTs).Sen-Hung Wang *et al.* [49] proposed a low-complexity PAPR reduction scheme for SFBC MIMO-OFDM systems, needing only one IFFT. The proposed scheme exploits the time-domain signal properties of SFBC MIMO-OFDM systems to achieve a low-complexity architecture for candidate signal generation.

Bhasker Gupta *et al.* [50] presented with an approach different from algebraic codes to achieve code rate MT with full diversity of MT MR Mb L. The received STF coded MIMO-OFDM signals has high decoder complexity. Computational complexity of decoder and latency induced by it can be resolved by employing sphere decoder (SD) and array processing decoder. The performance of presented STF code is analyzed and verified by simulation results. Bit error rate (BER) performance expressions for STFBC MIMO-OFDM systems are derived and evaluated for frequency selective block fading channels with MPSK constellations.

Gustavo Fraidenraich [51] presented the MIMO channel capacity over the Nakagami-m fading channel. The joint eigen value density function of $W = HH^{\dagger}$, where H is the channel matrix, was derived in a closed form in the 2×2 case and for integer values of m, as well as for $m \to \infty$. The author also derived the marginal eigen value distribution of W in closed form solution. For the more general $r \times t$ case, an asymptotic formulation is presented and is shown to be close to simulations, even for a small number of antennas. All the results are validated by numerical Monte Carlo simulations and are in excellent agreement.

Alan J. Coulson [52] considered the effect of narrowband interference on OFDM systems with particular regard to the receiver post detection bit error rate performance. Author showed both by analysis and by computer simulation that the ensemble average bit error rate is severely affected by narrowband interference and that particular value of interferer carrier frequency and phase can produce bit error rates significantly higher than the ensemble average. An interference suppression technique based on excision (notch) filtering was proposed and shown by computer simulation to improve ensemble average bit error rates to about 0.001 for BPSK modulated OFDM with signal-to-interference ratios as low as –30 dB.

2.2 History of IEEE 802.11

Since 1990s, WLANs for the 900 MHz, 2.4GHz and 5GHz license-free ISM (Industrial, Scientific and Medical) bands have been launched by using a range of proprietary techniques [53]. In June 1997, the Institute of Electrical and Electronics Engineers (IEEE) defined an international standard for WLAN, called 802.11. This standard specifies the Medium Access

Control (MAC) protocols and three different Physical Layers (PHYs), two of which are based on radio communication in 2.4 GHz band (the other uses infrared light). All the Physical layers support a date rate of 1 Mbps and optionally 2 Mbps. Upon the demand for higher bit rates, a new standard was defined, named IEEE 802.11b which describes a PHY providing a more robust rate up to 11 Mps. Motivated by the opening of new unlicensed spectrum in the 5 GHz, a new IEEE 80.11 working group, Task Group a (TGa), began to work on the third generation (3G) WLANs. Orthogonal Frequency Division Multiplexing (OFDM) was selected and the newly defined standard IEEE 802.11a was available in 2000 supporting data rates between 6 and 54 Mbps. A similar standard for 2.4 GHz band, namely IEEE 802.11g, was finished in 2003. At the same year, Task Group was authorized to created a single document that merged 8 amendments (802.11a, b, d, e, g, h, i, j) with the base standard. On approval on March 08, 2007, this standard was renamed to the current base standard IEEE 802.11-2007. 802.11n is a proposed amendment which improves the previous standards by deploying Multiple Input Multiple Output (MIMO) and many other newer features. It will significantly increase maximum PHY data rate from 54 Mbps to a maximum of 600 Mps.

2.3 OBJECTIVE OF THESIS

The objective of thesis is to analyze the BER and PAPR of 8x8 MIMO OFDM systems. As the antenna configuration is increased the BER goes on decreasing because of spatial diversity. One of the disadvantages associated with OFDM is PAPR. Another objective of this thesis is to decrease the PAPR of the proposed MIMO OFDM system using SLM (Selected Mapping Technique). The 8x8 MIMO OFDM systems is analyzed for BPSK and QPSK modulation using Rayleigh and Rician Fading Channels.

Chapter 3-MIMO OFDM SYSTEM

3.1 MIMO-OFDM SYSTEM

Multiple input Multiple Output Orthogonal Frequency division multiplexing is a technology that uses multiple antennas to transmit and receive radio signals.

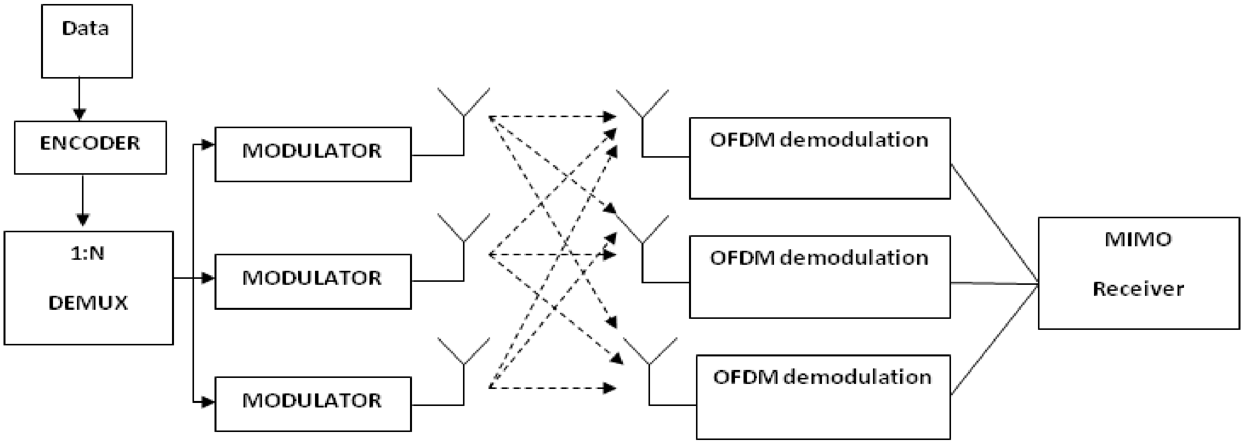

Figure 7: Block diagram of MIMO OFDM System

When much higher throughputs are aimed at, the multipath character of the environment causes the MIMO channel to be frequency-selective. OFDM can transform such a frequency-selective MIMO channel into a set of parallel frequency-flat MIMO channels and also increase the frequency efficiency. Therefore, MIMO-OFDM technology has been researched as the infrastructure for next generation wireless networks.

MIMO wireless systems, combined with OFDM, have allowed for the easy transmission of symbols in time, space and frequency. MIMO-OFDM takes advantage of the multipath properties of environments [54] using base station antennas that do not have LOS and uses both the advantages of MIMO and OFDM. Combination of MIMO and OFDM techniques will impact the evolution of wireless LANs, and is a leading candidate for future fourth generation (4G) wireless communications systems. Therefore, MIMO-OFDM [55] system has become a welcome proposal for 4G mobile communication systems. Advantage is very high capacity, spectral efficiency and improved communications reliability i.e., reduced bit error rate (BER) [56] achieved at reasonable computational complexity.

3.1.1 MIMO OFDM SYSTEM BLOCK DIAGRAM -Transmitter

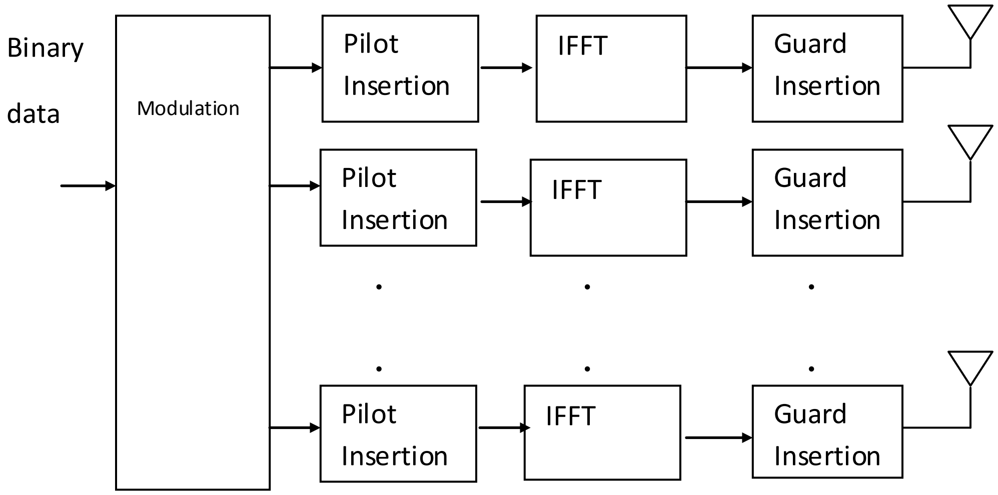

Figure 8: Transmission of MIMO OFDM System

At the transmitting end, a number of transmission antennas are used. An input data bit stream is modulated by OFDM and finally fed to antennas for sending out (radiation). At the receiving end, in-coming signals are fed into a signal detector and processed before recovery of the original signal is made.

Receiver

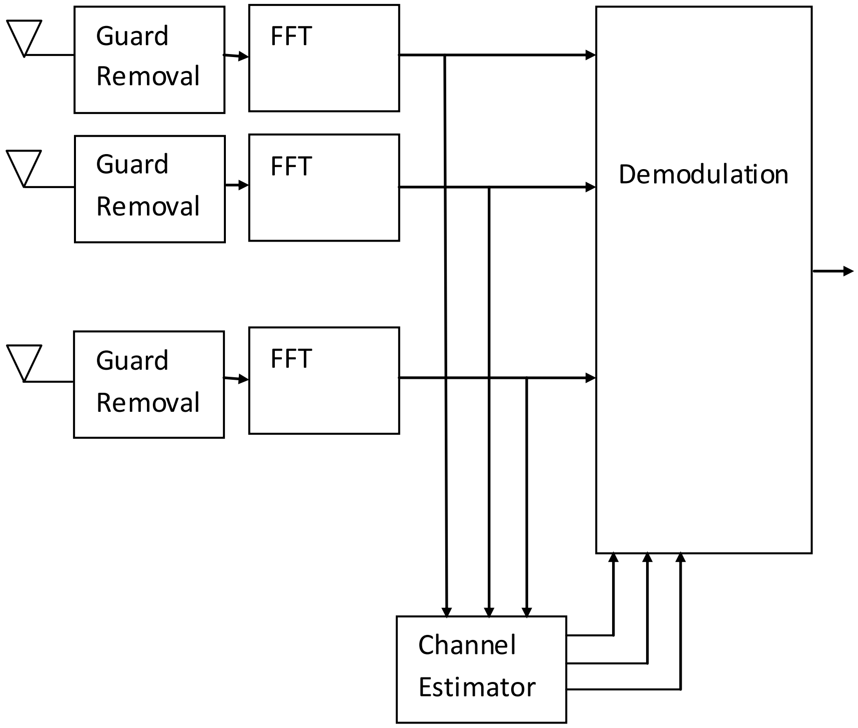

Figure 9: Reception of MIMO OFDM System

In the area of Wireless communications, MIMO-OFDM is considered as a mature and well established technology. The main advantage is that it allows transmission over highly frequency-selective channels at a reduced Bit Error Rate (BER) with high quality signal. One of the most important properties of OFDM transmissions is the robustness against multi-path delay spread. This is achieved by having a long symbol period, which minimizes the inter-symbol interference. MIMO can be used either for improving the SNR [57] or data rate. The combination of OFDM and MIMO seems to be very promising when aiming at the design of very high-rate wireless mobile systems. While multiple antennas at the transmitter and receiver elevate channel capacity, i.e. the achievable transmission rate, OFDM converts the wideband frequency selective radio channel into a set of parallel flat-fading channels, thus simplifying signal processing required at the receiver.

MIMO OFDM technology enables high capacities suited for Internet and multimedia services, increases the range and reliability. It Increases diversity gain and enhance system capacity on a time-varying multipath fading channel improving power-spectral efficiency in wireless communication systems besides optimizing the power efficiency. This technology guarantees each user's quality of service requirements, including bit-error rate and data rate and as a result ensures fairness to all the active users.

3.2 MIMO OFDM SYSTEM ADVANTAGES

The disadvantages of MIMO and OFDM separately can be overcome by using MIMO OFDM system.

- MIMO-OFDM systems support high data rate and high performance.
- The coding over the space, time, and frequency domains provided by MIMO-OFDM enables a much more reliable and robust transmission over the harsh wireless environment.
- These enable high capacities suited for Internet and multimedia services, and also dramatically increase range and reliability.
- The major advantages are increased capacity, coverage, and reliability.
- MIMO-OFDM is a promising road to future broadband wireless access, enhanced spectral efficiency and multiuser downlink throughput.

3.3 MATHEMATICAL ANALYSES

MIMO-OFDM system with 2 Transmitters and receivers is shown in fig 6 with total number of N subcarriers. X_k^t is modulated data using suitable modulation techniques for k^{th} subcarrier. After modulation, the mapping of modulated data is done so that on the first and second antenna same data is transmitted and modulated OFDM symbols. Signal after inverse fast Fourier transform (IFFT) at the transmitter can be written as [58]:

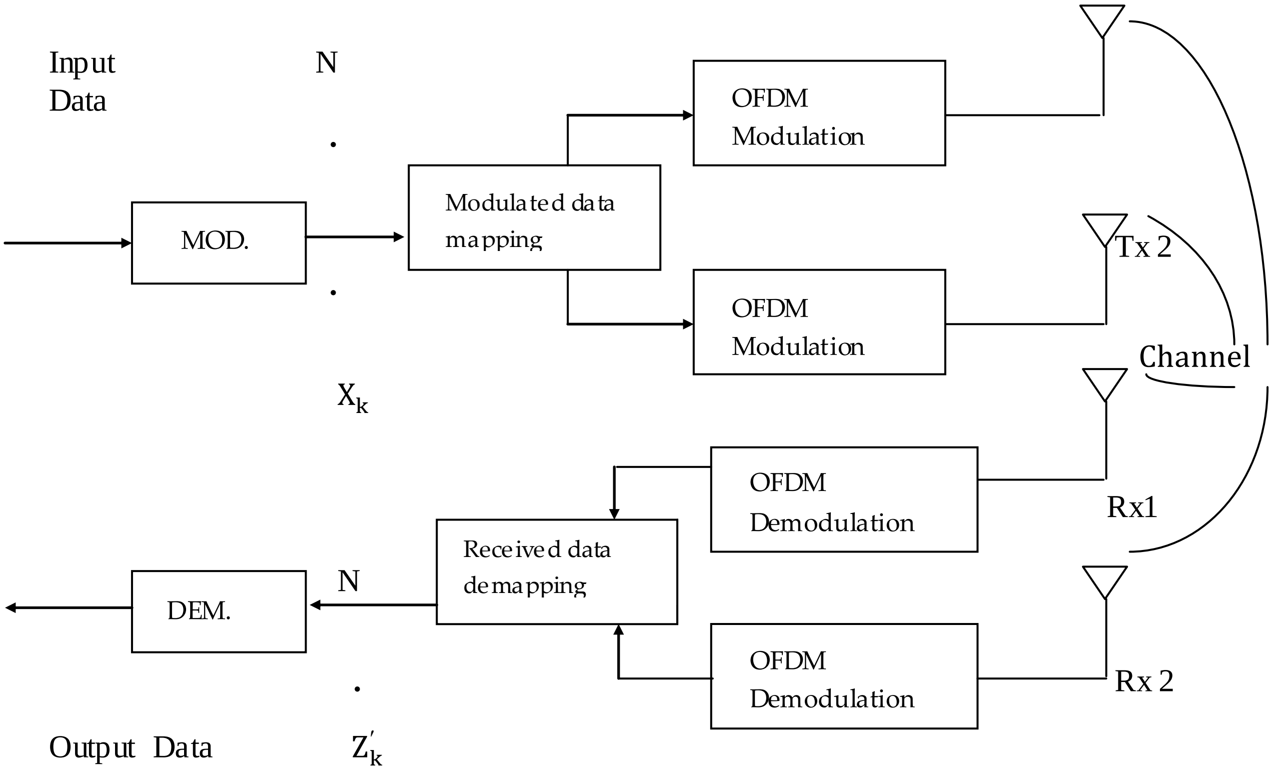

Figure 10: Tx, Rx Model of MIMO OFDM System

$$x^t(n) = \sum_{k=0}^{N-1} X_k^t e^{j(\frac{2\pi}{N})kn} \text{ for } 0 \le n \le N-1 \qquad (3.1)$$

t=1or2, j=$\sqrt{-1}$, t is transmitter antenna. The received signal afflicted by phase noise and frequency offset can be expressed as [58]:

$$r^\tau(n) = \{\sum_{t=1}^{2}[x'(n) \otimes h'(n) + w(n)]\}e^{j[2\pi\Delta f^\tau t+\varphi^\tau(n)]} \qquad (3.2)$$

$\tau = 1$ or 2, Δf^τ and $\varphi^\tau(n)$ are frequency offset and phase noise. τ is received antenna. x(n), h(n), w(n), r(n) are transmitted signal, channel impulse response, AWGN and received signal respectively. The received signal after fast fourier transform (FFT) can be written as[58]:

$$Y_k^{\tau} = \frac{1}{N}\sum_{n=0}^{N-1} r^{\tau}(n) e^{-j(\frac{2\pi}{N})kn} \tag{3.3}$$

$$= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{t=1}^{2}\sum_{l=0}^{N-1} X_l^t H_l^t e^{j\left[\left(\frac{2\pi}{N}\right)(l-k+\in^{\tau})n+\varphi^{\tau}(n)\right]} + N_k \tag{3.4}$$

$$= \sum_{t=1}^{2}\sum_{l=0}^{N-1} X_l^t H_l^t Q_{l-k}^{\tau} + N_k \tag{3.5}$$

where, Y_k,X_k *and* H_k are the frequency domain expression of r(n), x(n), h(n). $\mathrm{N_k}$ is the AWGN. ∈ is the normalized frequency offset and is given bΔfT y. T is the subcarrier symbol period.

