PERFORMANCE ANALYSIS OF MIMO–OFDM SYSTEM IN FADING CHANNEL USING RELAYING TECHNIQUES

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By

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DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the M.tech dissertation entitled **"PERFORMANCE ANALYSIS OF MIMO–OFDM SYSTEMS IN FADING CHANNEL USING RELAYING TECHNIQUES"** submitted at **Jaypee University of Information Technology, Wakhnaghat India,** is an authentic record of my work carried out under the guidance of **Dr. Shweta Pandit.** I have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the M.tech project dissertation entitled **"PERFORMANCE ANALYSIS OF MIMO–OFDM SYSTEMS IN FADING CHANNEL USING RELAYING TECHNIQUES"** which is being submitted by **Shivi Tikoo** in fulfilment for the award of Masters of Technology in Electronics and Communication Engineering by the Jaypee University of Information Technology, is the record of candidate's own work carried out by her under my guidance. This work is original and has not been submitted partially or fully anywhere else for any other degree or diploma.

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ABSTRACT

OFDM (orthogonal frequency division multiplexing) system is basically a large number of closely spaced orthogonal sub-carrier signals which are used to carry data on several parallel data streams or channels. In addition, the usage of multiple antennas at the transmitter and receiver side in wireless systems, is popularly known as MIMO technology. Both these technologies have rapidly gained in popularity over the last few years due to its powerful performance-enhancing abilities. Further, Rayleigh fading is one of the model which gives information about signal propagation in a radio environment. The assumption on this model is that the signal which propagates through a communication channel will vary randomly, or will subject to fading, according to a Rayleigh distribution. Rayleigh fading is basically applicable when there is no dominant propagation along a line of sight present in between the transmitter and receiver side.

In this thesis, we have tried to collaborate the advantages of both the systems i.e. MIMO system and OFDM system to work as one system namely MIMO-OFDM system. We have conducted an extensive analytical based study of MIMO-OFDM systems in MATLAB. We tried to analyze the performance of MIMO-OFDM under Rayleigh fading channel in terms of BER and spectral efficiency. Further, we analyzed different relaying techniques with MIMO-OFDM system that will exploit system advantages. These relaying techniques were namely, amplify and forward, decode and forward and hybrid relaying techniques. We have tried to compare different relaying techniques in MIMO-OFDM system in terms of BER and spectral efficiency in three different modulation schemes namely BPSK, 16-QAM and 64-QAM.

LIST OF ACRONYMS & ABBREVIATIONS

AF	Amplify and Forward
ATPT	Antenna transmit power for transmitting antenna
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BEP	Bit Error Probability
BPSK	Binary Phase Shift Keying
CP	Cyclic Prefix
CR	Cooperative Relaying
CS	Cyclic Suffix
DF	Decode and Forward
DL	Direct Link
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
FER	Frame error rate
HDAF	Hybrid Decode Amplify and Forward
HRS	Hybrid relay selection
IFFT	Inverse Fast Fourier Transform

ISI	Inter Symbol Interference
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
ML	Maximum likelihood
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RS	Relay Selection
SER	Symbol Error Rate
SIMO	Single Input Multiple Output
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
TD	Transmit Diversity
TDS	Transmit Diversity Selection
ZP	Zero Padding

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 MIMO SYSTEM

The usage of multiple number antennas at the transmitter side and at the receiver side in wireless systems, is known as MIMO which is abbreviated for multiple-i/p multiple-o/p technology, which has gained popularity over the last few years due to its magnificent performance-enhancing abilities. Laterly, for wireless communication the term "MIMO" was referred to the use of multiple antennas in the transmitter side and in the receiver side. Today, the term "MIMO" specially refers to the practical technique used for transmitting and receiving many data signal simultaneously by the same channel by the multipath propagation. The advantages of using MIMO systems are given as [1]:

(i) Spatial multiplexing gain

The term spatial multiplexing meant transmitting multiple number of independent data streams within the same bandwidth that is operational which enables MIMO to have a linear increment in data rate. The receiver can separate the data streams under suitable channel conditions, like rich environmental scattering. Further, each data stream in MIMO system due to spatial multiplexing experiences almost the same channel quality that would be experienced by a SISO system (single-input single-output system) which effectively enhances the capacity of the MIMO system by a factor of multiplication equal to the amount of data streams. Therefore in general, the data streams that are in a MIMO channel equals to the min. no. of transmitting antennas as well as the number of receiving antennas, i.e., min {M, N}. With the use of spatial multiplexing, the gain and the capacity of the wireless network is increased.

(ii) Spatial diversity gain

The signal level at the receiver side in a wireless system usually fades due to vaious reasons. Gain of spatial diversity lessen the fading and is implemented by providing receiver side with multiple number of copies of the transmit signal in frequency, space and/or time dimension which are ideally independent. The probability that atleast one copy is not experiencing any fade increases due to transmission of independent copies of signal, which thereby improves the quality and authenticity of reception of transmitted signal. Therefore the MIMO channel having M number of transmit antennas and N number of receive antennas will have M*N independent fading links, and hence achieve a spatial diversity of order MN.

(iii) Array gain

Array gain is the increment in receiver's SNR that result due to coherent merging of the signals at a receiver. Since the coherent merging may be realized through spatial processing at the antenna array of receiver.Array gain improves the capability of the system to resist noise, which thereby improves the coverage of the wireless network.

(iv) Interference avoidance and reduction

Interference in wireless N/W is due to many users sharing time as well as frequency sources. Interference can be reduced in MIMO systems by taking leverage of the dimension in space to enlarge the stretch among users. The spatial dimension can be used to combat interference, by directing the energy of the signal coming towards the particular user and thus depreciating the interference to other users. Range of a wireless network can be improved by the interference reduction.

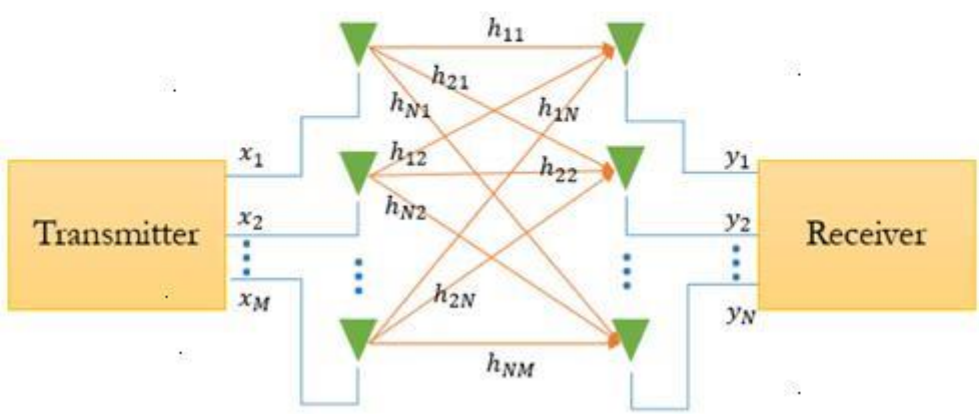


Figure 1.1: MIMO system model [2]

1.1.1 CHANNEL MATRIX FOR MIMO SYSTEM

As in Figure 1.1 the system contains M number of antennas at the transmitter side and N number of antennas at the receiver side. Here, each receiver antenna at the output side receives not only the direct signal which is intended for it, but it also receives signals from other transmitting antennas. The transmitted signals pass by means of the channel which consists of all paths between the transmit antennas at the transmitter side and receiver aspect side antennas. This system is known as the MIMO channel and the channel response is given as a transmission matrix which is also known as channel matrix H of the order of NxM

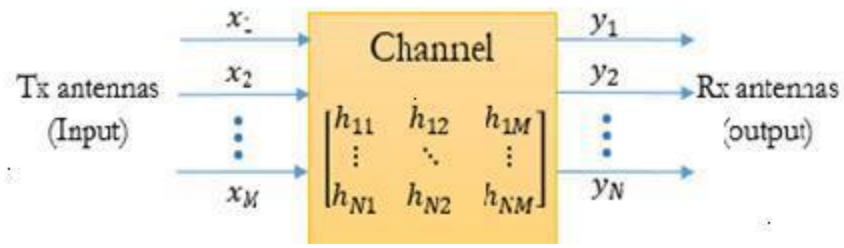


Figure 1.2: Channel matrix for MIMO systems [3]

The received vector y of the MIMO system is expressed in the form of the x input vector , channel matrix H, and noise vector n which is given by:

$$y = Hx + n.$$

1.2. OFDM SYSTEM

OFDM known as Orthogonal Frequency Division Multiplexing system is basically enormous number of orthogonal sub-carrier signals which are closely spaced, transport data on several parallel data streams or data channels[4]. Each and every sub-carrier signal is modulated by any of the modulation scheme like quaderately modulating or phase-shift keying at less data rate, thus maintaining the total data rates equivalent to the well-known single-carrier modulation schemes in the equal available bandwidth. OFDM is basically a specialized FDM where all carrier signals are orthogonal to one each other.

The major difference between FDM and OFDM is shown in Figure 1.3.

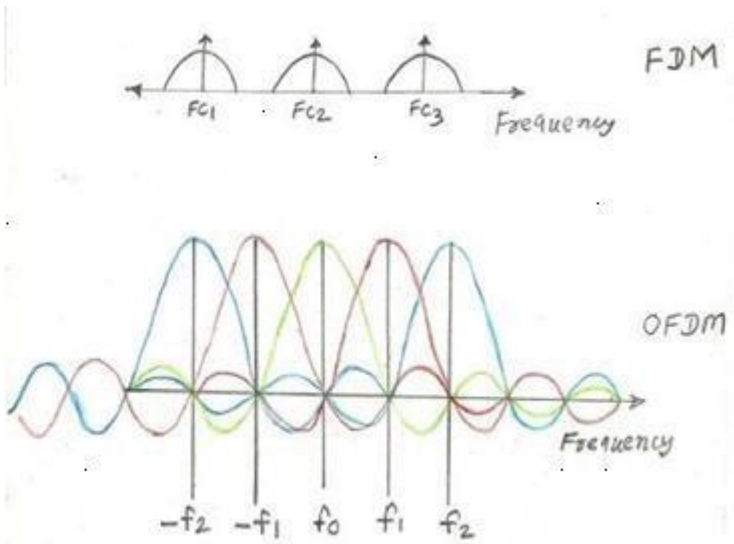


Figure 1.3: Difference between FDM and OFDM [5]

As laid out in the Figure 1.3, in FDM systems the carriers are apart from each other with respect to one another whereas in OFDM systems these carriers are tightly stuffed and also are orthogonal to the rest of the carriers [6]. Orthogonal carriers means that peak of one of the carrier occurs at zer-point of the other carrier in the system. Also, OFDM system is bandwidth efficient as compared to the FDM system. In FDM system, the carriers are not orthogonal that is why FDM is not bandwidth efficient. The signals that are proved to be orthogonal if the resulting integral of products for their fundamental and common period is zero.

The advantages of OFDM system are given as:

OFDM makes good use of the available spectrum by using the overlap phenomenon.

OFDM is very much more resilient to frequency (selective) fading than the previously used lone carrier systems which is due to by dividing the available channel into several flat fading narrowband sub-channels.

Using OFDM evict ISI and IFI by the use of a cyclic prefix.

In OFDM system there is an attractive feature that by using interleaving and channel coding we can recover the symbols that are lost due to the frequency selectivity of the given channel.

In OFDM the channel equalization computing becomes easier than the previously used single carrier system in which adaptive equalization techniques are used.

Decoding in OFDM is possible by using ML decoder with reasonable complexity.

OFDM gives profitable results in computing the modulation and demodulation functions by the use of FFT techniques.

Also OFDM provides resistance against co-channel interference.

Also, the disadvantages of OFDM system are given as:

The OFDM system generates signal with noise like amplitude which extends over a dynamic range, for which power amplifiers corresponding to RF with a high PAPR are needed.

For OFDM system high synchronism accuracy is required.

In OFDM system to keep the orthogonality unaffected the multipath propagation must be avoided.

Also in OFDM system there is a distortion problem that causes superposition of all subcarrier signals because of large peak-to-mean power ratio.

1.2.1. BLOCK DIAGRAM OF OFDM SYSTEM

A typical OFDM communication system is displayed in Figure. 1.4 and consist following blocks :

a) OFDM Transmitter: It has following blocks:

Input data block: Data comes serially from the source to the system.

Serial to parallel converter block: The serial to parallel converter takes the serial input data and gives parallel streams as the output of the converter. If there are ‘N’ number of parallel streams then they are numbered from 0 to N-1.

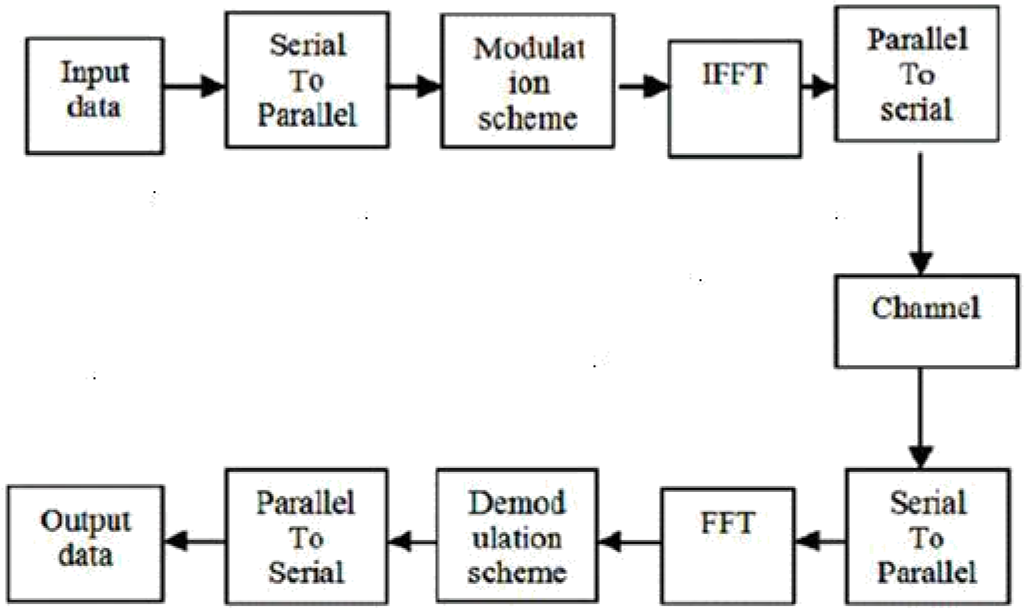
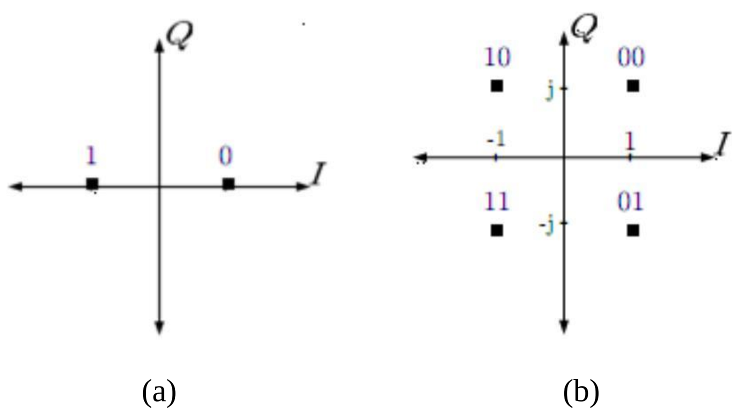
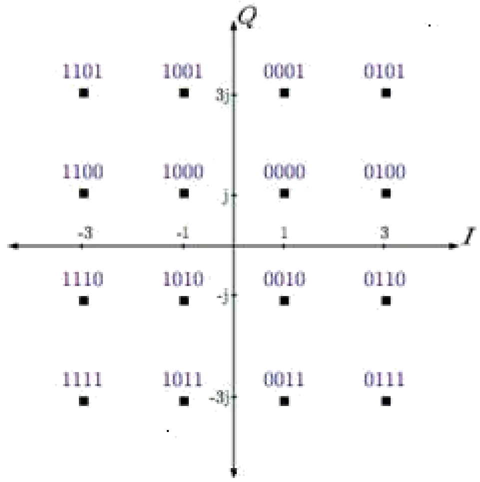


Figure 1.4: Block diagram of OFDM system [7]

Modulation scheme block: The individual parallel streams from serial to parallel converter block are translated into the required digital modulation type (e.g. BPSK, QPSK, QAM).The process of converting parallel data streams into the digitally modulated data is usually done by using a constellation mapper. The constellation mapping is implemented by the constellation diagrams which is given in Figure 1.5





(c)

Figure1.5: Constellation points [8] of (a) BPSK (b) QPSK(c) 16-QAM

(a) IFFT block: Inverse Fast Fourier Transform (IFFT) converts complex data points into the time domain of same number which is of the power of 2. The IFFT also transforms phase and amplitude of each peripheral into a time domain signal. The IFFT performs N-Point IFFT operation from the constellation Mapper for the received constellation points. Therefor,N time domain samples is the output of IFFT block. After N-point IFFT, these are converted to parallel form through parallel to serial converter.

(b) **Channel:** The channel can be assumed to be AWGN, Rayleigh or Rician channel according to the environment in which communication system is operating.

(c) **Receiver:** It has following blocks:

Channel block: The channel is chosen to be AWGN channel, Rician channel or Rayleigh channel according to the requirement.

Serial to parallel converter block: This block basically converts the serially received data streams from the OFDM Transmitter into parallel data streams. The output now is in time domain. These parallel symbols are now again to be converted to frequency domain.

FFT block: Fast Fourier Transform block changes time domain data to frequency domain data. FFT block performs the N-point operation to the parallel data which converts the time domain parallel data to frequency domain parallel data.

Demodulation or demapper block: This demapper block is used to convert complexed valued constellations data points to symbols.

Parallel to serial convertor block: The function of this block is to convert the symbols back to serial form.

1.2.2 REDUCTION OF ISI IN OFDM

The utmost property of OFDM transmission is its evincing strength to work against delay spread of multipath constituents. This robustness is achieved by the OFDM signal by possessing a expanded symbol period i.e. prolonged than an identical single carrier transmission period, which in turn miniaturize the ISI. Inclusion of a guard period in transmitted OFDM symbols can increase the level of robustness of the system. The guard period addition in the symbol acquiesce time for multipath signals from the later OFDM symbol to loose strength prior to the information gathered from the current OFDM symbol. There are two most effective ways to add guard period. One of which is to use a cyclic supplement of the symbol (CP; CS) and other is to use zero padding and are described in detail further.