$\mathrm{Q_L^{\tau}}$ can be given by:

$$Q_L^{\tau} = \frac{1}{N}\sum_{n=0}^{N-1} e^{j\left[\left(\frac{2\pi}{N}\right)(L+\in^{\tau})n+\varphi^{\tau}(n)\right]} \tag{3.6}$$

$$= exp[j\{2\pi(L+\in^{\tau}) + \varphi^{\tau}\}(1/2-1/2N)] \frac{sin[\{2\pi(L+\in^{\tau})+\varphi^{\tau}\}/2]}{N.sin[\{2\pi(L+\in^{\tau})+\varphi^{\tau}\}/2N]} \tag{3.7}$$

At receiver, OFDM symbols are demodulated and the signal can be recovered from the relation of $Z_k = Y_k^1 + Y_k^2$. Y_k^1 *and* Y_k^2 are the first antenna and the second antennas k$^{\mathrm{th}}$ subcarrier data. The innovative data can be detected through the detection process. For ease of system performance analysis we assume that $Q_L^{\tau,t} = Q_L^{\tau}$.

3.4 THEORETICAL EXPRESSION

Both antennas transmit the same signal of the form of $X_l^1 = X_l^2 = X_k$ the kth subcarrier signal. The received signal at the receiver 1 is

$$Y_k^1 = \sum_{l=0}^{N-1} X_l^1 . H_l^1 . Q_{l-k}^1 + \sum_{l=0}^{N-1} X_l^2 . H_l^2 . Q_{l-k}^1 + N_{1k} \tag{3.8}$$

$$= X_{k.} H_k^1 . Q_0^1 + \sum_{l=0,l\neq k}^{N-1} X_l^1 . H_l^1 . Q_{l-k}^1 + X_{k.} H_K^2 . Q_0^1$$

$$+ \sum_{l=0,l\neq k}^{N-1} X_l^2 . H_l^2 . Q_{l-k}^1 + N_{1k} \tag{3.9}$$

$$= X_{k.}\{H_k^1 . Q_0^1 + H_k^2 . Q_0^1\} + \sum_{l=0,l\neq k}^{N-1}\{X_l^1 . H_l^1 . Q_{l-k}^1 + X_l^2 . H_l^2 . Q_{l-k}^1\} + N_{1k} \tag{3.10}$$

$$= X_k + X_k\left\{H_l^1 . Q_{l-k}^2\right\} + H_k^2 . Q_0^1 - 1\} + \sum_{l=0,l\neq k}^{N-1}\left\{X_l^1 . H_l^1 . Q_{l-k}^1\right\} + N_{1k} \tag{3.11}$$

Similarly the received signal at the receiver can be given by:

$$Y_k^2 = \sum_{l=0}^{N-1}\left\{X_l^1 . H_l^1 . Q_{l-k}^2\right\} + \sum_{l=0}^{N-1} X_l^2 . H_l^2 . Q_{l-k}^2 + N_{2k} \tag{3.12}$$

$$= X_k + X_k\{H_k^1 . Q_0^2 + H_k^2 . Q_0^2 - 1\}$$

$$+ \sum_{l=0,l\neq k}^{N-1}\{X_l^1 . H_l^1 . Q_{l-k}^2 + X_l^1 . H_1^2 . Q_{l-k}^2\} + N_{2k} \tag{3.13}$$

Final signal is achieved as follows: $Z_k' = Y_k^1 + Y_k^2$

$$= 2X_k + X_k\{H_k^1 . (Q_0^1 + Q_0^2) + H_k^2 . (Q_0^1 + Q_0^2) - 2\} + \tag{3.14}$$

$$\sum_{l=0,l\neq k}^{N-1}\{X_l^1.H_l^1.Q_{l-k}^1 + X_l^1.H_l^1.Q_{l-k}^2\} + \sum_{l=0,l\neq k}^{N-1}\{X_l^2.H_l^2.Q_{l-k}^1 + X_l^2.H_l^2.Q_{l-k}^2\} + N_k \quad (3.15)$$

$$= 2X_k + 2X_k\{(Q_0^1 + Q_0^2)\text{-}1\} + \sum_{l=0,l\neq k}^{N-1}\{(X_l^1 + X_l^2).\,Q_{l-k}^1 + (X_l^1 + X_l^2).\,Q_{l-k}^2\} + \mathrm{N_k} \quad (3.16)$$

In order to evaluate the statistical properties [59], assuming average channel gain

$$E[|H_l^1|^2] = E[|H_l^2|^2] = 1 \text{ and} \quad (3.17)$$

$$E[|X_l^1|^2] = E[|X_l^2|^2] = |X|^2 \quad (3.18)$$

The desired received signal is generated by the k^{th} subcarrier. Consider l=k, the received signal power is expressed as:

$$\sigma_{\mathrm{DRS}}^2 = \{\mathrm{E}\,[|\mathrm{X_k}|^2].\mathrm{E}[|\mathrm{H_k^1}|^2].\,|\mathrm{Q_0^1}|^2 + \mathrm{E}\,[|\mathrm{X_k}|^2].\,\mathrm{E}[|\mathrm{H_k}|^2].\,|\mathrm{Q_0^1}|^2 +$$

$$E[|X_k|^2].E[|H_k^1|^2].\,|Q_0^2|^2 + E[|X_k|^2].E[|H_k^2|^2].\,|Q_0^2|^2\} \quad (3.19)$$

$$= 2\{|X|^2.\,|Q_0^1|^2 + |X|^2.\,|Q_0^2|^2\} \quad (3.20)$$

$$= 2|X|^2\{|Q_0^1|^2 + |Q_0^2|^2\} \quad (3.21)$$

$$= |X|^2[\left\{\frac{sin((2\pi\in^1+\varphi^1)/2)\}^2}{N^2.\{(2\pi\in^1+\varphi^1)/2N)\}^2}\right\} + \{\frac{sin((2\pi\in^1+\varphi^1)/2)\}^2}{N^2.\{(2\pi\in^2+\varphi^2)/2N\}^2}] \quad (3.22)$$

$$= |X|^2[\frac{4\{sin((2\pi\in^1+\varphi^1)/2)\}^2}{(2\pi\in^1+\varphi^1)^2} + \frac{4\{sin((2\pi\in^1+\varphi^1)/2)\}^2}{(2\pi\in^2+\varphi^2)^2}] \quad (3.23)$$

$$= |X|^2[\{sin((2\pi \in^1 + \varphi^1)/2)\}^2(34.7738) + \{sin((2\pi \in^2 + \varphi^2)2)\}^2(34.7738)] \quad (3.24)$$

As ICI is corrupted by adjacent subcarrier signal. Considering l≠k. So, the ICI power is expressed as:

$${\sigma_{ICI}}^2 = \sum_{l=0,l\neq k}^{N-1} E[|X_l^1|^2].E[|H_l^1|^2].|Q_{l-k}^1|^2 + \sum_{l=0,l\neq k}^{N-1} E[|X_l^2|^2].$$

$$E[|H_l^2|^2].\,|Q_{l-k}^1|^2 + \sum_{l=0,l\neq k}^{N-1} E[|X_l^1|^2].\,E[\left|H_l^1\right|^2].\,|Q_{l-k}^2|^2 +$$

$$\sum_{l=0,l\neq k}^{N-1} E[|X_l^2|^2].\,E[\left|H_l^2\right|^2].\,|Q_{l-k}^2|^2 \quad (3.25)$$

$$= 2\sum_{l=1}^{N-1} |X|^2.\,|Q_l^1|^2 + |X|^2|Q_l^2|^2 \quad (3.26)$$

$$= 2\sum_{l=1}^{N-1}|X|^2.\{|Q_l^1|^2 + \left|Q_l^2\right|^2\} \quad (3.27)$$

$$=2|X|^2[\{sin((2\pi \in^1 + \varphi^1)/2)\}^2 \sum_{l=1}^{N-1} \frac{1}{\left[Nsin\frac{2\pi(l-k+\in^1)+\varphi^1}{2N}\right]^2} + \{sin((2\pi \in^2 + \varphi^2)/2)\}^2$$

$$\sum_{l=1}^{N-1} \frac{1}{\left[Nsin\frac{2\pi(l-k+\in^2)+\varphi^1}{2N}\right]^2} |X|^2[\left\{sin\left(\frac{2\pi\in^1 + \varphi^1}{2}\right)\right\}^2 \quad (3.28)$$

$$= (0.6704) + \{sin((2\pi \in^2 + \varphi^2)/2)\}^2(0.6704)] \quad (3.29)$$

The signal to noise ratio (SNR) can be calculated as [60]:

$$SNR = \frac{|X|^2}{{\sigma_n}^2} \quad (3.30)$$

The signal to noise plus interference ratio (SNIR) of MIMO OFDM can be calculated as[60]:

$$SNIR = \frac{{\sigma_{DRS}}^2}{{\sigma_n}^2 + {\sigma_{ICI}}^2} = \frac{\frac{{\sigma_{DRS}}^2}{{\sigma_n}^2}}{1 + \frac{{\sigma_{ICI}}^2}{{\sigma_n}^2}} \tag{3.31}$$

$$= SNR.[$$

$$\frac{SNR.[\left\{sin\left(\frac{2\pi \in^1 + \varphi^1}{2}\right)\right\}^2 (34.7738) + \{sin((2\pi \in^2 + \varphi^2)/2)\}^2 (34.7738)}{1 + SNR.[\left\{sin\left(\frac{2\pi \in^1 + \varphi^1}{2}\right)\right\}^2 (0.6704) + \{sin((2\pi \in^2 + \varphi^2)/2)\}^2 (0.6704)}$$

(3.32)

Probability of error is given by [61]:

$$P = \frac{1}{2} erfc(sqrt(SNIR)) \tag{3.33}$$

Bit error rate in Rayleigh channel is calculated by multiplying the SNR by the Rayleigh envelope and then integrate with the Rayleigh distribution.

3.5 APPLICATIONS OF MIMO OFDM SYSTEM

- MIMO OFDM technology enables high capacities suited for Internet and multimedia services,
- Increases the range and reliability.
- It Increases diversity gain and enhance system capacity on a time-varying multipath fading channel improving power-spectral efficiency in wireless communication systems.
- Optimizes the power efficiency.
- This technology guarantees each user's quality of service requirements, including bit-error rate and data rate.
- Ensures fairness to all the active users.

3.6 Peak to average power ratio (PAPR)

PAPR [62] is the ratio between the maximum power and the average power of the complex pass band signal x_n, that is,

$$PAPR = \frac{P_{peak}}{P_{avg}} = 10log\frac{max\ [|x_n|^2]}{E[|x_n|^2]} \tag{3.34}$$

where, P_{peak} is the peak output power , P_{avg} is the average output power, $E[.]$ denotes the expected value, x_n represents the transmitted OFDM signals which are obtained by taking IFFT operation on modulated input symbols X_K. Mathematical, x_n is expressed as:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, W_N^{nk} \tag{3.35}$$

For an OFDM system with N sub-carriers, the peak power of received signals is N times the average power when phase values are the same. The PAPR of baseband signal will reach its theoretical maximum at PAPR (dB) =10log N. There is another important parameter called Crest Factor (CF), which is defined as the ratio between maximum amplitude of OFDM signal s(t) and root-mean-square (RMS) of the waveform. The CF is defined as [63]:

$$CF(s(t)) = \frac{max\,(|s(t)|)}{max\,(||s(t)|^2|)} = \sqrt{PAPR} \tag{3.36}$$

In most cases, the peak value of signal x(t) is equals to maximum value of its envelope |x(t) | . PAPR performance of OFDM signals is commonly measured by certain characterization constants which are related to probability.

3.6.1 Probability Distribution Function (PDF) for PAPR

As per the central limit theorem, for a large number of sub-carriers in multi-carrier signal, the real and imaginary part of sample values in time-domain will obey Gaussian distribution with mean value of 0 and variance of 0.5. Therefore, the amplitude of multi-carrier signals follows Rayleigh distribution with zero mean and a variance of N times the variance of one complex sinusoid [64]. Its power value obeys a χ^2distribution with zero mean and 2 degrees of freedom. Cumulative Distribution Function (CDF) is expressed as follows

$$F(z) = 1 - \exp\,(-z) \tag{3.37}$$

Assuming that the sampling values of different sub-channels are mutually independent, and free of oversampling operation, the probability distribution function [65] for PAPR less than a certain threshold value, is therefore expressed as

$$P(PAPR < z) = F(z)^n = ((1 - exp\,(-z))^N \tag{3.38}$$

It is preferred to take the probability of PAPR exceeding a threshold as measurement index to represent the distribution of PAPR. This can be described as “Complementary Cumulative Distribution Function” (CCDF), and its mathematical expression is

$$P(PAPR > z) = 1 - P(PAPR \leq z) = 1 - F(z)^n = 1 - ((1 - exp\,(-z))^N \tag{3.39}$$

3.7 Factors affecting PAPR

- **Type of modulation or modulation scheme**

  Different modulation schemes produce different PAPR performance. There is only small difference between different modulation schemes. Thus, different modulation schemes have minimum influence on PAPR performance.

- **Number of sub-carriers**

  Different number of sub-carrier results in different PAPR performances due to the varying information carried. When the number of sub-carriers increases, the PAPR also increase.

3.8 PAPR Reduction Techniques

There are different algorithms to solve the high PAPR problem of OFDM system. These reduction solutions can be roughly divided into three categories:

- **Signal Distortion**

One of the most pragmatic and easiest approaches is clipping and filtering which can snip the signal at the transmitter so as to eliminate the appearance of high peaks above a certain level. Clipping can be implemented to the discrete samples prior to digital-to-analog-convertor (DAC) or by designing analog-to-digital-convertor (DAC) and/or amplifier with saturation levels which are lower than the dynamic range [66]. But due to the nonlinear distortion introduced by this process, orthogonality will be destroyed to some extent which results in serious in band noise and out of band noise. In-band noise cannot be removed by filtering, it decreases the bit error rate (BER). Out-of- band noise reduces the bandwidth efficiency but frequency domain filtering can be employed to minimize the out-of-band power. Although filtering has a good effect on noise suppression, it may cause peak re-growth. To overcome this drawback, the whole process is repeated several times until a desired situation is achieved.