(a) Cyclic prefix: CP extends the OFDM symbol by replicating the end bits of the OFDM symbol into its forepart. Let N signifies the length of samples in CP. Then, the extended OFDM symbols now have the period of $T_{sym} = T_{sub} + N$ where T_{sym} is total length of symbol and T_{sub} is OFDM symbol original length. There is the condition for adding the CP to combat ISI which is if the length of CP is kept fewer than the max. delay spread of a multipath channel, then the end part of an OFDM symbol will affect the head part of the next OFDM symbol, resulting in the ISI. Therefore, the length of CP should always be more than the length of delay spread.

(b) Cyclic suffix: It is same as CP but with one difference that CS is replica of the forepart of an OFDM symbol, and it is added at the limiting end of the symbol.

(c) Zero padding: Another technique to combat ISI is implemented by addition of zeroes in the guard interval. Since in zero padding the guard interval is stuffed with zeros which implies that the OFDM symbol’s length with zero padding is smaller than the length of OFDM symbol with CP or the length of OFDM symbol with CS.

All these three techniques help in reducing the ISI effect.

1.3. MIMO-OFDM SYSTEM

All wireless systems are affected by three common but major problems namely speed, reliability and range. These parameters are interconnected to each other by rigorous rules. Speed could have high values only by having low values for range and reliability. Reliability can be improved by leveraging speed and range and finally range could be extended at the expense of speed and reliability. Thus MIMO-OFDM [9] is a system which provides the speed, range and reliability in ‘all in one package’.

It can be seen that with OFDM, a single wideband symbol within a spectrum band can be divided into multiple and smaller sub-signals that transmit signal information simultaneously without any kind of interference. Since MIMO technology is capable of linking together many smaller antennas to work as one unit, therefore it can receive and send these multiple OFDM sub-signals in such a way that allows the bandwidth to be substantially increased for each user as per the requirement.

OFDM is the technique used to combat the multipath propagation problem and MIMO is used for the efficient usage of available spectral bandwidth thus combining these two techniques results in the wireless system which has the most spectral coverage, reliable transmission in any obstructive environment, and high data rates which are in hundreds of megabits.

MIMO uses the spatial diversity whereas OFDM uses either FDD or TDD multiplexing techniques. MIMO systems will provide greater capacity in the spatial domain. Inter-symbol interference (ISI) can be eliminated by the equalization process of the OFDM modulation method in time domain. The combination of MIMO and OFDM helped in maintaining greater channel capacities which could be realized with evincing strength to channel impairments like multipath fading and ISI through CP.

OFDM creates the slow time varying narrowband channel streams and MIMO has capability of transmitting these narrowband signals over multiple channels by making the use of antenna arrays thus the resulting combination of OFDM system & MIMO system can generate important and beneficial results. OFDM signals have an adverse effect of the presence of objects, while on the other hand the MIMO system takes the advantage of number of objects from multipath propagation. So the concept basically is to generate the narrowband OFDM signals and subject them to number of MIMO antennas.

1.4. RELAY NETWORK

A relay network shown in Figure 1.7.is defined as a broad class of network topology which is commonly used in wireless networks. Basically in a relay network the source and destination are connected by means of some nodes popularly known as relay nodes. This relay network is used where the source side and destination side cannot directly interface with each other because of the distance between them. Here the distance between the source node and the destination node is greater than the transmission range of each of them, so because of this there is the need for intermediate nodes to relay [10].

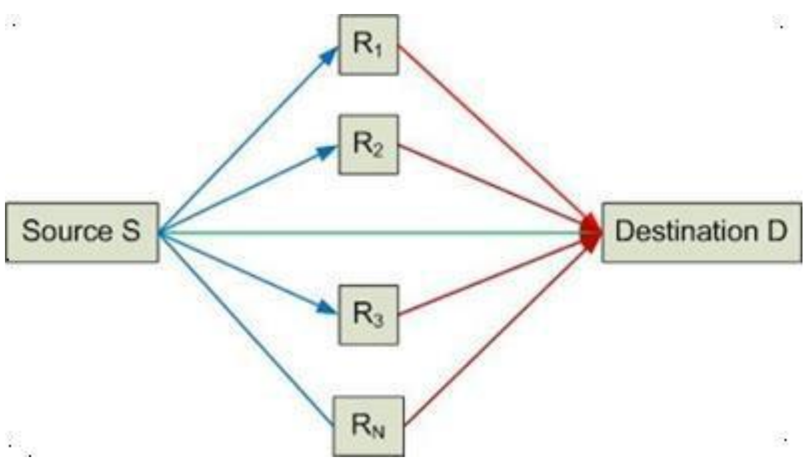


Figure 1.6: Relay network [11]

For improving the quality of wireless communications relayed transmission is a promising technique.Advantages of relay network in a wireless system [12] over direct link wireless communication are as follows:

Increased connectivity: For N number of relay nodes there are (N-1) number of connections between source nodes and destination nodes whereas in direct link communication only one direct link is available. Thus relay network gives better connectivity than direct link communication.

Improve reliability: As there are (N-1) number of links in the relay network then the probability of receiving error free signal increases which in turn increases the reliability of relay networks.

Good scalability: In relay network number of relays can be increased or decreased according to the system requirement which is not be able to be done in direct link communication.

Increase the throughput: According to the Friis Transmission formula the power received is inversely proportional to the distance between them. Since the gap between source node and destination node is greater than the distance between the source and relay node or between destination and relay node, the power received by relay nodes (in case of source and relay or between destination and relay) are greater than the power received by destination node (in case of source node and destination node).This leads to increase throughput in relay network as compared to direct link communication.

Extended transmission range: As relay nodes are placed in between source and destination node, the transmission range of the relay networks is very much greater than the direct wireless transmission.

The different methods by which the relay networks are implemented are known as relaying techniques. They are:

i. Amplify and Forward: The AF relay node amplifies the recepient signal from the source side node and transmits it to the destination side node. The recipient signal from the source node includes the desired signal as well the added noise as well.

   This technique is very much difficult to be implemented in TDMA systems as this requires massive measur of analog data to be stored.

   AF suffers from the problem that degrades the signal quality speacially at low SNR due to noise amplification.

ii. Decode and Forward: The two types of decode and forward realy techniques:

- Fixed Decode and forward: In this fixed decode and forward technique, the relay node firstly reduces the noise by translating the received signals with the help of decoder and then regenerates and again re-encodes the signal to be supplied to the destination. DF endure from problem of the error which can occur if the relay is able to detect a message incorrectly and forwards this erroneous information to the destination node. This causes problem.

- Adaptive Decode-and-forward: In adaptive DF the relay node dispatches the signal to the destination side only if it has the capability to decode the signal correctly. If it is not able to decode the signal correctly it will not send the code to the destination as it will discard it. The correct decoding of the data can be monitored using any of the many error detection check algorithm or SNR threshold.

  If the relay detects but able to decode then this scheme is called detect-and-forward.

iii. Hybrid AF and DF: In hybrid AF and DF case the relay node switches between AF and DF depending on the channel conditions.

iv. Demodulate-and-forward: In this case the received signal is demodulated i.e. it doesn’t detect the recipient signal and forwards the resultant signal to the destination node.

v. Best Relay Selection: Best relay selection improves the resource utilization in terms of relay nodes. For this, the best relay is selected to forward the signal from the source to the destination.

These different relay techniques will be discussed in detail in the next section.

1.4.1. AMPLIFY AND FORWARD RELAY TECHNIQUE

The amplify and forward relay technique just amplifies the received signal from the source node and transmits it to destination node. The received signal from the source node includes the desired signal as well the added noise as well. This technique is difficult to be implemented with the help of TDMA systems as this requires large amount of analog data to be stored.AF suffers from the problem which can lower down the signal quality, notably at minimum SNR value which is noise amplification.

AF as compared to other relaying techniques require much less delay as the relay node operates according to the time-slot that is one time-slot at a time. As in AF there is no requirement of decoding or quantizing operation as compared to other relaying techniques so AF requires much less computing power and low symbol error rate [13].

For cooperative communication system, AF relaying technique bring spatial diversity technique to combat fading and for estimating capacity of the relay network, such relaying technique provide desirable low bounds that are best in some communication systems. These relay schemes provides a strategy that is able to achieve high production with less complexity in calculation at the given relay nodes for analog coding network which has the telecasting nature of the wireless channel that permit the mixing of the signals in the air.

1.4.2 DECODE AND FORWARD RELAY TECHNIQUE

In this fixed decode and forward technique, the relay node firstly abolishes the noise by decoding the received data signals and then regenerates and again re-encodes the signal which is to be forwarded to the destination [14]. DF undergoes the error propagation problem which can occur if the relay decodes the message incorrectly and then forwards this erroneous information to the destination nodule.

This formation of the signal at the relay has to make hard decisions as the data information sent by the relay will not be including any additional data information about the source-relay link reliability [15]. In this relaying technique when uncoded data modulation is used then it is known as Detect and Forward relaying technique.

Decode and forward is straight forward decoder but there is a problem with this relaying technique that the decoding operation at the destination node is not simple. The optimal detection at the receiver end is done by the use of detectors [16]. Since ML detector is the optimal detector but for higher order type modulation it becomes complicated. Thus regress analysis is done to find a detector which is suitable for relay detection of signal in this technique. We are using Reed Solomon encoder and decoder in this thesis which is explained in further section. It can be seen from the hard decision making rule, that the destination needs to know about the channel state information only for the Relay to Destination links and Source to Destination links.

The overall system performance is affected by the quality of the decision made at the relay node. At the destination side the quality of the decision at the relay for the DF technique is not taken into cogitation on the destination side which means in simple words that no information data about source to relay is to be required at destination node. Performance of the system can be deteriorated by this property of DF. For example, in case for a not so good source and the relay channel, lot of the wrong decisions can be made at the relay node. Also the destination cannot be able to inform about the preciseness of the signal by the relay node even if the source and relay link is strong enough.

The advantage of the relaying technique DF is not much affected by the noise propagation as in other relaying techniques and gives best comparable performance timeliness or scalability. DF relay network can be used to extend general relay network in order to achieve the capacity even if the channel is degraded physically. Since it is not an ideal system, there are two main reasons that reduces the potential of this technique. First reason being the decoding of the full data transmitted from the source to all the relay nodes is often very much harsh. Second reason being that during the transmission of multiple number of messages it is not clear that how the message should be forwarded as in which relay node must be allocated to forward the message signal. Unlike AF, the DF does not allow the noise amplification. In addition, with reference to encoding, Reed Solomon Encoder has been discussed further.

Reed–Solomon codes: These are from error-correcting codes group . They find their application in satellite communication also. Basically in the coding theory, this Reed–Solomon code is the member to the category of cyclic error-correcting codes for non-binary. Theoretically it is proved that Redd Solomon code is able to detect and correct multiple number of symbol errors. Let us say that by adding ’t’ number of check bits to the data transmitted, by the use of Reed–Solomon code any coalition of up to t wrong valued symbols can be detected, and up to $t/2$ symbols can be corrected. Being as an error correcting code of up to t known errors can be corrected, or combinations of erasures and errors can be detected and corrected [17]. Further, Reed–Solomon codes mainly eare suitable for multiple number of burst bit error correcting codes, since with a trail of b+ 1 number of successive errors of two symbols of size b can affected. The value of *t* is chosen by the code designer that is chosen within the limits.

The Reed Solomon code is basically from the code family, where every code is generalized by three parameters which are block length *n*, alphabet size *q* and *k* message length, with condition where $k < n \leq q$. The condition with these symbols is that it would be deciphered as the finite field *q* order, and thus, for which *q* has to be a prime power. For characterizations of the Reed–Solomon code, length of block is usually preferred to be some invariant multiplative factor of the message length, which implies that the rate $R = k/n$ is some constant, and also the block length is given as to be equal to or one minus than the given alphabet size, which is, $n = q$ or $n = q - 1$

In Reed Solomon code, let that the encoder takes *k* information symbols each of *s* bits and adds the given parity bits to make an *n* symbol data codeword. Now there are difference of n and k number of parity symbols of 's' bits each. Also t symbols can be corrected by a Reed Solomon decoder that contain some bits in errors in the codeword, for which $2t = n-k$.

The diagram given below shows Reed-Solomon data codeword. This is the systematic code because here the data is left as it is and only the parity bits or symbols are adjoined.

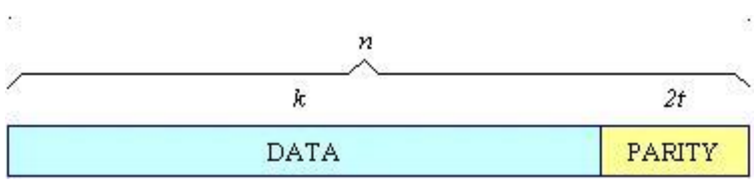


Figure1.7: Schematic of Reed Solomon codeword [18]

1.4.3. HYBRID RELAYING TECHNIQUE

In hybrid DF and AF case the relay node swaps between AF and DF depending on the channel status. Since there a lot of problems associated with AF and DF therefore to combat this problem HDAF technique [19] was proposed in order to refine the amplification of noise in the AF technique and the error generation process in DF technique. In order to improve the system performance this HDAF relay switches in between the DF and the AF techniques in a manner corresponding unlike channel conditions. Other technique known as incremental HDAF was proposed in [20] to enhance the spectral efficiency of the previously discussed HDAF method. In this incremental relay, the relay may decide whether to keep the messages silent messages or transmit them in the either DF or the AF mode. This decision is entirely based on the channels conditions among the source nodes, the relays and the destination nodes. It is researched that the BER and the outage probability are improved majorly when HDAF is compared with other the fixed relaying techniques.

1.5. RAYLEIGH CHANNEL

Rayleigh fading is one of the model of signal propagation in a radio environment which is often used by the wireless devices. The assumption on which Rayleigh fading models work is that the signal which considerable magnitude propagates through such a communication channel also known as transmission medium will vary randomly, or will subject to fading, according to Rayleigh distribution which is nothing but sum of two uncorrelated Gaussian random variable's radial component.[21].

Rayleigh fading is basically used when there is none dominant propagation of signal along a line of sight present in between a transmitter side and receiver side. There is another fading known as Rician fading which is applicable when there is a dominant line of sight present. Also it can be said that Rayleigh fading is a model used when the environment is occupied with many objects that would scatter the radio signal very much before it arrives at the receiver. It is known that the Rayleigh fading is basically a small-scale fading effect. There are some adverse effects of the environment termed as shadowing and path loss onto which the fading is superimposed.

Rayleigh fading is just the phenomenon but the amount by which the channel fades is dependent upon the motion of the receiver or the transmitter. Motion of the receiver or the transmitter is caused by the Doppler shift present in the received signal components.

The probability distribution function (pdf) of Rayleigh distribution[k] is given as:

$$() = \{ 2 \quad \frac{-\,^{2}}{} \; .\,_{2}{}^{2}, \quad 0 \le \; < \infty \qquad 0, \quad \ge 0$$

Where = RMS value of received voltage signal
^{2}= time average power of received signal

The cumulative distribution function of Rayleigh distribution is given as:

$$F(X) = F_x\,(x \leq X) = 1- \frac{-\ ^2}{_{2\ 2}} \qquad \text{for } X>0$$

The corresponding Rayleigh pdf is given as in Figure:

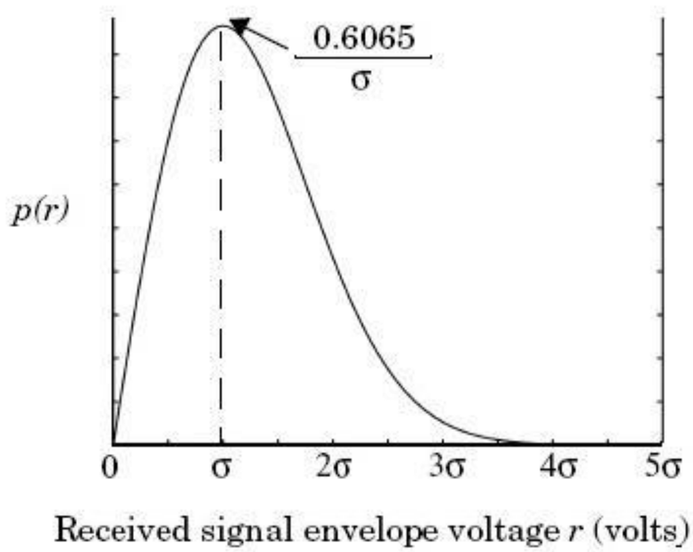


Figure 1.8: Rayleigh probability distribution function [21]

CHAPTER 2

MOTIVATION AND RELATED WORK

MIMO-OFDM system as a whole is the dominant communication link between wireless communication devices and is also used in 4G and 5G communication. MIMO-OFDM is basically defined as transmission of OFDM signal via number of antennas in order to achieve higher transmission rate and diversity [22]. Like all other communication systems the MIMO-OFDM system has transmitter side and also receiver side, but the basic difference is that it has multiple antennas both at transmitter and receiver end. Since MIMO system has number of advantages thus it can be executed in various ways. Taking diversity as the main advantage of MIMO to combat fading then there would be the need of sending the same data signals through several MIMO antennas and all the data signals would be received by MIMO antennas which traveled from various path. For this case all the received data signal must propagate through various uncorrelated channels. Now taking capacity increment as the main advantage then we can send different data signals through a number of various antennas and will be able to receive the data signal from the same number of antennas in the receiving end. Accordingly for the MIMO systems to be efficient the antenna spacing has to be done carefully which is at least half of the wavelength of the transmitting signal. The advantages of MIMO-OFDM system are given as:

Less interference as compared to OFDM system(ICI)

Diversity gain is increased as number of antenna is increased over SISO system

Increase data capacity is provided in comparison to single channel communication link

Power efficiency is also increased

Bandwidth gain is increased in the same available bandwidth of simple OFDM system. Some of the limitations of MIMO-OFDM are given as:

Antenna spacing between MIMO antennas at transmitter side as well as receiver side must be proper depending on the type of channels namely Rayleigh channel or Rician channel or AWGN channel

Due to collaboration of two systems, the resulting MIMO-OFDM has very complex transmitter and receiver block.