- **Signal Scrambling Techniques**

The fundamental principle of this technique is to scramble each OFDM signal with different scrambling sequences and select one which has the smallest PAPR value for transmission. This technique can reduce the appearance probability of high PAPR to a great extent. This type of approach include: Selective Mapping (SLM) and Partial Transmit Sequences (PTS). SLM method applies scrambling rotation to all sub-carriers independently while PTS method only takes scrambling to part of the sub-carriers. These two methods can be applied to any scenarios without restriction on the number of sub-carriers and type of modulation.

- **Coding Techniques**

The core of encoding method is to apply special forward error correction technique to remove the OFDM signals with high PAPR. The classical schemes include linear block code [67], Golay codes and Reed-Muller code. As far as linear block code method is concerned, it is only suitable to the scenario which has a small number of sub-carriers, which results in limited applications. Reed-Muller code is a high efficiency coding scheme, it obtains a lower PAPR for the second order cosets code by classifying the Walsh-Hadamard transform (WHT) spectrum of the code words. By using Reed-Muller code, PAPR can be reduced to 3dB at most with a good error correcting performance. The encoding method is limited to types of constellation.

3.8.1 Signal Scrambling Techniques

The emergence of high peak power signal in OFDM system is due to the superposition (IFFT operation) of multiple sub-carrier signals. If multiple sequences which carry the same information are used to represent one transmission process, then the best one can be chosen among those candidates for a given PAPR threshold condition. In this way the occurrence probability of peak power signal can significantly be reduced.

The phase rotation method used for reducing the PAPR of OFDM signal is a special case of multiple signal representation (MSR) technology. Its fundamental principle is: Generating multiple signal waveforms which carry the same information and then choose the waveform from those candidates with the smallest PAPR for transmission. This approach can reduce the occurring probability of high peak power signal effectively, and optimize the statistical characteristics of PAPR in an OFDM system so as to reduce the PAPR successfully. This method is one of the non-distortion methods used for reducing PAPR. The basic structure of multi-signal representation includes an S/P converter, phase rotation module and parallel output signals which are obtained by executing IFFT operation simultaneously. Finally, the side band information which contains the optimum signal value will be transmitted to the other end of communication. In practice, the side band information can also be encoded by an error-correction code and transmitted through a plurality of reserved sub-carriers [68]. This method is equivalent to performing a linear transformation on modulated data symbols X in frequency domain. The process can be written as

$$X_{m,n} = A_{m,n} . X_n \quad (n=0, 1... N\text{-}1; m=1, 2....M) \tag{3.40}$$

where X_n represents an element of modulated data symbols X in frequency domain, X_n is the N-point data symbols before applying IFFT transform. The final goal of this transform is going to find N-point weighting factors $A_{m,n}$. It has the ability to reduce the appearance probability of high peak value x_n=($X_{m,n}$) in time domain.

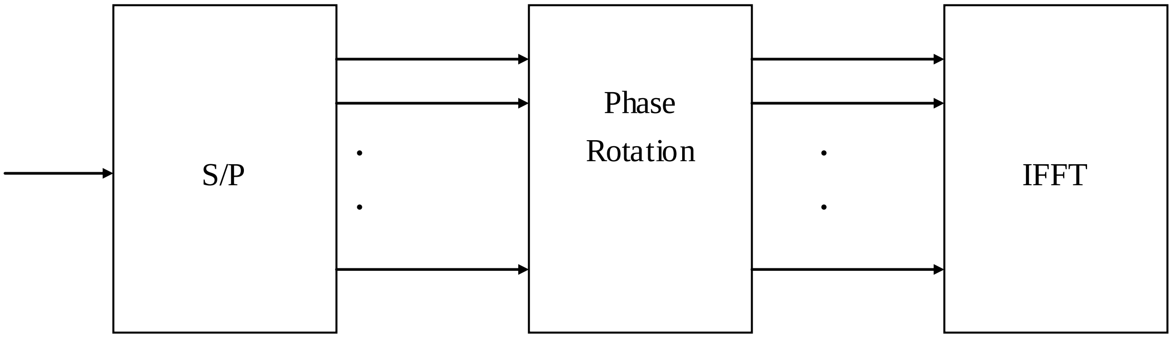

Figure11: Block diagram of phase rotation [69].

This method has lots of merits, such as high coding rate and low redundancy, although it only optimizes the statistical characteristics of PAPR in OFDM system. Phase rotation method contains a lot of different schemes. Two most effective and meritorious proposals are SLM and PTS. The two have received so much attention since they both can provide a low reduction in throughput and have relatively high bandwidth utilization.

3.8.1.1 Selected Mapping Method

The CCDF [70] of the original signal sequence's PAPR above a threshold PAPR_0 is written as $Pr\ \{PAPR > PAPR_0\ \}$. Thus for K statistical independent signal waveforms, CCDF can be rewritten as $Pr\ [\{PAPR > PAPR_0\ \}]^{K}$, so that the probability of PAPR that exceeds the same threshold will drop to a small value.This technique uses signal scrambling Technique. The fundamental principle of this technique is to scramble each OFDM signal with different scrambling sequences and select one which has the smallest PAPR value for transmission.

This can reduce the appearance probability of high PAPR to a great extent. SLM method applies scrambling rotation to all sub-carriers independently. This method can be applied to any scenario without restriction on the number of sub-carriers and type of modulation. The probability of PAPR larger than a threshold z can be written as

$$P(PAPR > z) = 1 - ((1 - e^{-z})^{N}) \tag{3.41}$$

Probability of PAPR greater than z is equals to the product of each independent candidate's probability and can be written as

$$P\{PAPR_{low} > z\} = (P\{PAPR > z\})^{M} = ((1 - exp(-z))^{N})^{M} \tag{3.42}$$

First M statistically independent sequences which represent the same information are generated then resulting M statistically independent data blocks $\mathrm{S_m}=[\mathrm{S_{m,0}}, \mathrm{S_{m,1}}, \ldots \mathrm{S_{m,N-1}}]^{\mathrm{T}}$, m=1, 2,…, M are forwarded into IFFT. Finally, at the receiving end, OFDM symbols $x_m=[x_1, x_2, \ldots x_N]^T$ in discrete time-domain are acquired, and then the PAPR of these M vectors are calculated separately. The sequences x_d with the smallest PAPR will be elected for final serial transmission. Assuming that for a single OFDM symbol, the CCDF probability of PAPR larger than a threshold is equals to p. The general probability of PAPR larger than a threshold for k OFDM symbols can be expressed as $\mathrm{p^k}$.The new probability obtained by SLM algorithm [71] is much smaller compared to the former. Data blocks S_m are obtained by multiplying the original sequence with M uncorrelated sequence $\mathrm{P_m}$.Different pseudo-random sequences $\mathrm{P_m}=[\mathrm{P_{m,0}}, \mathrm{P_{m,1}}, \ldots \mathrm{P_{m,N-1}}]^T$, m=1,2,…,M, where $\mathrm{P_{m,n}}=\mathrm{e}^{\mathrm{j}\varphi_{\mathrm{m,n}}}$ and stands for the rotation factor. $\varphi_{m,n}$ is uniformly distributed in [0 2π]. The N different sub-carriers are modulated with these vectors respectively so as to generate candidate OFDM signals. All the elements of phase sequence $\mathrm{P_1}$ are set to 1 so as to make this branch sequence the original signal. The symbols in branch m is expressed as

$$S_m=[X_0 P_{m,0}, X_1 P_{m,1}, \ldots X_{N-1} P_{m,N-1}]^T, m=1,2,\ldots,M \tag{3.43}$$

and then transfer these 'M' OFDM frames from frequency domain to time domain by performing IFFT calculation. The entire process is given by

$$x_m(t) = \frac{1}{\sqrt{N}} \sum_{0}^{N-1} X_n P_{m,n} \cdot e^{j2\pi n \Delta f t}, m=1,2,\ldots M. \tag{3.44}$$

Finally, the one which possess the smallest PAPR value is selected for transmission. Its mathematical expression is given as

$$x_d = argmin_{1 \le m \le M}((x_m)) \tag{3.45}$$

where *argmin(·)* represent the argument of its value is minimized. At the receiver, the whole sequence of branch number *m* as side information transmitted to the receiving end is selected. It can be realized by sending the route number of the vector sequence. This is only possible when the receiving end is able to restore the random phase sequence P_m by means of look-up table or any other method. Since the side information plays a vital role for signal restoration at the receiver, channel coding is used to guarantee a reliable transmission. Once channel coding technique is adopted during the data transmission process, sending of any additional side information is not required. In this way, all possible routes are detected at the receiving end from which the most likely one is chosen as the optimum.

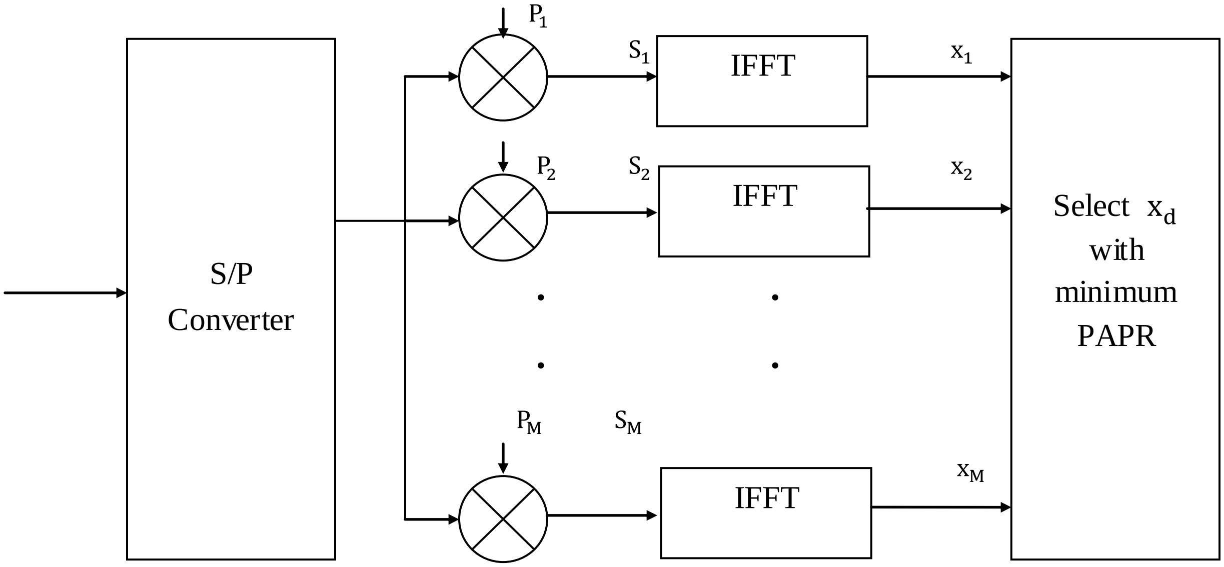

Figure12: Selected mapping Technique

3.9 THE STANDARD IEEE 802.11ac [72]

- IEEE 802.11ac is a wireless computer networking standard of 802.11 which is currently under development and will provide high throughput Wireless Local Area Networks (WLAN) below 6 GHz.
- This specification will enable multi-station WLAN throughput of at least 1 Gigabit per second and a maximum single link throughput of at least 500 megabits per second (500 Mbit/s).

- Fifth generation in Wi-Fi networking standards and will bring fast, high quality video streaming and nearly instantaneous data syncing and backup to the notebooks, tablets, and mobile phones.
- Entry-level IEEE 802.11ac products will provide a data rate of 433 Mbps (megabits per second), which is at least three times faster than that of the most common devices using the current wireless standard.
- This specification will enable multi-station WLAN throughput of at least 1 gigabit per second and a maximum single link throughput of at least 500 megabits per second (500 Mbit/s). This is accomplished by extending the air interface concepts embraced by 802.11n: wider RF bandwidth (up to 160 MHz), more MIMO spatial streams (up to 8), multi-user MIMO, and high-density modulation (up to 256 QAM).

3.10 GENERAL CHANNEL MODELS

3.10.1 AWGN

- It is a channel model in which the only impairment to communication is a linear addition of wide band or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude.
- This model does not account for fading, frequency selectivity, interference, non linearity or dispersion. It is commonly used to simulate background noise of the channel under study, in addition to multipath, terrain blocking, interference, ground clutter and self interference that modern radio systems encounter in terrestrial operation. In AWGN channel [73], we assume there is no fading effect. So the received signal can be represented by $$y = \gamma x + n \tag{3.46}$$ where γ is the constant channel gain and n is the Additive White Gaussian Noise, normally generated by the thermal noise in the system and x is the input signal.

3.10.2 RAYLEIGH FADING CHANNEL

In real wireless communication systems, signals being received may come from different paths associating with various channel gains and arrival time. Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium will vary randomly, or fade according to a Rayleigh distribution. Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver.

- It is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices.
- Assumes that the magnitude of a signal that has passed through such a transmission medium will vary randomly, or fade, according to a Rayleigh distribution.

  A typical situation is shown in Figure below, where a stands for the amplitude.

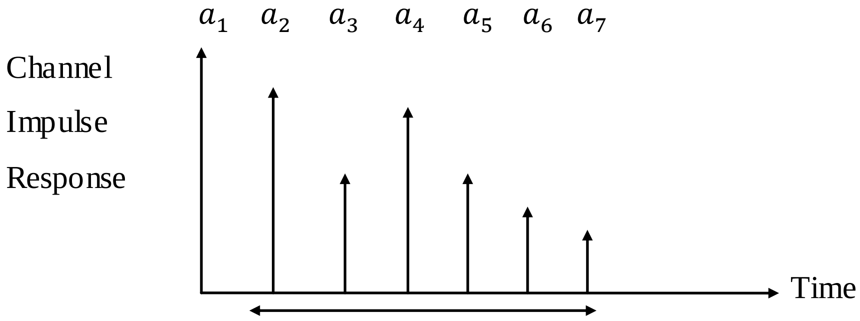

Figure 13: Multipath Rayleigh Fading [74]

In the above figure, we assume symbol period >> delay spread, so the delay results only in phase difference. We can write the channel as follows

$$a = \sum a_i e^{j\omega\tau_i} = \sum Re(a_i e^{j\omega\tau_i}) + \sum Img(a_i e^{j\omega\tau_i}) \tag{3.47}$$

When the number of arrival path is large enough, i.e. in the full scattering condition, by Central Limit Theorem, this equation becomes

$$a = a_I + a_Q = re^{j\theta} \tag{3.48}$$

where a_I and a_Q are zero mean Gaussian random variables. r is called Rayleigh envelope and the channel equation becomes

$$y = re^{j\theta} x + n \tag{3.49}$$

Provided that perfect channel information is known, the phase θ is known. We can multiply a negative phase to the above equation. Noise always has random phase (whether there is a phase change does not matter), so this equation can be simplified as

$$y = rx + n \tag{3.50}$$

The Probability Density Function (PDF) of *r* follows the Rayleigh distribution [75]. In simulations the expected value of r is always normalized to 1. Since r has a variance, the performance is much worse than that in the case of AWGN channel. To reduce the variance so that improve the performance, diversity is needed.

3.10.3 RICIAN FADING CHANNEL

- Rician fading channel is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself, the signal arrives at the receiver by two different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening).
- Occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution. In Rician fading, a strong dominant component is present.

Chapter 4-MIMO & OFDM SYSTEM

4.1 MIMO

Multiple-input–multiple-output (MIMO) wireless systems are those that have multiple antenna elements at both the transmitter and receiver. The multiple antennas increase the average SNR seen at the combiner output. Multiple-input multiple-output (MIMO) systems are used in developments in antenna array communication. The channel of a two transmitter two receiver MIMO system can be represented by

$$y = Hx \tag{4.1}$$

$$\mathrm{H} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \tag{4.2}$$

This formula can be generalized to any number of transmit and receive antennas. By using MIMO there are two possible gains, multiplexing gain and diversity gain, where x and y are 2x1 matrix, representing transmitted and received signal on each antenna. The four entries of the channel matrix H correspond to the channel gains between antennas, as shown in Figure14. Several different antenna configurations are used in defining space-time systems. In MIMO system, a number of antennas are placed at the transmitting and receiving ends, separated by a considerable distance. The distance between different base station antennas can be set as 10 times the carrier wavelength and mobile station antennas can be separated by half carrier wavelength. In this way, independent channels between the transmitting and receiving ends are formed so as to achieve spatial diversity or space division multiplexing. The idea is to realize spatial multiplexing and data pipes by developing space dimensions which are created by multi-transmitting and receiving antennas.