Some esteemed authors and publishers have discussed and proposed some methods to enhance different characteristic of MIMO-OFDM system which is discussed below section.

2.1 RELATED WORK

The authors in paper [23] discussed that OFDM is basically an enhanced version of FDM scheme in terms of orthogonality. This paper aimed at analysing BER performance characteristics of the MIMO-OFDM system over AWGN Channel, Rayleigh Fading Channel along with various modulation technique. Also the analysis result of this paper suggested some of the important methods for the better way in order to improve the BER characteristic of the MIMO-OFDM system as a whole.

The methods were adding any of CS, CP, zero padding in the time domain of the OFDM signal. Adding cyclic prefix means adding a part of the OFDM signal is in the front, this part is basically the 25% of the original OFDM signal. The resulting OFDM signal is supposed to prevent ISI in the OFDM signal. Similarly adding the cyclic suffix means addition of the front part of the OFDM signal at the back of OFDM signal. Also in the case of zero padding, zeros are added in the OFDM signal.

The performance of the system was enhanced to a great extent on acceptable worth of guard period with agreeable modulated technique. Also the results that were analyzed gave the fact that the in presence of guard period QPSK is most suited of modulation technique for MIMO OFDM system. In [23] the BER evaluation of MIMO-OFDM was discussed whereas in [24] paper presented the capacity performance characteristic of multiple antennas system for wireless communication. Since SIMO, MISO and MIMO systems are the different type of multiple antenna system. The outcome of this paper showed that while making an increment in the number of transmitting antennas and receiving antennas for a MIMO channel definitely improves the capacity of the channel. In [24] paper, the results concluded that there is a direct relation among number of antennas and capacity of antennas which means the capacity of the system is increased by increasing the number of transmitting and receive antennas in MIMO channel.

The objective of paper [25] was to demonstrate the performance of OFDM system by varying some of its important and major characteristics. This was done in order to easily investigate that on which factor OFDM system mainly depends. In order to combat the inter-symbol interference (ISI) the symbol period must be kept much greater than the delay spread. It is also known that since data rate is inversely proportional to symbol period, which means the symbol having long time period will have low data rate and will also suffer to inefficiency. The orthogonal multi carrier communication known as OFDM can solve both the problems. Spectral efficiency and SNR were two parameters on which OFDM signal performance analysis was done .In [25] paper, there was comparison between different modulation techniques Vs BER and BER Vs SNR. It was concluded that in OFDM, the SNR and BER have inverse proportionality relation. It was also simulated that as the PSK order increases correspondingly the BER increases.

The aim of paper [26] was to present an idea of an OFDM system and its main structure and therefore analyze the obtained results of the simulations testing. The OFDM system has the ability to support various M-QAM modulating schemes. Also [26] paper aimed to review the impact of the completely varied designing parameters on the OFDM systems with various digitally modulating schemes.

There were 3 attempts for that; within the 1st attempt the dynamical of FFT or IFFT length with fastened SNR had been studied, within the 2nd experimentation the variation of the SNR with fastened FFT/IFFT length had been mentioned, and within the 3rd experiment the result of the various values of the SNR on scatter plot at the detector had been given. The final results of the experimentation were that the optimal FFT\IFFT length was 1024 points and therefore the best worth for the SNR was 60dB; and it absolutely was discovered that once this value there was no impact of varied the SNR worth. Later in [26] the comparison betwixt different OFDM systems was discussed and it was observed that the best suited system is the OFDM system with 64-QAM for max and min ,SNR and BER resp.

The aim of the paper [27] was to convey a plan of what's associate OFDM system and its schematic and also the analyzation of the results from simulations and investigation however its performance is modified by varied a number of its major parameters which were no. of carriers, M-PSK, SNR worth, IFFT size. The objective of the paper was met by MATLAB program in order to simulate a basic OFDM system in an AWGN channel. In paper [27], the demodulated information is compared to the initial baseband information to find the entire variety of errors. BER is calculated by distinguishing the total no. of errors in the symbol by total number of demodulated symbols.

It was concluded that in OFDM system, the number of carriers was entirely dependent on IFFT size and by this higher data transmission rate was achieved. The higher order of PSK led to large symbol size due to which fewer number of symbols were in need to be transmitted and best suited data rate was achieved and conjointly for a higher value of modulation, the PSK modulation is optimum for OFDM.

A decode-and-forward relaying theme is wherever an N_T antenna supply was assisted by many N_T antenna relays to forward its data to a N_D antenna destination was mentioned in [28]. Its SER and ATPT were derived and validated by simulations done in MATLAB. In DF relay technique, each relay node decode the information from the source side then re-encodes it, and then forwards it to the final destination side. The affect of relays quantity on the SER performance had been observed for distinctive modulation technique namely, 16 QAM, 8 PSK, BPSK, QPSK and for N_T=N_D=2. The SER versus PDT/N0 which implied the ratio of the average transmission power per transmit antenna in a time-slot to noise power for QPSK, and16QAM and (no. of relay) R=8 and 4. It was observed that for the same modulation, the SER characteristic of the considered transmission schemes had been significantly reduced with increment of R. The CR with DL achieved a SNR gain of more than 2.3dB and 1dB over direct transmission and the CR without DL. This paper [28] analyzed the performance of co-operative MIMO systems in terms of two parameters namely SER and ATPT of antenna. With the help of theoretical and simulated results the prevalence of the cooperative relaying with the DL over transmission mechanism and the co-operative relaying in absence of DL for any position of relay, modulation level, SNR, the amount of transmit/receive antennas, and for various relay node was presented. The paper [29] gives information about the performance of cooperative-diversity networks using decode-and-forward relays Rayleigh fading channels with incremental relaying

It was discussed before that since co-operative-diversity N/W make use of the near by nodes to aiding the source by forwarding the source info to the destination for spatial diversity achievement. Regular co-op-diversity networks create associate degree incompetent use of the channel resources as a result of relays forward the supply signal to the destination each time notwithstanding the channel conditions. In Incremental relaying with cooperative diversity was mainly projected for, to save lots of the channel resources by limiting the relaying method to the unhealthy channel conditions solely. Progressive relaying with cooperative relaying networks exploit the restricted feed-back from the destination node that is one bit indicates success or indicate failure of the transmission mechanism. If this destination node gives a negative acknwledgment by feedback; during this case solely, the relay re-transmits in an endeavor to use spatial diversity by adjoining the signals which the destination received from the supply and therefore also from the relay. The results of [29] showed that progressive relaying technique is able to do vital spatial diversity with a high outturn compared with regular coo-perative diversity. Results showed that the outturn and error performance were extremely keen about the error threshold utilized at the destination (the worth of this threshold depends on the appliance used at the destination). Moreover, it had been conjointly seen that progressive relying has high outturn like that of transmission mechanism significantly above SNR.

In [30] a brand new hybrid relay choice protocol was planned. The distinction of this work compared with exploitation DF solely or AF solely, is that the use of DF and AF relays along and therefore the exploitation of the merits of each.

The main plan of this method was that each and every relay was enclosed into either AF or DF relay cluster then 2 relays among the teams were elected by achieving most SNR at the destination. The primary one was the simplest relay from AF cluster and also the second was the simplest relay from DF cluster.

The BEP results showed that the performa of the planned technique was superior to alternative schemes (only DF or solely AF). it had been finished that increasing the quantity of relays in every cluster, leads to augmented performance of the system with hybrid relay choice protocol. In [31] paper, the MIMO-OFDM system transmits one signal with TD at the moment relay side is completed use of DF protocol and AF protocol and signal is transferred towards receiver.

Four major facet of the planned algos were analyzed that showed their benefits over the existing strategies. The four areas covered were procedural complexness, diversity gain, and feedback necessities. There had been substantial quality savings due to the utilization of the planned algo over the thoroughgoing solutions; these were savings that increased with the quantity of relays and the antenna components in total within the system. The 2nd feature of importance is the saving which was made up of introducing RS into optimum thoroughgoing and planned strategies. These savings conjointly provide increase with system size and make sure that those created by RS might exceed the value of its implementation. A serious advantage is their low feedback needs. No precoding is needed at the transmittal nodules, TDS solely operates, and every one receptions are at the receiving nodes solely need domestically accessible CSI. Subsequently, solely the feedback of given TD choices to the relays is needed.

The method of TDS and RS confines the amount of transmit methods used and so lowers only the utmost advantage which is diversity. However, it permits the less complexness MMSE-based techniques to extend their profiteering of the variety at an SNR by removing ways that bring very little or none advantages to the co-operative transmissions. It absolutely was verified during this paper that MIMO OFDM is best than standard system while not TDS.

In this paper [32] it absolutely was projected that underneath joint optimisation of channel in OFDM and relay together with sub carrier paring and allocation of relay choice to maximise the output and optimize the combinatory error by constructively perceptive the results of against power, relay nodes and SNR of cooperative and orthogonal OFDM systems. Conjointly exploitation Rayleigh attenuation channel the noise was reduced and obtained the SNR as an improved high SNR. Further, MIMO-OFDM with multiple relays were value-added for rising the performance of the system and decreasing error transmission rate.

The channels of operation were of 3 modes particularly simplex, full duplex and half duplex. The relaying schemes used were decode and forward, amplify and forward and compress and forward. It was discovered that amplify-and-forward and the chosen type decode-and-forward have a similar high SNR performance. Once the relay cannot absolutely rewrite the supply message and also the supply repeats, i.e., the outage event of amplify-and-forward is neither a set nor a superset of the outage event for chosen decode-and-forward.

2.2 OBJECTIVE OF THESIS WORK

In this thesis, we have tried to conduct an extensive analytical based study of MIMO-OFDM systems. We have tried to analyze the characteristics of performance of MIMO-OFDM under disparate fading channel that were Rayleigh fading channels and AWGN channel in terms of spectral efficiency and BER. We also tried propose different relaying techniques that will exploit MIMO-OFDM system advantages. The relaying techniques were named as amplify and forward, decode and forward and hybrid relaying technique. The main objective was to compare the performance characteristics of MIMO OFDM system with different relaying technique under different modulation techniques which were BPSK, 16 QAM and 64QAM.

CHAPTER 3

IMPLEMENTATION OF MIMO-OFDM SYSTEM

3.1 INTRODUCTION

Firstly we tried to collaborate the MIMO-OFDM system in AWGN channel. As AWGN is the abbreviation of Additive White Gaussian Noise, each part of the abbreviation is self-explanatory and gives a unique meaning to this fading channel. Each constituent is explained as:

- Additive term refers to the fact that it can be added to any noise which is inherent from the information system.
- White refers to the concept which illustrates that it has equal amount of power among the band of frequencies for the data system. Alikeness to the white color that has uniform emission for all frequencies within the color spectrum.
- Gaussian as a result of it's a time domain normal distribution with a mean time domain worth of zero value.

The AWGN Channel block in the MIMO system in which white Gaussian noise is added to complex or real valued input signal. When i/p signal is real or non-complex, then this block adds real. Gaussian noise to it and outputs a real valued output signal similar to input signal. When the complex valued input signal is used, then this AWGN block will add the complex Gaussian noise and will produce a complex output signal as that for complex input signal

AWGN channel as discussed earlier in this section is a channel that adds a white Gaussian noise to the signal propagating through it. This conforms that the channel has flat amplitude frequency response irrespective of the unlimited or infinite bandwidth. Since all the frequencies have linear phase frequency response so all the modulated signals that will pass through it will have neither the amplitude loss nor the phase distortion of frequency components. With channel as AWGN the phenomenon of fading will not exist. The sole problem introduced by the AWGN is distortion.

As discussed in section 1.1 the output of MIMO system is given as:

$$y=hx+n$$

Where, y= received vector; h= channel matrix; x= transmitted vector; n= noise vector This is a general expression for MIMO antenna system.

When MIMO system is subjected to AWGN channel, then the received vector would be like

$$y=x+n$$

As explained earlier the AWGN channel will only distort the signal keeping the frequency and the phase components unchanged. For this channel, the channel matrix 'h' is unity.

This chapter is divided into four sections. Section 3.1 gave the introduction about the implementation of MIMO-OFDM system, section 3.2 illustrated about the system model, some idea about the analytics of different components in the system model will be given section 3.3 and finally the section 3.4 will help in understanding the implementation of MIMO-OFDM system in a better way with MATLAB simulation outputs.

3.2 SYSTEM MODEL

The system model for the MIMO-OFDM system is given as:

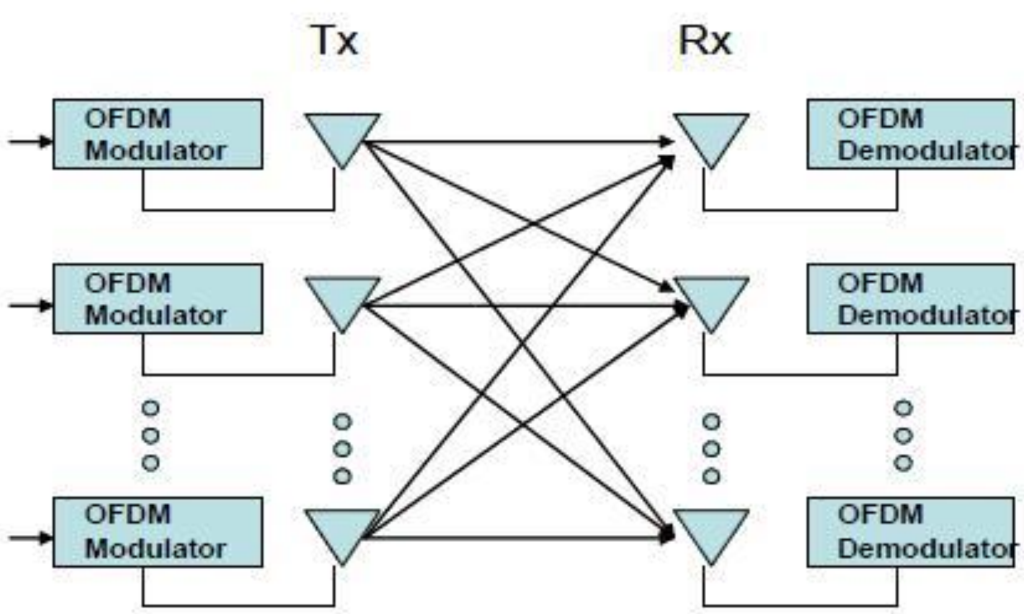


Figure 3.1: MIMO-OFDM system model [33]

This Figure 3.1 gives the diagrammatical representation of MIMO-OFDM system. This Figure explains how the MIMO system is embedded with the OFDM system.

The OFDM block diagram shown in Figure 1.4 has the ‘channel block’ in it which is usually meant for direct communication link which is SISO system. Using MIMO system in the OFDM system makes the system complex but also provides more advantages. The advantages are less interference as compared to OFDM system (ICI); Diversity gain is increased as number of antenna is increased over SISO system; Increase data capacity is provided in comparison to single channel communication link; Power efficiency is also increased; Bandwidth gain is increased in the same available bandwidth of simple OFDM system.

3.3 ANALYTICAL APPROACH

After the qualitative description of the system model, it's valuable to debate the mathematical translation of the modulation system. This enables us to visualize how the signal is generated and the way receiver should operate, and it provides us a tool to know the results of imperfections within the channel. As noted earlier, OFDM transmits an outsized range of narrow band carriers, closely spaced within the frequency domain. So as to evade an outsized range of filters and modulators at the transmitter side and also the demodulators and filters at the receiver side, it's desirable to use trendy digital signal process techniques, like quick FFT.

The key feature of OFDM over FDM is its orthogonality. The sub-carriers during this system[34] are of the form $\frac{}{}^{2}$ where k = 0, 1,…,N − 1. These sub-carriers in OFDM are orthogonal i.e. they will not interfere with one another. The orthogonality is tested by the given formula:

$$\frac{1}{} \int_{0} 2 \quad -2 \quad = \{^{1}_{0} \qquad =_{h} \tag{1}$$

The above orthogonality condition is an essential precondition for the OFDM signal to be free ICI..

OFDM transmitter plans the message bits into a series of PSK or QAM symbols that is completed by the constellation mapper and can be afterwards regenerate into N parallel streams. Every of N symbols from S/P conversion is administered by the various subcarrier.

Let Xl[k] denote the lth transmit symbol which isl at the kth subcarrier, l = 0, 1, 2,…, ∞ and k = 0,1, 2,…,N-1. Due to the parallel transformation, the span of transmission time for N symbols is extended to NTs, which will form a single OFDM symbol with length of Tsym (i.e., Tsym = NTs). Let Ψl.k(t) denote the lth OFDM signal at the kth subcarrier, and would be like :

$$\Psi l.k(t)= \{ \quad {}^{2\,(-\ )} \quad ,0< < \qquad 0 \quad . \tag{2}$$

Inverse Fast Fourier Transform (IFFT) converts a number of complex data points into the same number of points in time domain which is of the power of 2. The IFFT also transforms amplitude and phase of each component into a time domain signal. The IFFT performs N-Point IFFT transformation for the received constellation points from the constellation map of signal. The IFFT o/p is of N samples in time domain. After computating N-point IFFT these values were transformed to parallel form through parallel to serial convertor.

The formula for IFFT is given by:

$$X(n)=\sum_{=0}^{-1} (\ )\sin(\ \frac{2}{\ }) - \sum_{=0}^{-1} (\ )\cos(\ \frac{2}{\ }) \tag{3}$$

After IFFT, the serially received data streams from the OFDM Transmitter is converted into parallel data streams. The output now is in time domain. The IFFT conversion is followed by the guard period insertion which may be cyclic prefix, cyclic suffix or zero padding.

The guard period CP is added to the OFDM symbol by replicating the last few samples of the OFDM symbol to its front side. Let TG express the length of CP in terms of samples. Then, the enlarged OFDM symbols will be of the length given as Tsym= Tsub +TG.

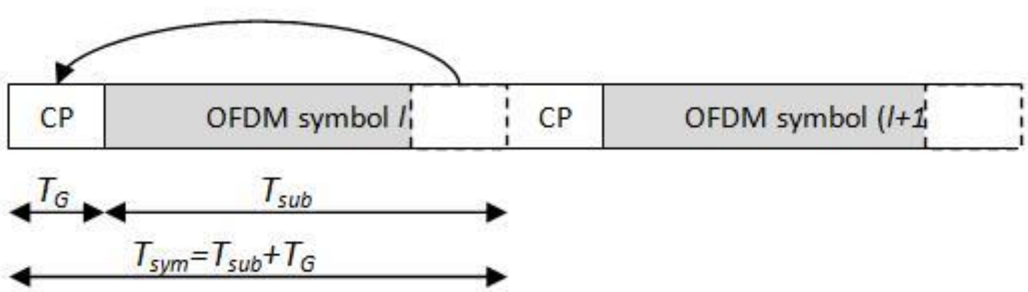


Figure 3.2 cyclic prefix addition [34]

Figure 3.2 shows two OFDM symbols, with CP length T_G, for this the OFDM symbol of length is given as $T_{sym} = T_{sub} + T_G$.