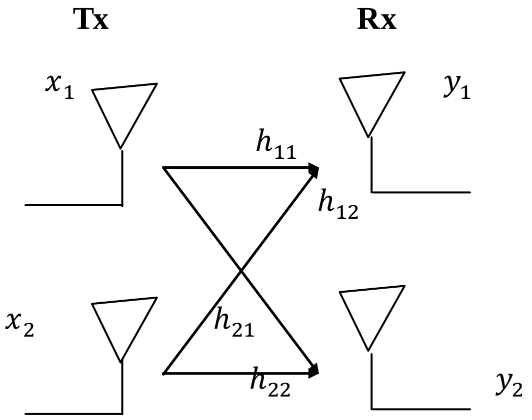

Figure 14: MIMO structure

4.1.1 Multiplexing Gain

To achieve multiplexing gain, multiple independent spatial channels is created (shown in Figure11 [76]). Independent information sequences can be transmitted on each channel at the same time. The maximum number of channels is *min* (*M,N*) where *M* is the number to transmission antennas (Tx) and N is the number of receive antennas (Rx). As *min* (*M, N*) increases, the number of spatial channels increase linearly. The system capacity also increases linearly.

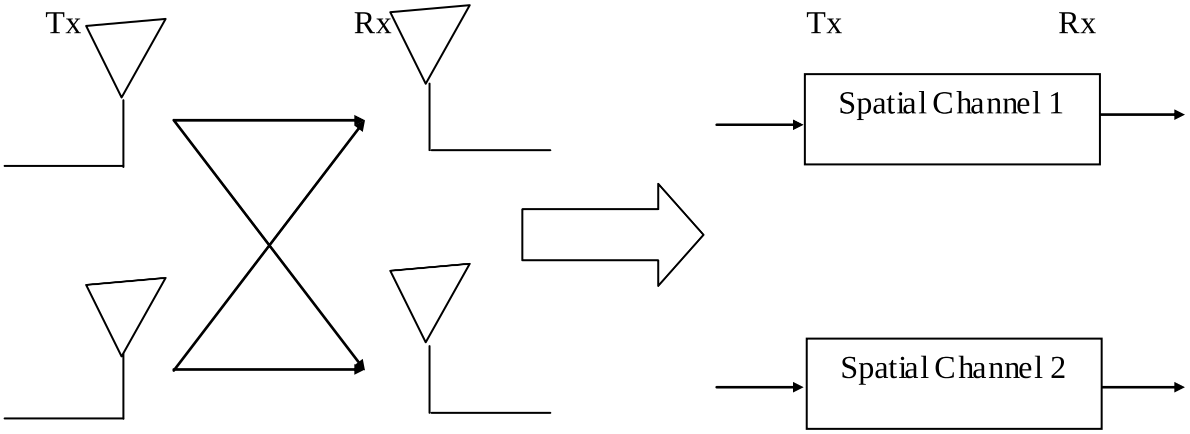

Figure 15: MIMO multiplexing feature

4.1.2 Diversity Gain

Instead of two independent information sources, we can send some processed representation of a single information source in order to achieve the diversity. The four channels can be seen as independent faded branches (shown in Figure16). So the MIMO channel now has a diversity order of 2 × 2 = 4. For the generalized MIMO channel, the diversity order is M × N.

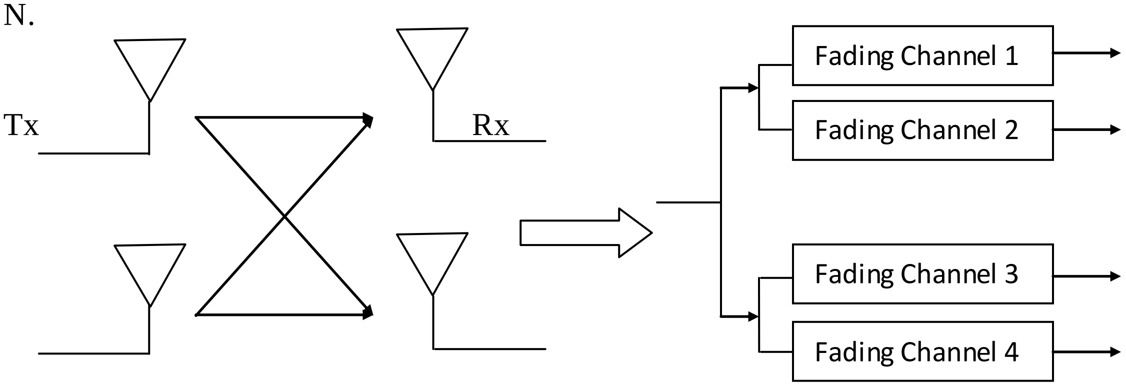

Figure 16: MIMO diversity feature

4.2 Zero-Forcing Detection

The simplest MIMO detector is the zero-forcing linear detector, which simply inverts the channel matrix. For the case when the inverse of the channel does not exist, the pseudo inverse of the channel matrix is used. The linear detector begins by multiplying the channel output by the channel matrix pseudo inverse:

$$y = (H * H)^{-1} H^{*} \mathrm{r} \tag{4.4}$$

$$= a + (H * H)^{-1} H^{*} \mathrm{w} \tag{4.5}$$

A slicer is used to make a decision regarding the k^{th} channel input. The slicer chooses the element from the symbol alphabet nearest y_k:

$$\hat{a}_k = \underset{\mathrm{a}\epsilon A}{argmin} ||y_k - a||^2 \tag{4.6}$$

The total complexity of a MIMO detector is divided into preprocessing and core processing complexity. The preprocessing complexity includes those computations which are performed only once for a given channel matrix. Once the channel estimation is updated or changed, the preprocessing computations need to be recalculated. The core processing complexity includes only those computations that are necessary for every symbol period. The faster the channel changes, the more important it becomes to reduce preprocessing complexity. On the other hand, if the channel changes slowly then the preprocessing contributes relatively little to the total complexity, and reducing the core processing complexity is most important. There is a fundamental trade-off in MIMO detection systems between performance and complexity.

4.3 Block Diagram

The block diagram for a MIMO wireless communication system is shown illustrating transmitter and receiver respectively, between which is the communication channel.

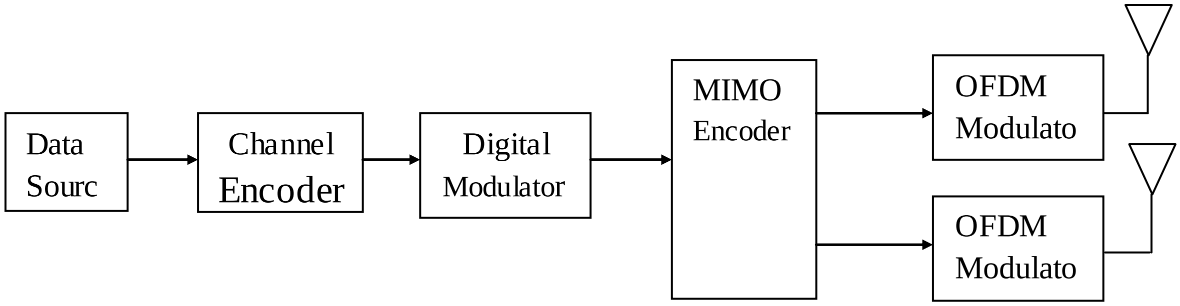

Figure 17: The block diagram at transmitter side

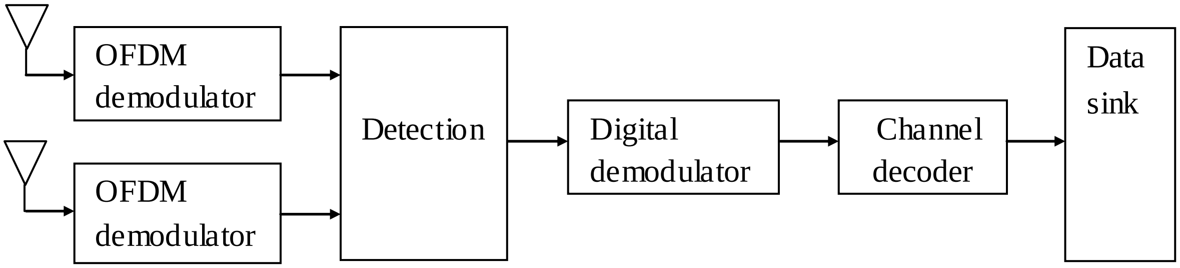

Figure 18: The block diagram at receiver side

The bit sequence is generated by the information source which contains information to be communicated. After the encoding and modulation processes, the bit sequence becomes the symbol stream. The symbol stream passes through the channel where it experiences interference from the environment and the noise at the receiver. As a result, detection is needed at the receiver side. The detected symbols will be demodulated and decoded and finally sent to the data sink.

4.4 MIMO Channel and Capacity

There are several kinds of channel impairments in wireless communication.

1. Free space path loss

This refers to power loss of electromagnetic wave when there is an unobstructed line-of-sight path exists between transmitter and receiver. The free space power received by receiving antenna, which is separated from transmitting antenna by a distance d, is given by [77]

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{4.7}$$

Where P_t is transmitted power, $P_r(d)$is received power, G_t is transmitting antenna gain, G_r is receiving antenna gain, d is the transmitter-receiver (T-R) separation distance in meters, L is the system loss factor (not related to propagation, $L \geq 1$) and λ is the wavelength in meters. The gain of an antenna is related to its effective aperture by

$$G = \frac{4\pi}{\lambda^2} A_e \tag{4.8}$$

where λ is wavelength of carrier and $\lambda = c/f$, f is carrier frequency in Hz and c is the speed of light in meters/sec (3×10^8 m/sec), A_e is effective aperture of antenna in m^2.

2. Shadow fading

Large obstructions such as hills or large buildings hinders the main signal path between the transmitter and the receiver, which will lead to shadowing and amplitude fluctuation of receiving signals. In fact, free-space path loss and shadow fading belong to large-scale fading or slow fading.

3. Small-scale fading (multipath)

Rapid fluctuation of amplitude and phase over a short period of time or travel distance is called small scale fading. Small-scale fading can be generally related to reflection, diffraction and scattering. The interaction of these three different propagation mechanisms cause fading at a specific location [78].

Rayleigh fading is an applicable model to describe small-scale fading when there is no dominant propagation along the line of sight between the transmitter and receiver. If there is a dominant propagation along the line of sight, Rician fading may be more applicable. System capacity can be defined as maximum transmission data rate in condition of small error probability.

The transmitted signal bandwidth is so narrow that its frequency response can be considered as being flat. The channel matrix H is $N_r \times N_t$ complex matrix, elements of it are fading coefficients from the j-th transmit antenna to the i^{th} receive antenna. Assuming that a MIMO system with a transmit array of N_T antennas and a receive array of N_R antennas, the transmission can be expressed as: $y = Hx + n$, where y is $N_R \times 1$ receiving vector, x is $N_T \times 1$ transmitting vector, n is additive white Gaussian noise with autocorrelation matrix

$$R_n = E\{nn^H\} = N_0 I_{NT}.I_{NT} \qquad (4.9)$$

is an N_T x N_T identity matrix, N_0 is identical noise power of each receiving branch. Assuming that the signals transmitted by separated antennas are independent of each other and for each one its mean value equals to 0 and variance equals to 1. MIMO system capacity can be expressed as [79]:

$$C = max_{T_r(R_{ss})} = N_T\{log_2[det\,(I_{NR} + \frac{E_s}{N_T N_0})]\} \qquad (4.10)$$

The unit of system capacity C is bit per second per hz, $det(\cdot)$ denotes matrix determinant. If channel knowledge is unknown for the transmitter, and the signals transmitted from each antenna have equal powers, that is, $R_{ss} = I$. In this situation, the system capacity can be rewritten as :

$$C{=}log_2[det\,(I_{NR} + \frac{E_S}{N_T N_0} HH^H)] \tag{4.11}$$

These formulae shows that Multi-antenna system has indeed improved the channel capacity compared to traditional single-antenna system. The increased channel capacity can be used to purely raise the information transmission rate or improve the reliability of communications systems by enhancing information redundancy in condition of maintaining the information transmission rate.

4.5 MATHEMATICAL MODEL

If we consider K independent users in the multi-user MIMO system assuming that the Receiver and each Transmitter are equipped with M_B and N_M antennas, respectively. Let x_u $\in C^{N_M X 1}$ and $y_{CH} \in C^{N_B X 1}$ denotes the transmit signal from the u^{th} user, u= 1, 2,… ,K, and the received signal at the receiver respectively. The channel gain between the u^{th}user transmitter and receiver is represented by $H_u^{UL} \in C^{N_B X N_M}$, u = 1, 2…., K. The received signal is expressed as [80]

$$y_{CH} = H_1^{UL} x_1 + H_2^{UL} x_2 + \cdots + H_K^{UL} x_K + z \tag{4.12}$$

$$= [H_1^{UL} H_2^{UL} \, ... \, H_K^{UL}] \begin{bmatrix} x_1 \\ . \\ . \\ . \\ x_K \end{bmatrix} + z \tag{4.13}$$

$$= H^{UL} \begin{bmatrix} x_1 \\ . \\ . \\ . \\ x_K \end{bmatrix} + z \tag{4.14}$$

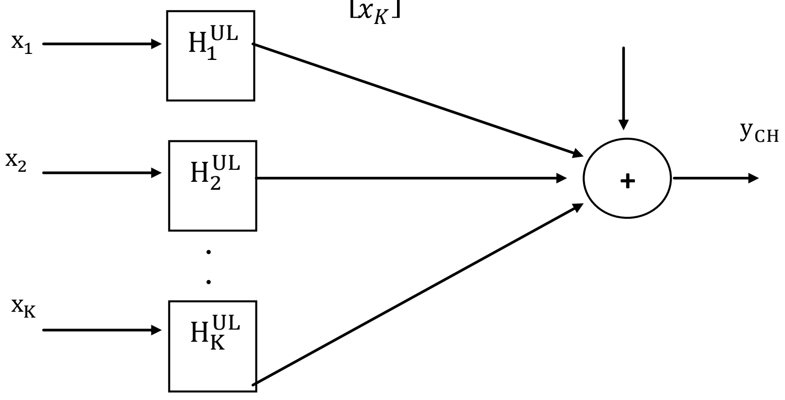

Figure 19: Forward channel model

where z $\in C^{N_B X 1}$ is the additive noise in the receiver and it is modeled as a zero-mean circular symmetric complex Gaussian (ZMCSCG) random vector. For receiver to transmitter channel , x$\in \mathrm{C}^{\mathrm{N_B X1}}$ is the transmit signal from the receiver and $\mathrm{y_u} \in \mathrm{C}^{\mathrm{N_B X1}}$ is the received signal at the u^{th} user, u = 1,2,…, K. Let $\mathrm{H_u^{DL}} \in \mathrm{C}^{\mathrm{N_B X N_M}}$ represent the channel gain between receiver and the u^{th} user. In transmitter to receiver channel, the received signal at the u^{th} user is expressed as

$$y_u = H_u^{DL} x + z_u, u= 1, 2,....K \tag{4.15}$$

where $z_u \in C^{N_M X 1}$ is the additive ZMCSCG(zero-mean circular symmetric complex Gaussian) noise at the u^{th} user. Representing all user signals by a single vector, the overall system can be represented as

$$\begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_K \end{bmatrix} = \begin{bmatrix} H_1^{DL} \\ H_2^{DL} \\ . \\ . \\ . \\ H_K^{DL} \end{bmatrix} x + \begin{bmatrix} z_1 \\ z_2 \\ . \\ . \\ . \\ z_K \end{bmatrix} \tag{4.16}$$

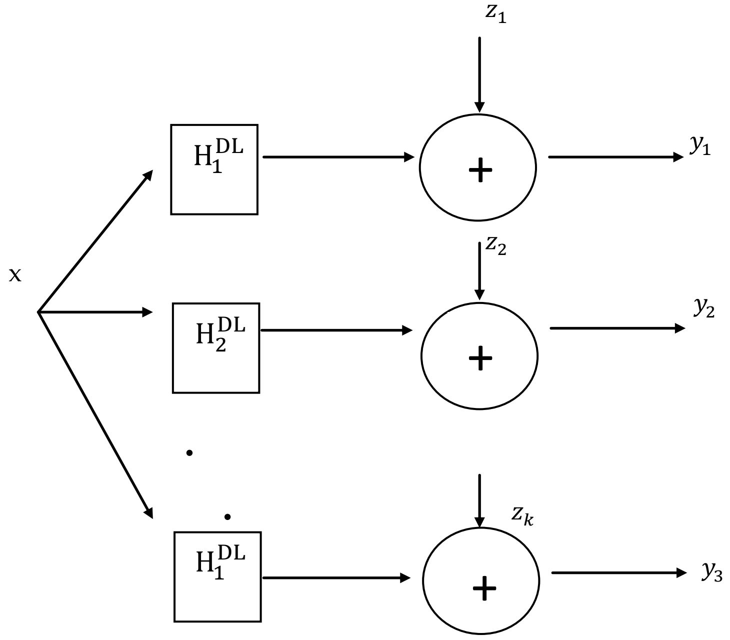

Fig 20: Reverse channel model

A 4x4 MIMO system has 4 transmit antennas and 4 receiver antennas. Because of the spatial diversity the BER of a 4x4 MIMO system is less compared to lower systems. But when we increase the number of transmitters and receivers further we get even less BER. So if we use 8x8system [81], the BER is much reduced compared to a 4x4 system.