Figure 3.3 shows the ISI effect of multipath medium on subcarriers of the OFDM symbol. It could be seen in Figure 3.2 that if CP is set extended than or equal to the a multipath channel's maximum delay, OFDM symbol's ISI effect which is shown by a dotted line on the next OFDM symbol but is restricted within the GP length so that it shall not affect the FFT of the next coming OFDM symbol, which is taken for the duration of T_{sub}. This informs that if the guard interval is kept longer than the multipath channel's max delay, it maintains the orthogonality of the subcarriers.

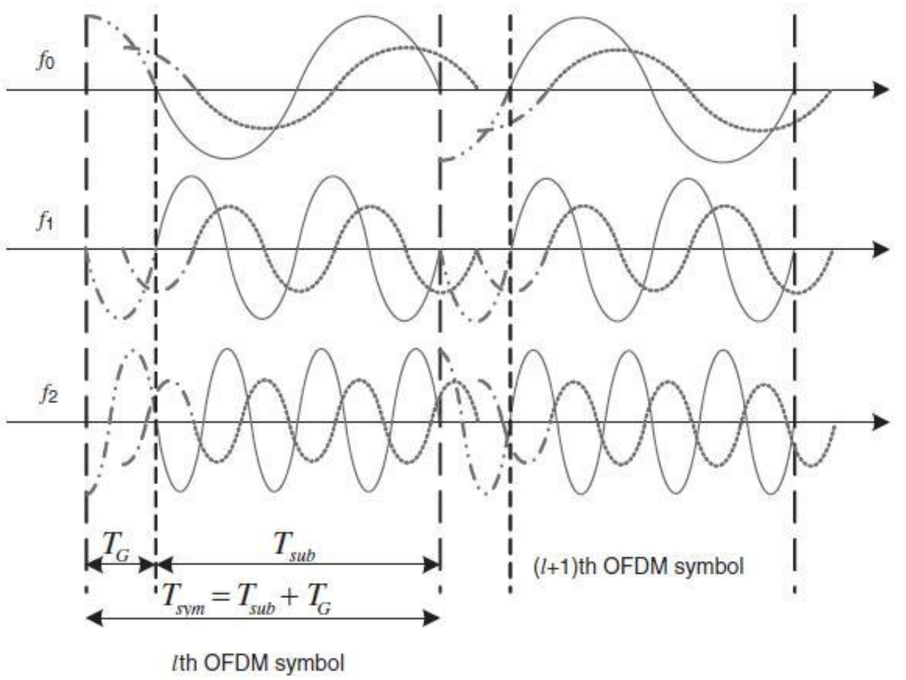


Figure 3.3: Representation of ISI in OFDM [34]

As connection of any delayed subcarrier that has been kept by CP, its orthogonality with all other subcarriers will be maintained over T_{sub}, such that for the previous OFDM signal will arrive with a delay of t_0,

$$\frac{1}{\quad}\int_{0} \quad 2 \quad (- \quad {}_0) \quad -2 \quad (- \quad) = 0 \quad , \neq \qquad (5)$$

The second OFDM signal will arrive with a delay of $t_0 + T_S$ and will be given as

$$\frac{1}{\quad}\int_{0} \quad 2 \quad (- \quad -2 \quad (-) = 0 \quad , \neq \qquad (6)$$

These parallel symbols are now again to be converted to frequency domain.

Till now we discussed about the transmitter side of the OFDM signal. After fleeting by the AWGN channel the signal will have noise added in it which will only cause distortion with no variations in amplitude and phase of the signal. In the receiver side, the FFT process, demodulation and removal of cyclic prefix is done. FFT of any signal is given by:

$$X(n)=\sum^{-1} (\,)\sin(\frac{2}{\;}) - \sum^{-1} (\,)\cos(\frac{2}{\;}) \qquad (7)$$

For the data to be computer adaptable form, it is converted into serial form.

3.4 SIMULATION RESULTS

To implement the MIMO-OFDM system on MATLAB, the data of 64 bits is randomly generated which is shown in Figure 3.4

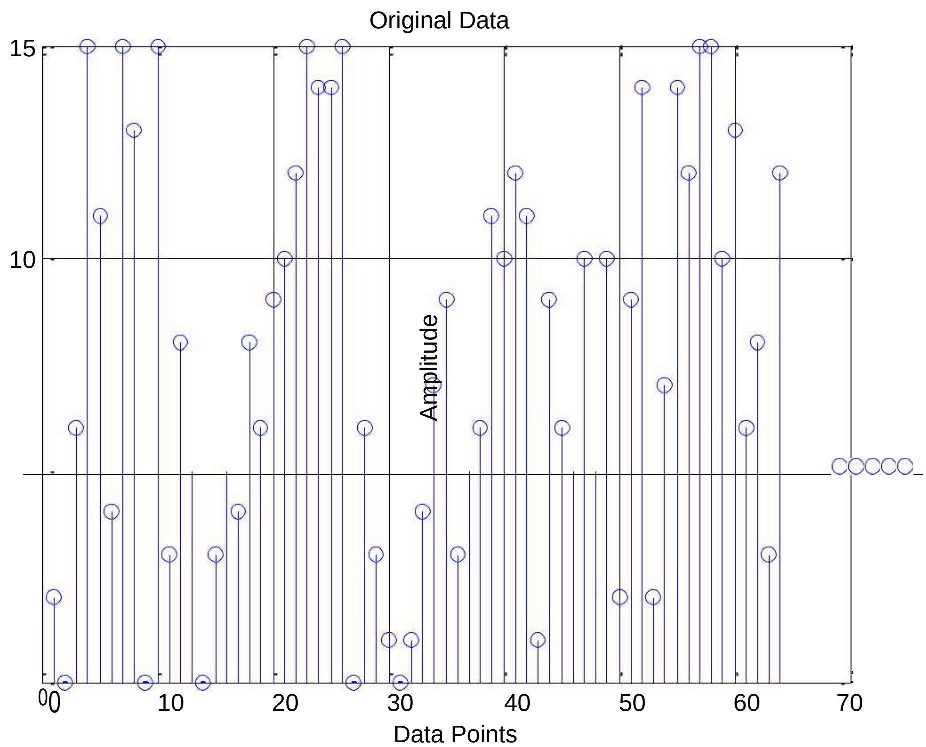


Figure 3.4 Randomly generated data of 64 bits

After random generation of data bits, modulation is done. Here 16QAM modulation technique is used. The modulation is done with the help of constellation mapper. From the simulation it is clear that the maximum amplitude that the data can have in 16QAM is 3. Figure 3.5 represents the 16QAM modulation for complex points.

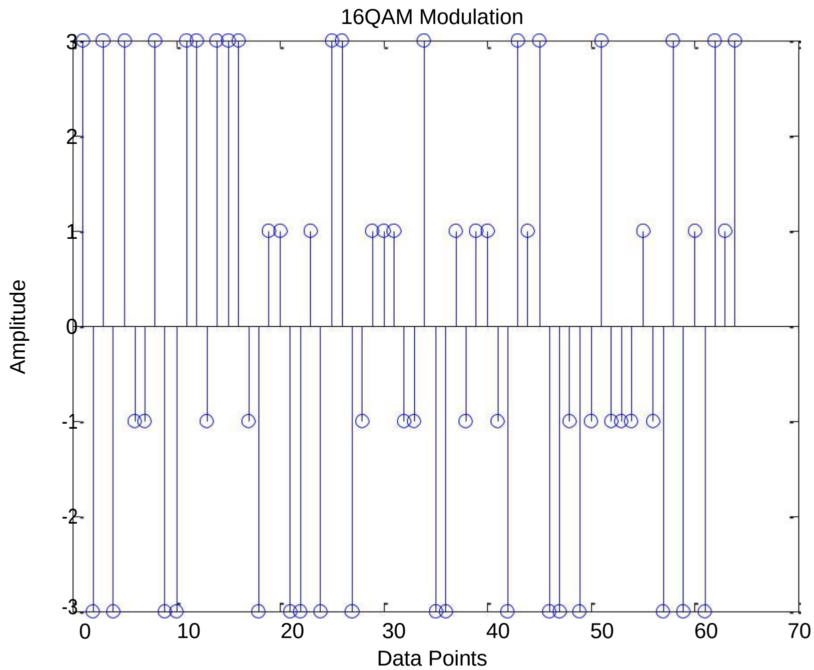


Figure 3.5: 16QAM modulation

The modulated data is converted to parallel form. Number of sub-carriers is calculated by dividing the data bits with the modulation used. So the serial data is divided into four sub-carriers as here total bits are 64 and modulation used is 16. This is illustrated in Figure 3.6