4.6 MIMO DRAWBACKS

- Complexity, Power consumption and Size of the mobile device.
- Increased component costs within an Access Point required for the MIMO implementation.
- Multiple antennas and the use of higher performing CPU and DSP chips mean that, initially, manufacturer's costs of goods per Access Point may rise.
- The operation of multiple radio chains requires more power than the SISO systems, both in transmit and receive operations.

4.7 Single Carrier System

In a single carrier system, signals are pulse-formed by a transmitter filter $h_t(t)$ before being applied to a multipath channel. At the receiver, the incoming signal is passed through a receiving match filter h_r {t) to maximize the signal-to-noise ratio (SNR). The basic diagram of a single carrier system is shown in Fig 21.

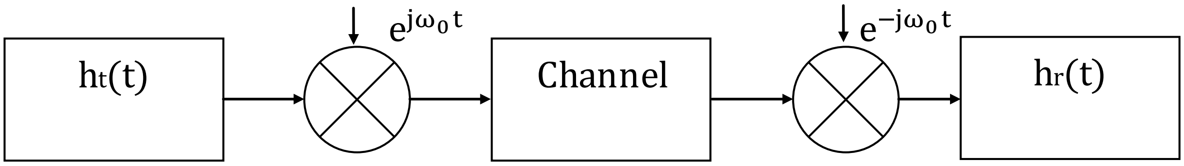

Figure 21: Basic structure of a single carrier system.

4.8 Multicarrier system

In a multicarrier system, input signals which are divided by a multiplexer are applied to pulse-formed $h_t(t)$ filters before being transmitted through multipath environment. The receiving ends consist of N parallel paths. Each one is passed through a respective match filter $h_r(t)$ to realize maximum SNR. In a general wireless communication model, the transmitted signal arrives at the receiver via various paths. Thus, extracting the original signal at the receiving end becomes extremely difficult. If the signal is transmitted at time intervals T, then the parameter concerning the multipath channel is the delay τ_{max} of the longest path with respect to the earliest path. The received signal can be theoretically influenced by $\frac{\tau_{max}}{T}$ previous signals, which must be considered seriously by receiver.

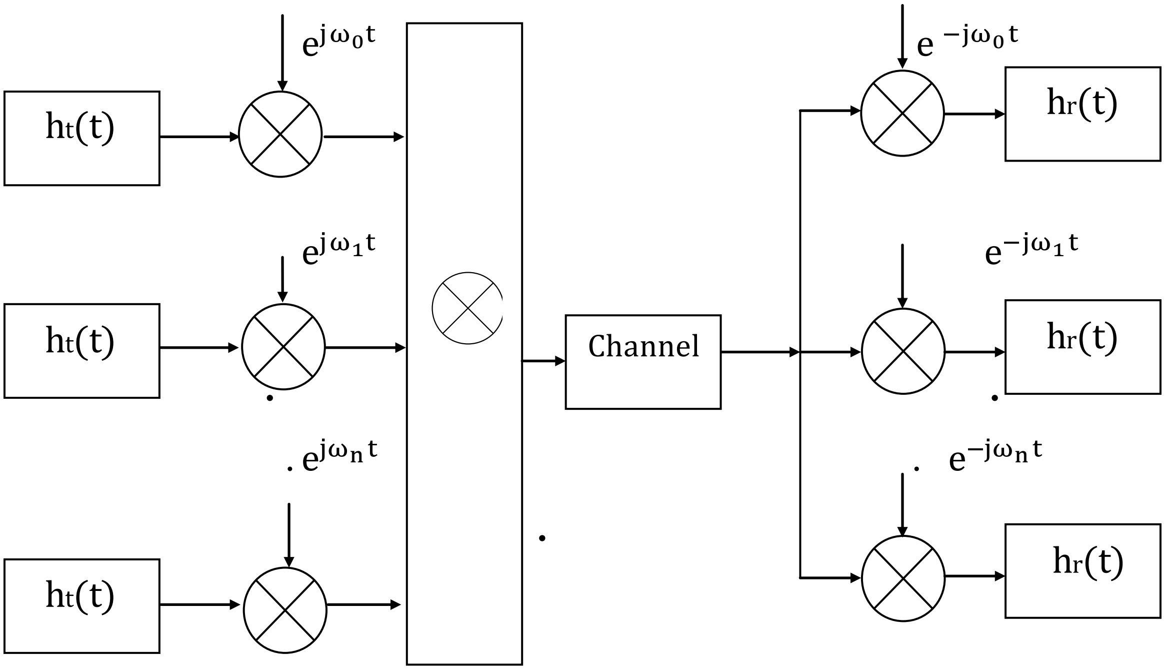

Figure 22: Basic structure of a multicarrier system.

In a single carrier system, it is assumed that transmission rate R =1/T and maximum channel delay is τ_{max}. In a multicarrier system [82], the original data stream of rate R is multiplexed into N parallel data streams with rate $R_{mc}=1/T_{mc}=R/N$. Each of the sub streams is modulated with a different subcarrier frequency and all the data streams are transmitted in the same band. In this case, the ISI of each sub-system reduces to $\tau_{max}/T_{mc} = \frac{\tau_{max}}{N.T}$. As the value of N increases, inter-symbol interference (ISI) decreases.

In a single carrier system, fading or interference can make the entire link fail. However, in a multicarrier system, only a small part of subcarriers will be affected. Error correction coding methods can be employed to correct the errors which happen in subcarriers. OFDM is a special form of multicarrier modulation (MCM), in which a signal is transmitted over a number of lower rate subcarriers.

4.9 OFDM and FDMA System

In the traditional frequency division multiplexing (FDM) system, signals are transmitted in different channels. Guard intervals are needed for channel isolation and filtering so as to prevent interference and guarantee an effective wireless communication. But, at the receiving end, a series of band-pass filters are needed to separate and extract information, which results in low frequency spectrum utilization. Up to 50% of the total spectrum is wasted in this manner. Another problem is that realization of filter banks is not easy. Figure 23 shows the frequency spectrum utilization efficiency in FDM and OFDM system [83], respectively.

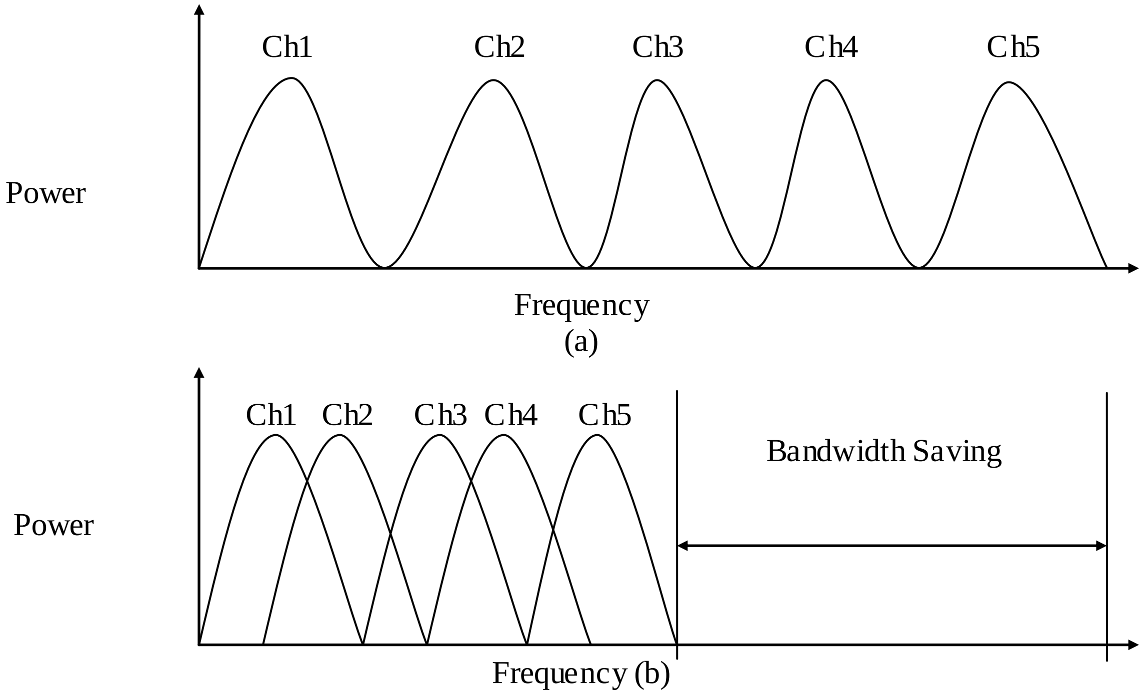

Figure 23: Comparison of frequency spectrum in (a) FDM and (b) OFDM system.

OFDM technology overcomes this problem by dividing available bandwidth into a number of sub channels. Sub-channels are made orthogonal to one another. OFDM signal consists of N sub-carriers, which are transmitted with equal interval. Each subcarrier has a null at the center frequency of the adjacent carrier, which results in zero interference among the carriers. The frequency spectrum is 1/2 overlapped. Figure 24 displays OFDM signal in frequency domain.

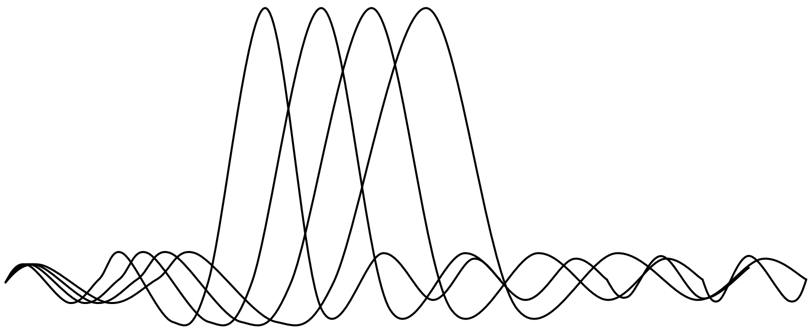

Figure 24: Frequency spectrum of OFDM signal.

Each subcarrier in OFDM system signal has a very narrow bandwidth with low symbol rate. The signal therefore, has immunity on multipath delay spread. At the receiving end, correlation modulation technique can be employed to separate different sub-carriers, thereby avoiding the use of filter banks and increasing spectrum utilization. Since OFDM signal is transmitted in low-speed parallel subcarriers, it has increased symbol period which help to reduce the time dispersion and ISI of the system.

4.10 WORKING PRICIPLE OF OFDM

OFDM stands for "Orthogonal frequency division multiplexing". It is a technique for transmitting data in parallel by using a large number of modulated sub-carriers. In this a higher bit rate channel is divided into multiple orthogonal sub-channels in the frequency domain with lower bit rates. The Orthogonality [84] of the carriers means that each carrier has an integer number of cycles over a symbol period. Due to this, the spectrum of each carrier has a null at the centre frequency of each of the other carriers in the system. This results in no interference between the carriers, although their spectra overlap. The separation between carriers is theoretically minimal so there would be a very compact spectral utilization.

OFDM systems are attractive for the way they handle ISI (inter symbol interference), which is usually introduced by frequency selective multipath fading in a wireless environment. Each sub-carrier is modulated at a very low symbol rate, making the symbols much longer than the channel impulse response. In this way, ISI is diminished. Moreover, if a guard interval between consecutive OFDM symbols is inserted, the effects of ISI can completely vanish. This guard interval must be longer than the multipath delay. Although each sub-carrier operates at a low data rate, a total high data rate can be achieved by using a large number of sub-carriers. ISI[85] has very small or no effect on the OFDM systems hence an equalizer is not needed at the receiver side.

At present OFDM is mostly used in digital audio broadcasting (DAB), digital video broadcasting (DVB), Wireless LAN and MAN such as IEEE802.11a, IEEE802.11g and IEEE802.16a, HIPERLAN/2 and other high speed data application for both wireless and wired communications. It is advantageous to combat frequency selective fading channels, especially in wide-band applications.

The subcarriers in OFDM have the minimum frequency separation required to maintain Orthogonality of their corresponding time domain waveforms, still the signal spectra corresponding to the different subcarriers overlap in frequency domain. The spectra of sub carriers overlap each other but individual sub carrier can be extracted by base band processing. This overlapping property makes OFDM more spectral efficient than the conventional multicarrier communication scheme.

This Orthogonality can be completely maintained with a small reduction in SNR, even though the signal passes through a time dispersive fading channel, by introducing a cyclic prefix (CP). In order for the cyclic prefix to be effective, the length of the cyclic prefix must be at least equal to the length of the multipath channel. The size of cyclic prefix is usually taken as one fourth the symbols. OFDM requires a relatively simple equalizer at the receiver and is well suited for transmission of high data rate applications in fading channels due to its robustness to inter-symbol interference. It is very easy to achieve accurate symbol synchronization. The nowadays solution method of frequency selective fading of the MIMO system is to use OFDM. It has quite good response, especially in indoor environments since fading caused by multipath can be combated with OFDM to improve quality of signal. Several research work has been carried out on the performance evaluation of an OFDM system both analytically and also by simulations.

In existing wireless communications systems a user can choose between either a very high data rate or a high mobility [86]. For multimedia applications a high data rate is essential. A communications system based on OFDM seems to be suitable to provide such a high data rate even in a mobile environment. OFDM is also used for dedicated short-range communications (DSRC) for road side to vehicle communications and as a backbone for fourth-generation (4G) mobile wireless systems. If knowledge of the channel is available at the transmitter, then the OFDM transmitter can adapt its signalling strategy to match the channel. Combining of OFDM technology and cognitive radio technology could increase utilization of spectrum and enhance performance of Cognitive Radio system, and spectrum resource may be distributed reasonably. Different FFT sizes [87] have different impact on the BER.

4.10.1 BLOCK DIAGRAM OF OFDM SYSTEM

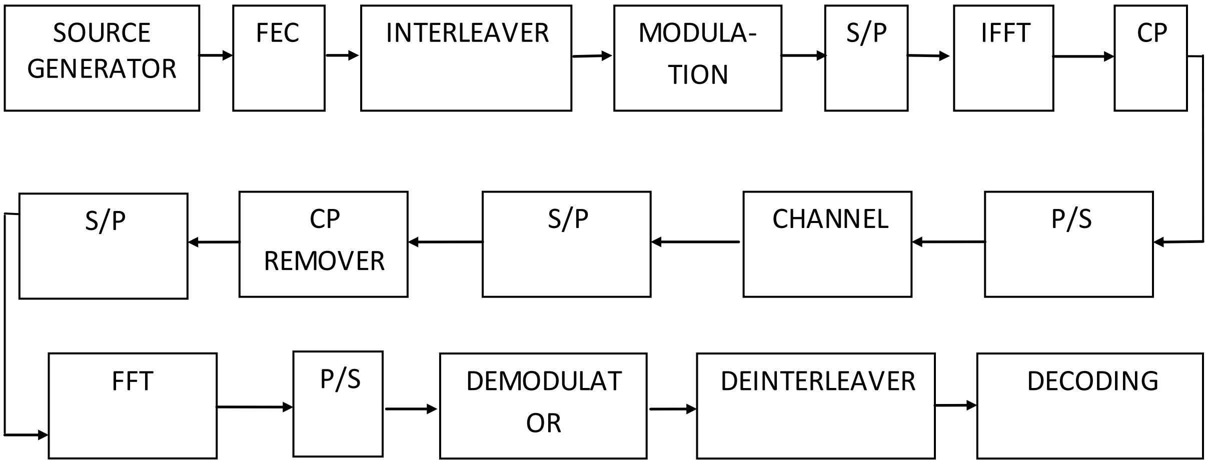

Fig 25: Block diagram of OFDM System

4.10.2 BLOCK DIAGRAM DESCRIPTION

SOURCE GENERATOR

Source generation block is used to generate the information bits.

INTERLEAVING

Interleaving can be employed in digital data transmission technologies to mitigate the effect of burst errors. When too many errors exist in one code word, due to a burst error, the decoding of a code word cannot be done correctly. To reduce the effect of burst error, the bits in one code word are interleaved before being transmitted. When interleaving occurs the place of bits will change, which means that a burst error can not disturb a huge part of one code word. Only a small part of each code word is distorted with interleaving, so the decoding of code word can be done correctly. All encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of bits in a single OFDM symbol.

IFFT

Once the pilots have been inserted into the data symbols, the data is put through an Inverse Fast Fourier Transform (IFFT). This maps the complex data symbols to a Time Domain OFDM symbol. The OFDM symbol is made of a number of discrete, baseband and orthogonal sub-carriers, which carry the data symbols and other, required timing information. All sub carriers are not used for data and pilot information. There are some sub-carriers that are used as guard barriers and preamble at the start and finish of the OFDM symbol. To enable the most efficient use of the IFFT function, the number of subcarriers is kept to a power of two, namely 2 to power n. An inverse Fourier transform converts the frequency domain data stream into the corresponding time domain. Then a parallel to serial convertor is used to transmit time domain samples of one symbol. The Fast Fourier Transformation (FFT) is used to convert data in time domain to the frequency domain at the receiver.

CYCLIC PREFIX

In telecommunication the term cyclic prefix refers to the prefixing of a symbol with a repetition of the end. Although the receiver is typically configured to discard the cyclic prefix samples, the cyclic prefix serves two purposes.

- As a guard interval, it eliminates the intersymbol interference from the previous symbol.
- As a repetition of the end of the symbol, it allows the linear convolution of a frequency-selective multipath channel to be modelled as circular convolution, which in turn may be transformed to the frequency domain using a discrete Fourier transform. This approach allows for simple frequency-domain processing, such as channel estimation and equalization.

The length of the cyclic prefix must be at least equal to the length of the multipath channel for cyclic prefix to be effective.

RADIO CHANNEL:

Different channels are used for simulation purpose like AWGN, Rayleigh fading, Rician fading.

4.11 Cyclic Prefix of OFDM System

The use of Cyclic Prefix (CP) can guarantee orthogonality of signals even when they travel through multi-path channels [88]. To avoid ISI, the condition; $T_G > T_{max}$ should be satisfied, where T_G is the length of CP and T_{max} is the maximum delay spread.

As shown in Fig26, a CP is a copy of the last part of a OFDM symbol moved to the front of symbol. Assuming that the number of the extended OFDM symbol is N_G, then the period of a practical OFDM symbol is $T+T_G$, where T is cycle for the FFT transform, T_G is the length of guard interval, which is inserted to suppress ISI caused by multipath distortion. Operation between the signal and channel changes from linear convolution to cyclic convolution when CP is used with OFDM. In the frequency domain, linear weighing will be used. These changes avoid inter-symbol interference, while ensuring orthogonality among the sub-carriers all the time.

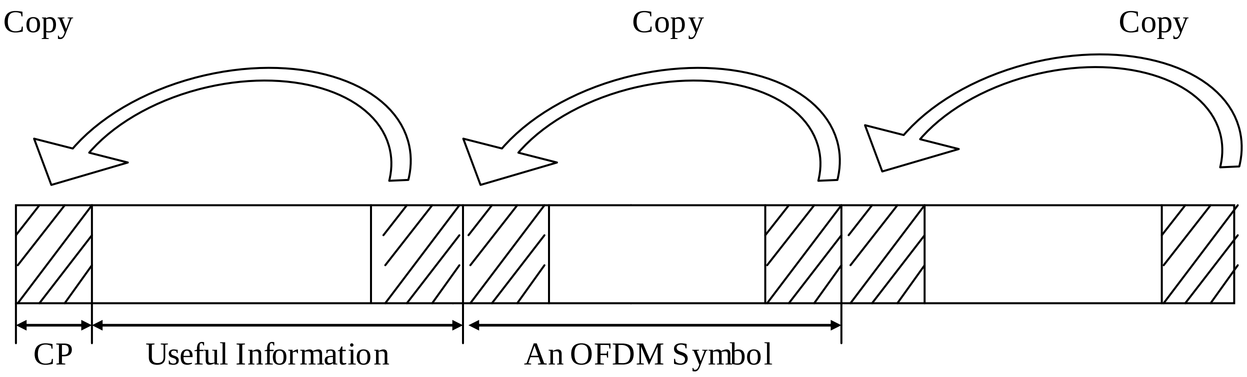

Fig26: OFDM symbol with CP

4.12 DISADVATAGES OF OFDM SYSTEM

- **ORTHOGONALITY**

The fact to have several carriers is actually advantageous whenever they are mathematically orthogonal. So carriers orthogonality is a constraint that can lead to a wrong operation of OFDM systems if not respected. The orthogonality is provided by IFFT that a numerical manipulation, an error of computation could change lightly spacing between two consecutive carriers and break the Orthogonality of the whole system.

- **SYNCRONIZATION**

One of the crucial problems in the receiver is to sample the incoming signal correctly. If the wrong sequence of samples is processed, the Fast Fourier Transform shall not correctly recover the received data on the carriers. The problem is more embarrassing when the receiver is switched on. There is therefore a need for acquiring timing lock. If the signal transmitted is really time domain periodic, as required for the FFT [89] to be correctly applied, then the effect of the time displacement is to modify the phase of all carriers by a known amount. This is due to the time shift theorem in Convolution transform theory. The signal is not really repetitive, we have cheated and performed the mathematical transform as if it were repetitive, but then chosen different symbols and transmitted them one after the other. The effect of the time shift would then be not only to add the phase shift referred to above, but also to add some intersymbol interference with adjacent symbols. This interference could hardly degrade reception.

To avoid these problems, we decide to transmit more than one complete sequence of time samples in order to increase the tolerance in timing. It's an additional data guard interval. It is built by repeating a set as long as channel memory of last samples taken in the original sequence. The longer the guard interval, the more rugged the system, but guard interval does not carry any useful information and its transmission leads to a penalty of power. One technique used to obtain good synchronization is to add a null (zero samples) symbol between each OFDM symbol.

- **PHASE NOISE**

At the receiver, a local oscillator can add phase noise to an OFDM signal. The phase noise could have two effects, these are: Common Phase Error (CPE) due to a rotation of the signal constellation and, Inter Carrier Interference (ICI), similar to additive Gaussian noise. The CPE arises simultaneously on all carriers. Signal constellation within a given symbol is subject to the same rotation for all carriers and this effect can be corrected by using reference information within the same symbol. ICI is more difficult to overcome, due to the additive noise[90], which is different for all carriers. This difference can be interpreted as a loss of orthogonality.

- **FREQUENCY ERROR**

An OFDM system can be subject to two types of frequency error. They are Frequency offset[91] (as might be caused by the tolerance of the local oscillator frequency) and, Error in the receiver master clock frequency (which will cause the spacing of the demodulating carriers to be different from those transmitted). Before to find solutions to those problems, the system designer needs to determine how much residual frequency error is permissible, and understand exactly how errors affect the received signal. Both of these error situations have been analyzed so, a frequency offset affects most carriers equally, with the very edge carrier less affected. ICI resulting from a fixed absolute frequency offset increases with the number of carriers, if the system bandwidth is kept constant. About error in the receiver clock frequency, in absence of frequency offset, it affects carriers unequally (the centre carrier suffers a little while the worst affected carrier lies close to, but not at the edge).

4.13 ADVANTAGES OF OFDM

- OFDM has very high frequency spectrum efficiency. Since in the OFDM system, sub-carriers are orthogonal to each other, channel spectrum overlapping is allowed, which can utilize limited spectrum resources maximally [92].
- OFDM system is relatively simple to realize. Modulation and demodulation can be achieved by FFT and IFFT.
- OFDM has the ability to combat multi-path interference. In OFDM, high-speed serial data streams are transferred to parallel transmission which increases the duration of data symbols carried by corresponding sub-carriers. This effectively reduces the channel time dispersion caused by ISI.
- OFDM can use a different number of sub-channels to provide different transmission rates between uplink and downlink. Currently, wireless data services are often non-symmetrical, that is, downlink channels carry more traffic than uplink channels. This requires a physical layer that supports non-symmetric high-speed data transmission.

Chapter 5

5.1 RESULTS & DISCUSSION

The spatial diversity of the 8x8 system makes it the strongest contender for low BER. SNR v/s BER plot for different modulations and fading channels have been shown. Here different antenna configurations viz 2x2, 4x4 and 8x8 were used. The FFT size of 128 is used. The analysis is done for two channels Rayleigh and Rician.

5.2 BER v/s SNR for 8x8, 4x4 and 2x2 configuration using BPSK modulation in Rayleigh fading channel

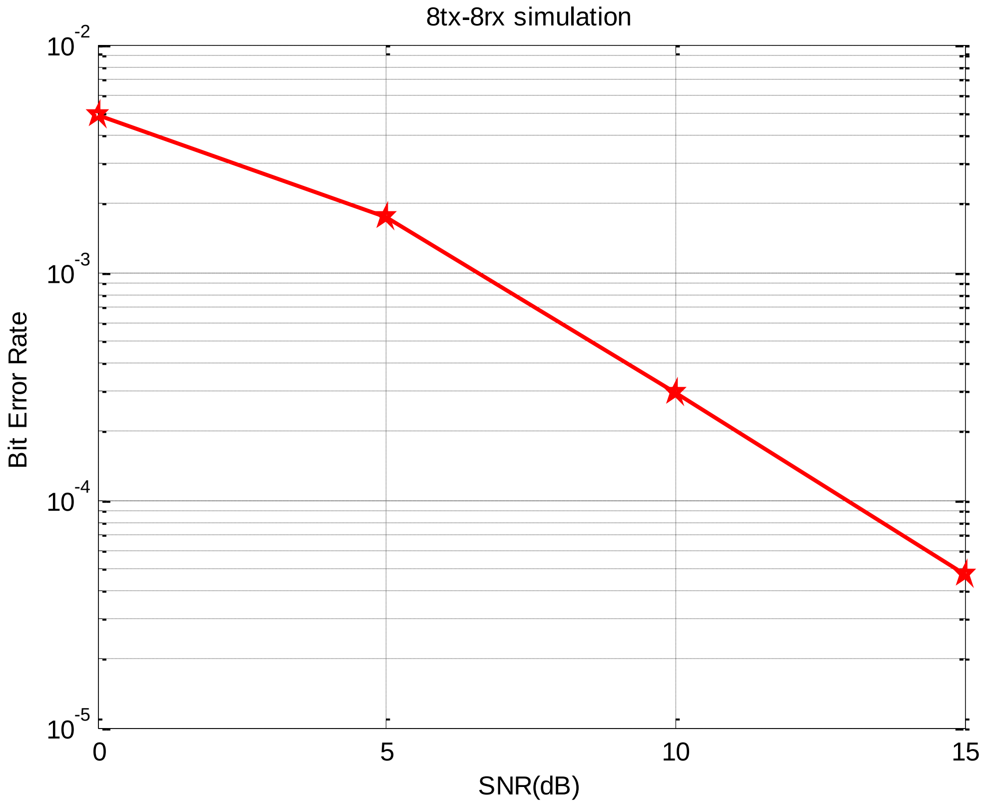

Figure 27(a): BER v/s SNR plot for 8x8 MIMO OFDM using BPSK modulation for Rayleigh fading channel

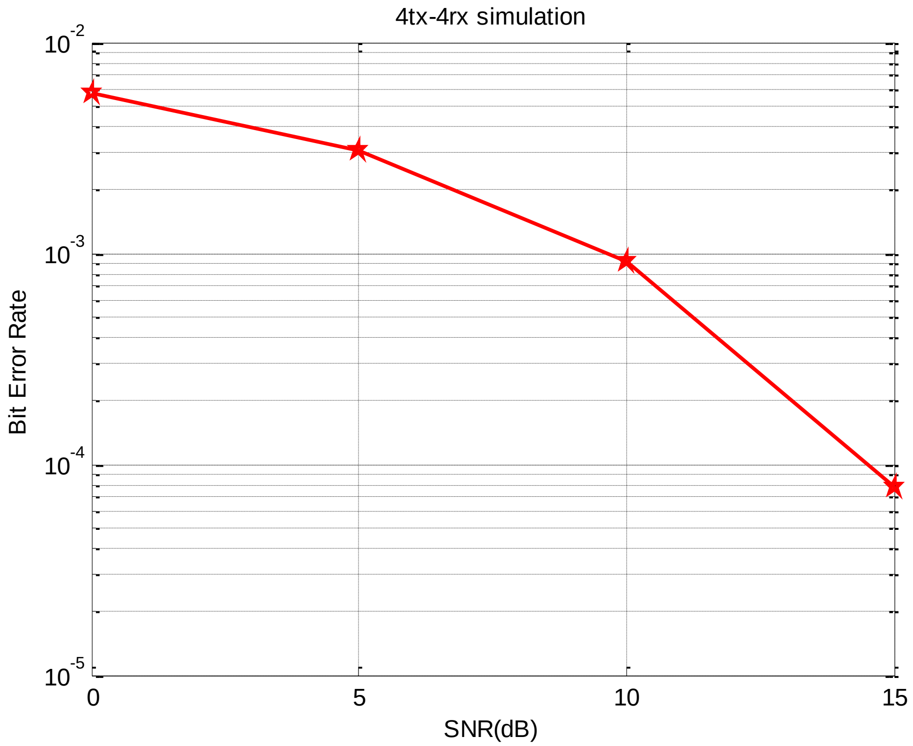

Figure 27(b): BER v/s SNR plot for 4x4 MIMO OFDM using BPSK modulation for Rayleigh fading channel

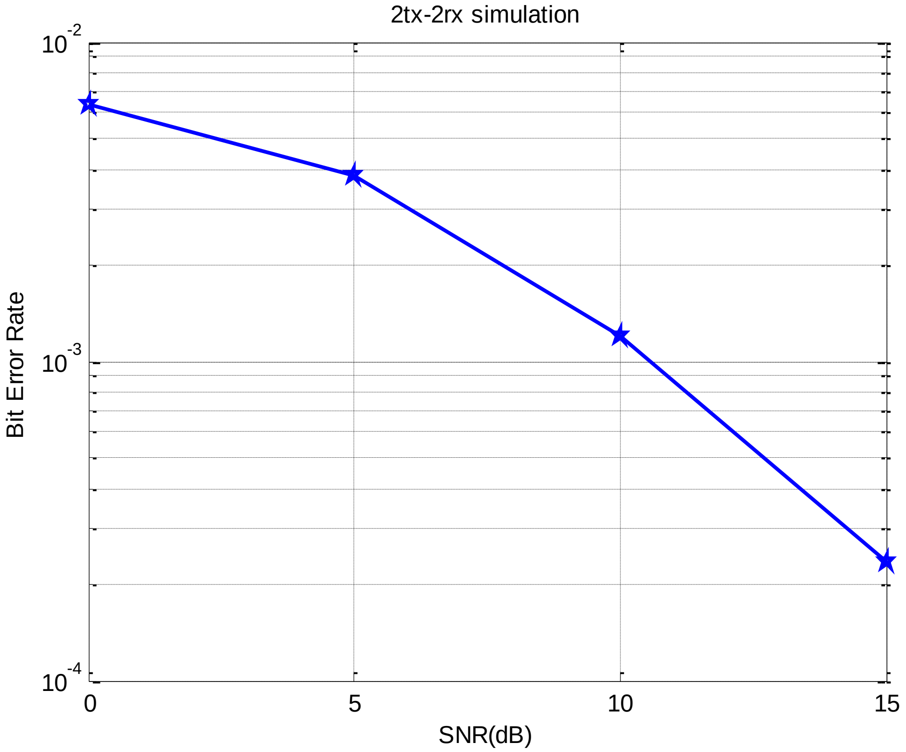

Figure 27(c): BER v/s SNR plot for 2x2 MIMO OFDM using BPSK modulation for Rayleigh fading channel

5.3 BER v/s SNR for 8x8, 4x4 and 2x2 configuration using QPSK modulation in Rayleigh fading channel

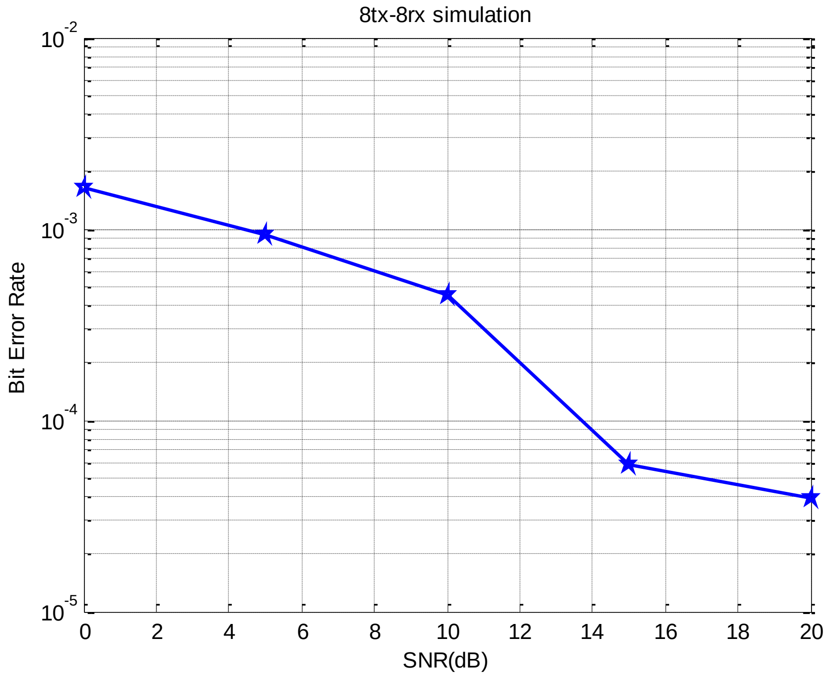

Figure 27(d): BER v/s SNR plot for 8x8 MIMO OFDM using QPSK modulation for Rayleigh fading channel

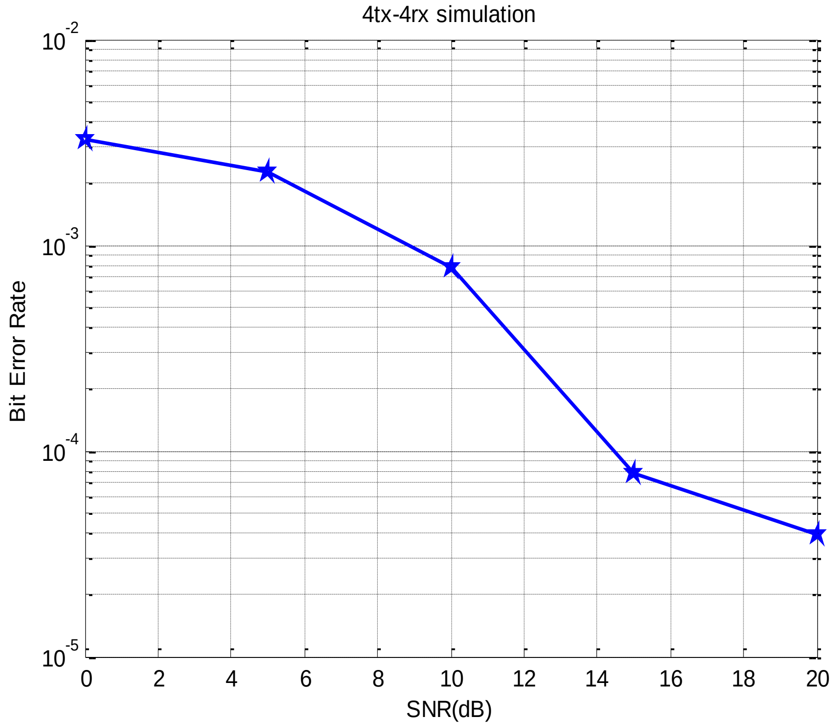

Figure 27(e): BER v/s SNR plot for 4x4 MIMO OFDM using QPSK modulation for Rayleigh fading channel

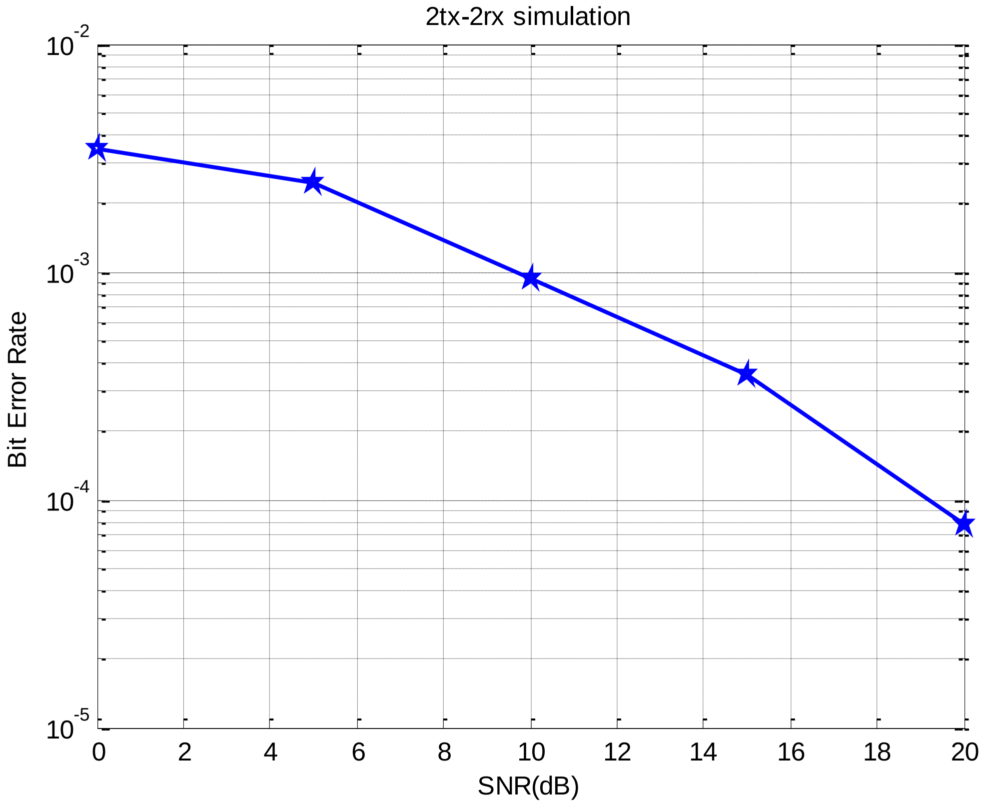

Figure 27(f): BER v/s SNR plot for 2x2 MIMO OFDM using QPSK modulation for Rayleigh fading channel

Figure 27 (a)-(f): SNR v/s BER plots for BPSK, QPSK over Rayleigh channel for MIMO-OFDM system employing different antenna configurations.

The curves show that in MIMO-OFDM system as we increase the number of Transmitters and Receivers the BER keeps on decreasing because of space diversity and the proposed system provide better BER performance as compared to the other antenna configurations used.

Table 1: SNR improvement for BPSK, QPSK in Rayleigh channel by using 8 X 8 antenna configuration over 4 X 4 antenna configuration

Type of Modulation used	**SNR improvement for Rayleigh channel (dB)**
BPSK	3 dB at BER of 10^{-3}
QPSK	4.5 dB at BER of 10^{-3}

Table 1

In Table 1 the advantage of using higher order (8 X 8) antenna configuration over lower order (4x4) antenna configuration is shown in the form of SNR improvement in dB for BPSK and QPSK modulation over Rayleigh fading channel. The SNR improvement of 3 dB is achieved using BPSK modulation and 4.5 dB for QPSK modulation at a BER of 10^{-3}.

5.4 BER v/s SNR for 8x8, 4x4 and 2x2 configuration using BPSK modulation in Rician fading channel

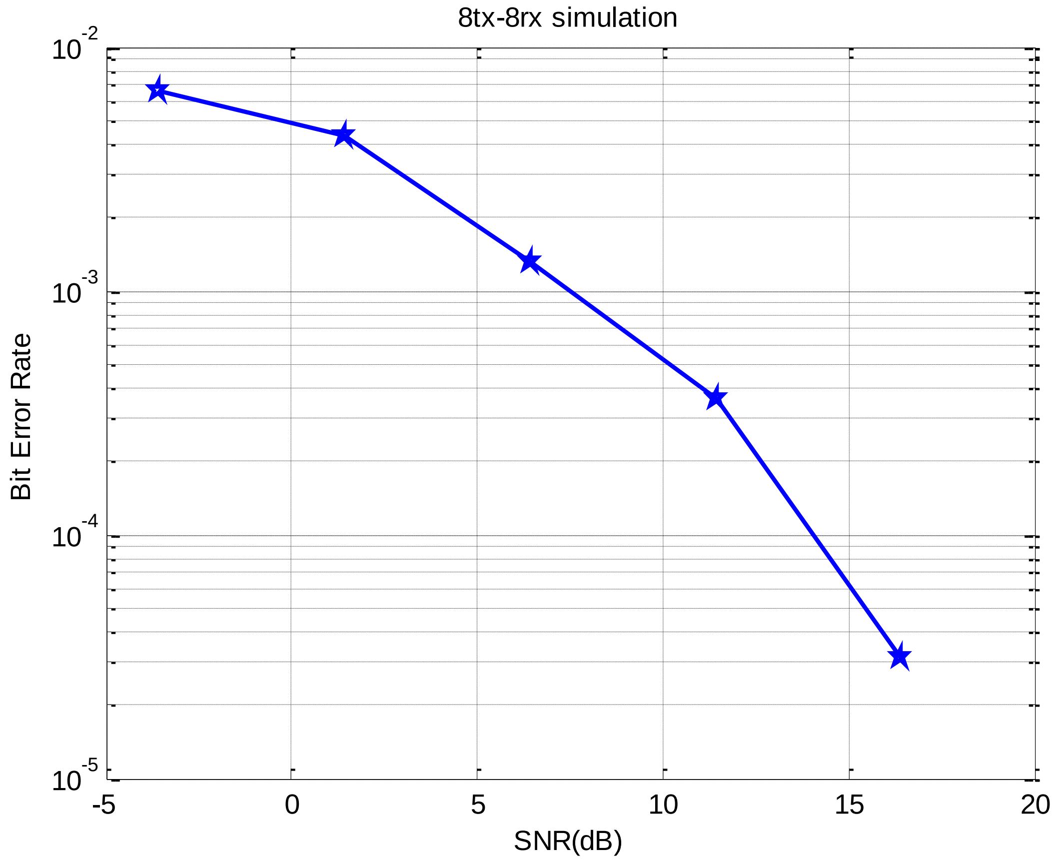

Figure 28(a): BER v/s SNR plot for 8x8 MIMO OFDM using BPSK modulation for Rician fading channel

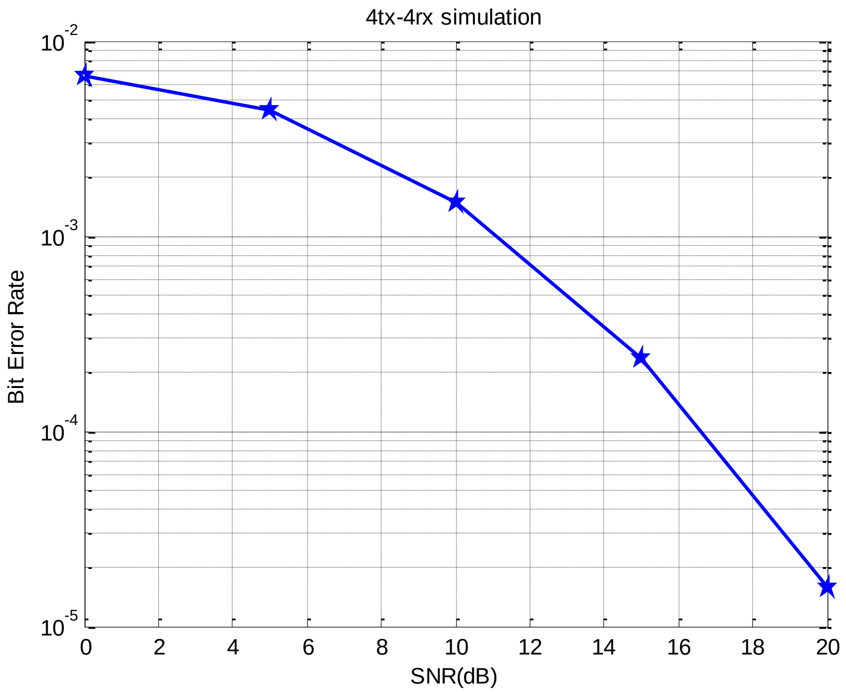

Figure 28(b): BER v/s SNR plot for 4x4 MIMO OFDM using BPSK modulation for Rician fading channel

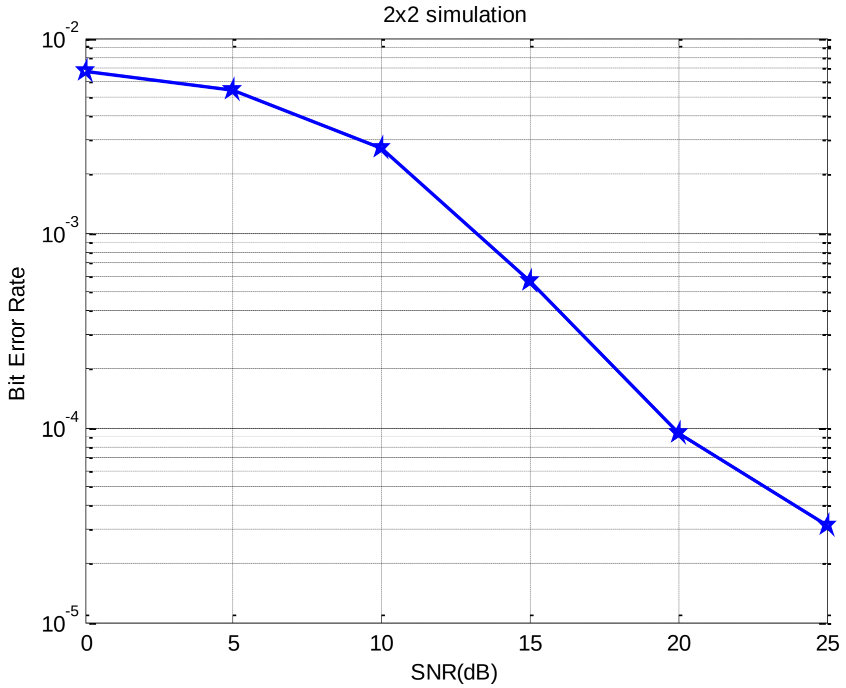

Figure 28 (c): BER v/s SNR plot for 2x2 MIMO OFDM using BPSK modulation for Rician fading channel

5.5 BER v/s SNR for 8x8, 4x4 and 2x2 configuration using QPSK modulation in Rician fading channel

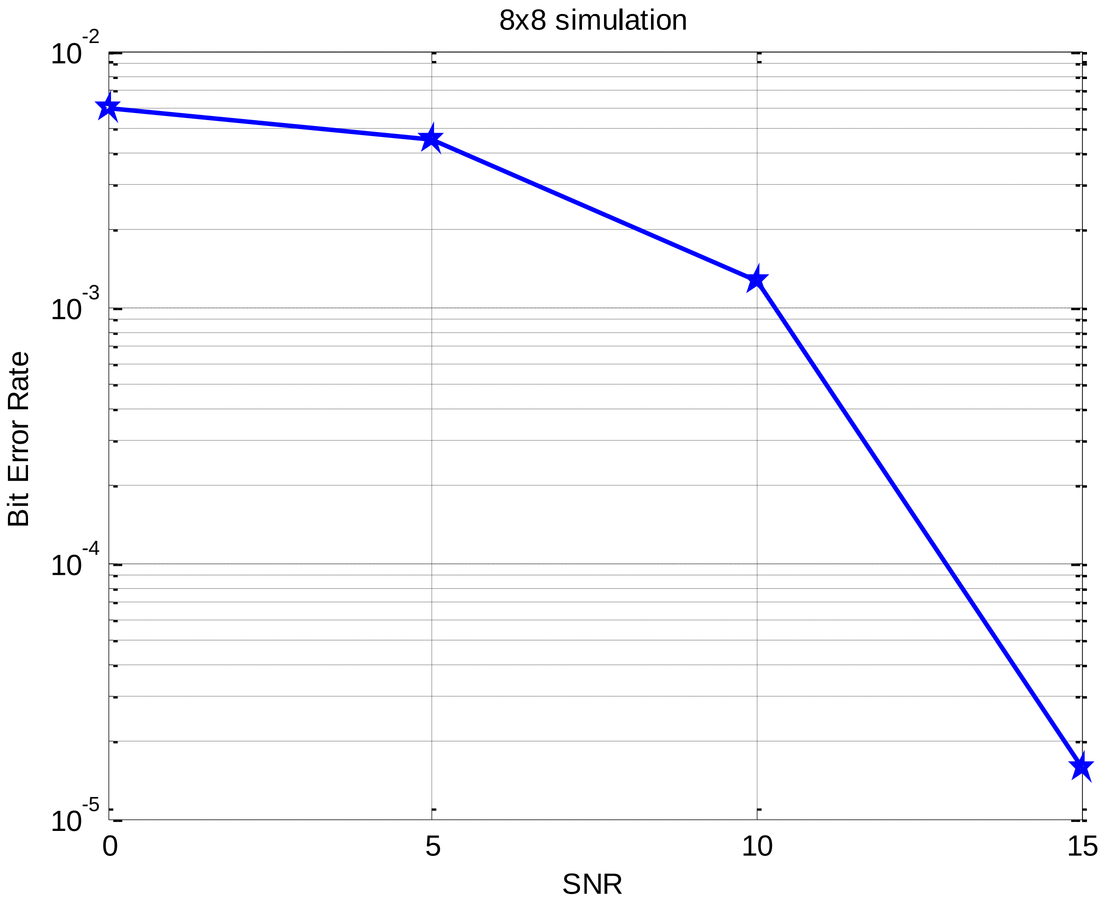

Figure 28(d): BER v/s SNR plot for 8x8 MIMO OFDM using QPSK modulation for Rician fading channel

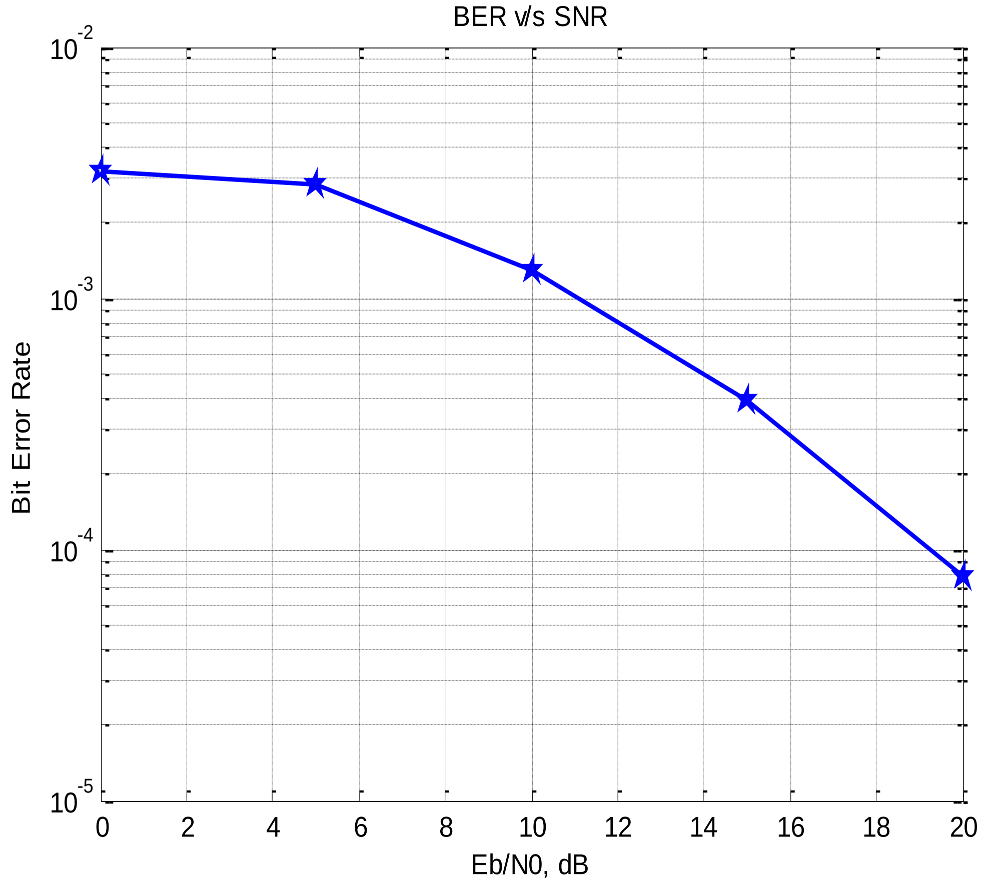

Figure28 (e): BER v/s SNR plot for 4x4 MIMO OFDM using QPSK modulation for Rician fading channel

Figure 28 (a)-(e): SNR v/s BER plots for BPSK, QPSK over Rician channel for MIMO-OFDM system employing different antenna configurations.

Table 2

Modulation used	SNR improvement for Rician channel (dB)
BPSK	4 dB at BER of $10^{-2.9}$
QPSK	6 dB at BER of 10^{-4}

From the graph b/w BER v/s SNR for the two modulations ie BPSK & QPSK over Rician fading channel, we observed that the SNR improvement for BPSK modulation is 4 dB at a BER of $10^{-2.8}$ whereas for QPSK modulation the improvement is 6 dB at a BER of 10^{-4} . We concluded that by using the proposed system ie 8x8 MIMO OFDM system the BER is reduced for the same value of SNR values compared to 4x4 and 2x2 systems.

5.6 PAPR reduction using Selected mapping Technique

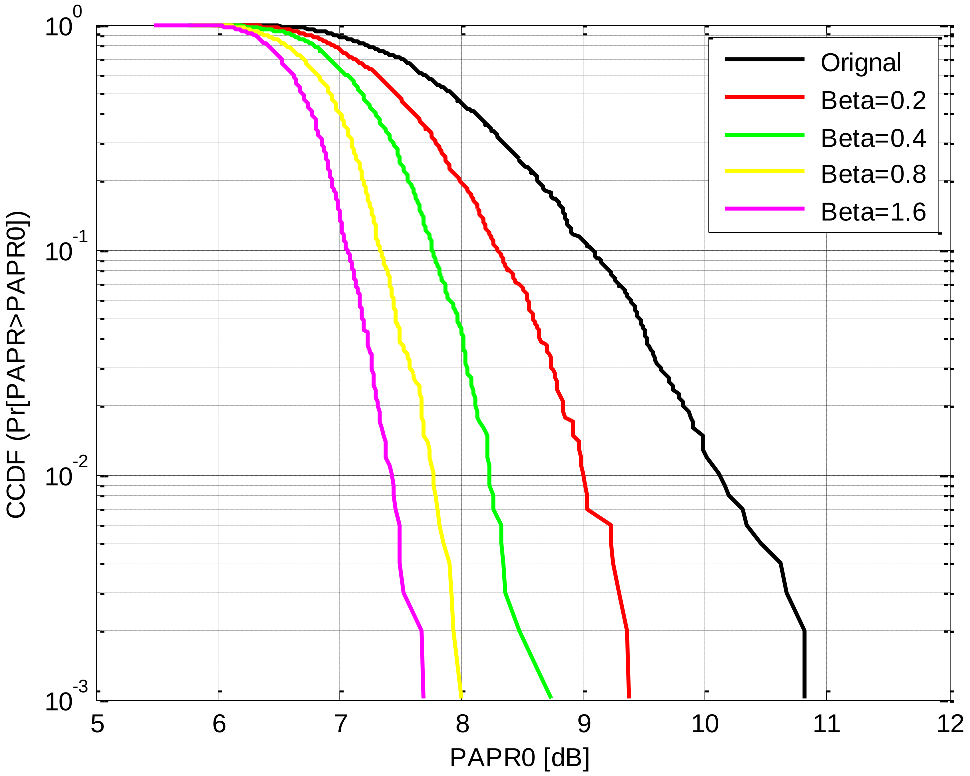

Figure 29: PAPR of 8x8 MIMO OFDM System

Fig 29 shows the PAPR of the 8x8 MIMO-OFDM system. We can see that the PAPR of the original system is shown in black colour and it is 10.7 dB. By using SLM technique the PAPR is reduced. PAPR values for different roll off factors is also shown. We conclude that as the roll off factor is increased the PAPR starts reducing. With a beta value of 1.6 the PAPR is reduced to a value 7.5 dB. So there is an improvement of 3.3 dB in PAPR. The black curve shows the original PAPR, red shows PAPR with beta=0.2, green curve shows PAPR with beta=0.4, yellow with beta= 1.4, pink with beta = 1.6. The PAPR is calculated for QPSK modulation using Rayleigh fading channel.

SLM technique can be used for any type of modulation technique. SLM method applies scrambling rotation to all sub-carriers independently. QPSK modulation technique is preferred when dealt with PAPR. The PAPR is least when calculated using QPSK modulation technique.

5.7 PAPR of OFDM system

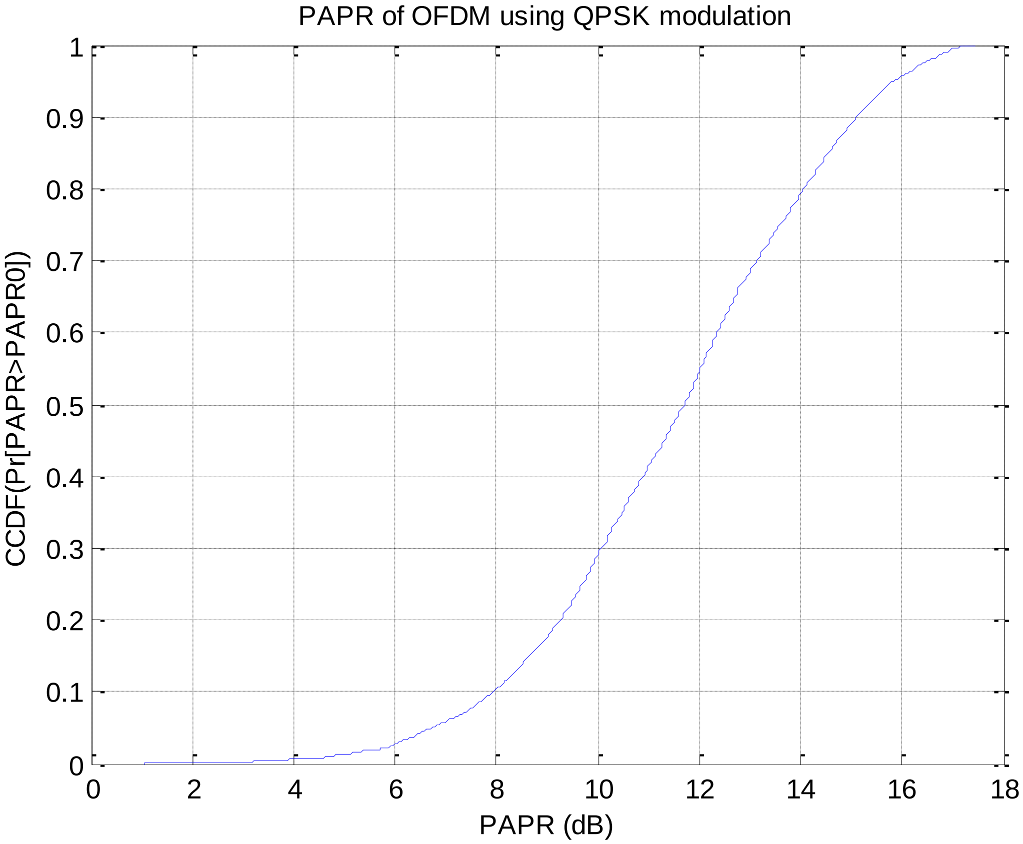

Figure 30: PAPR of OFDM System with QPSK modulation

From the Fig 30 we conclude that the PAPR of the OFDM system using QPSK modulation came out be 17 dB. But by using the 8x8 MIMO OFDM system with SLM technique, it can be reduced to a much lower value and can give approximately 9 dB improvement over the PAPR value of simple OFDM system. Both the graphs (8x8 MIMO OFDM and OFDM) were plotted with a FFT size of 128.

Chapter 6

6.1 CONCLUSION

The BER analysis of 8x8 MIMO-OFDM system for different modulation techniques using different fading channels was presented. Different antenna configurations were used for analysis. One important advantage of MIMO OFDM system is data capacity, as it combines advantages of both MIMO and OFDM.

As the number of transmitters and receivers increase, the space diversity increases. So an 8x8 antenna configuration will lower the BER at given SNR as compared to lower order Antenna configurations (4x4, 2x2). High data capacity at a given value of SNR can be achieved. The performance of the proposed system is better in terms of SNR as compared to systems with lower antenna configurations (4x4, 2x2). As seen in the results above the SNR of 8x8 MIMO-OFDM system for BPSK and QPSK modulation using Rayleigh Fading channel is 3 dB and 4 dB improved respectively compared to 4x4 system. For the Rician fading channel using BPSK and QPSK modulation the SNR is improved by 4 dB and 6 dB respectively.

One of the problems associated with OFDM systems is PAPR. PAPR of the 8x8 MIMO-OFDM system using QPSK modulation for Rayleigh fading channel came out to be 10.8 dB. This is already 6 dB less than the PAPR of OFDM system. The PAPR of 8x8 MIMO OFDM system is further reduced using SLM technique and an improvement of 9 dB is achieved. It is also seen that the PAPR decreases as the roll off factor increases. So, PAPR of proposed system is reduced to a low value of 7.5 dB using this scheme.

6.2 FUTURE WORK

In the present work, an idea about the performance of the MIMO-OFDM systems and for different antenna configurations is presented. Performance of MIMO OFDM system is analyzed under different fading channels. MIMO-OFDM system can be implemented using higher order modulations to achieve large data capacity. But there is a problem of BER (bit error rate) which increases as the order of the modulation increases. Because on increasing the order of modulation the decision region for the demodulator in the constellation diagram also decreases, as a result of this the demodulator will produce erroneous results at its output. The channel will distort the signal more severely at lower values of SNR (signal to noise ratio). These distortions will cause the shifting of the constellation points of the signal and this will cause the demodulator to produce the degraded results at its output. But as SNR is increased the effect of the distortions introduced by the channel will also goes on decreasing, as a result of this the BER will also decreases. In this way large data capacity can be achieved over the existing channels by using higher order modulations, the only thing that should be kept in mind is the extent to which we can increase the values of the SNR. Higher the SNR higher will be the data capacity.

Further this work can be extended to increase the performance of the MIMO-OFDM system by using the other channel encoder types . Also there is a chance to implement the MIMO-OFDM system by using different Modulation types. The space diversity can also be increased by using more no. of transmitting and receiving antennas. By carefully choosing the specified coding techniques available at the Transmitter, Channel or Receiver, the BER can further be reduced. The PAPR of the MIMO OFDM system can also be reduced further using coding techniques although the signal scrambling technique used in this paper is also quite effective in reducing the PAPR. As PAPR depends on the type of modulation and the number of subcarriers, so it can be reduced further by using some different permutation combination of modulation technique and subcarriers.

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