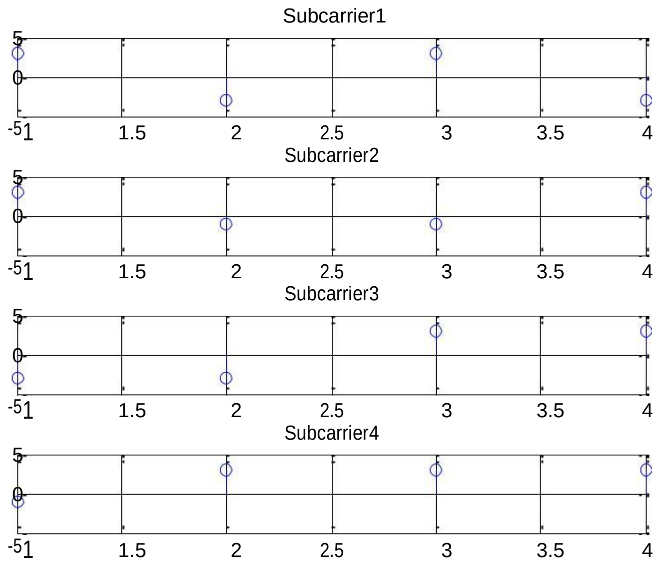


Figure 3.6 Sub-carrier formation

Till now the work was done in frequency domain, in order to add the guard period the symbol should be converted to time domain which is done by IFFT as shown in Figure 3.7

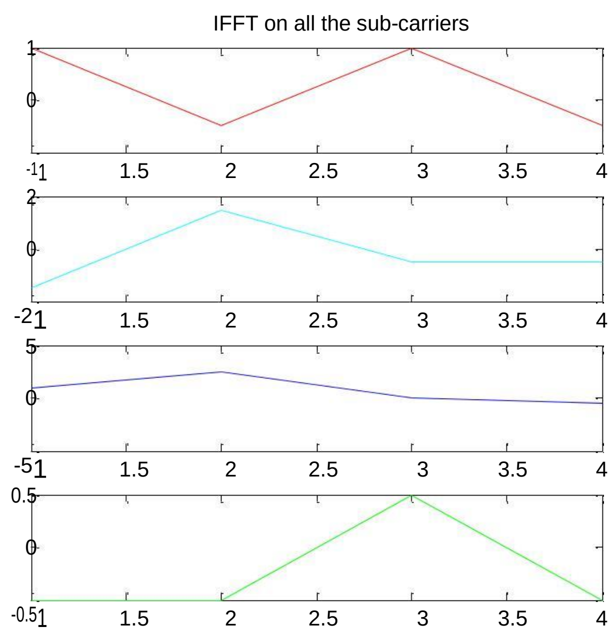


Figure 3.7: IFFT implementation on all sub-carriers

Basically cyclic prefix is addition of 25% or 1/4th of the last part of the OFDM symbol to its head part in order to avoid ISI which is discussed in section 1.2.2 and also in section 3.3.the addition of cyclic prefix is shown in Figure 3.8.

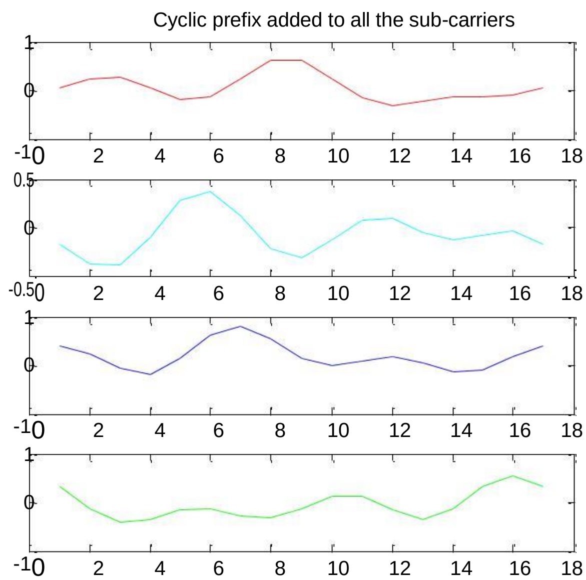


Figure 3.8: Addition of cyclic prefix

After parallel to serial conversion, OFDM signal is generated as in Figure.3.9

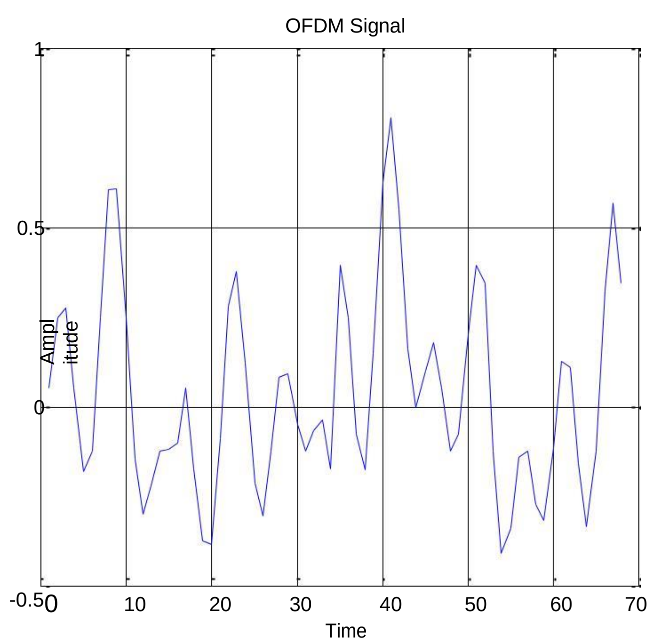


Figure 3.9: OFDM signal

The channel used here is AWGN channel which will cause distortion only in the signal. This is represented in Figure.3.10

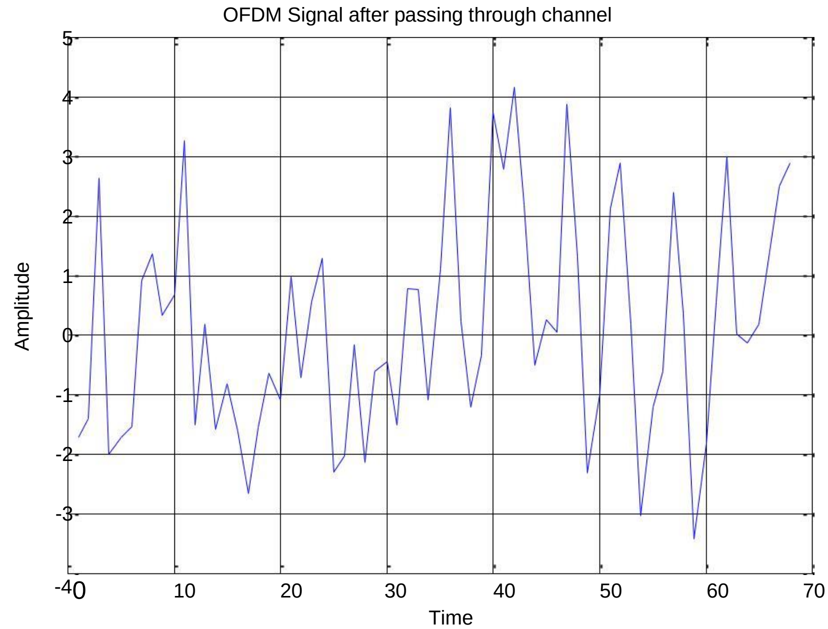


Figure 3.10: OFDM signal after passing through AWGN channel

CHAPTER 4

IMPLEMENTATION OF MIMO-OFDM SYSTEM IN RAYLEIGH CHANNEL USING RELAYING TECHNIQUES

4.1 INTRODUCTION

In chapter 3, the implementation of MIMO-OFDM system was illustrated in AWGN channel. Now to enhance the performance characteristics of the MIMO-OFDM system relay nodes were introduced. These relay nodes are placed in between the source and destination node particularly when the distance between the source and destination is very large. Relay nodes added to the MIMO-OFDM system will cater a lot of advantages over the basic MIMO-OFDM system in terms of increased connectivity, enhanced reliability, improved scalability, increment in throughput and also provides extended transmission range. Some disadvantages also come along with the supremacy which are system complexity is increased and that the initial set-up cost of this system is very much high.

There are in total five relaying techniques namely (a) amplify and forward (b) decode and forward (c) hybrid decode and amplify (d) incremental relaying (e) best relay selection

Our research work is based on three out of five relaying techniques which are (a) amplify and forward (b) decode and forward (c) hybrid decode and amplify. These relaying techniques have been discussed in section 1.4.

In the previous chapter the implementation of MIMO-OFDM system was done without relay nodes in AWGN channel. Unlikely in this chapter the performance characteristics i.e. BER and spectral efficiency of MIMO-OFDM system with the use of these relaying techniques have been studied and analyzed in Rayleigh channel. The main purpose of using Rayleigh channel was the channel doesn’t require direct line of sight propagation of signal from source to destination. Different modulation schemes like BPSK, 16QAM and 64QAM have also been used with different relaying techniques.

This chapter is divided into four sections. Section 4.1 gave introduction about the implementation of MIMO-OFDM system using relaying techniques whereas section 4.2 will describe about the system model, some idea about the analytics of various components in the system model will be section 4.3 and finally the section 4.4 will help in understanding the implementation of MIMO-OFDM system with relaying in an efficient way with MATLAB simulations.

4.3 SYSTEM MODEL

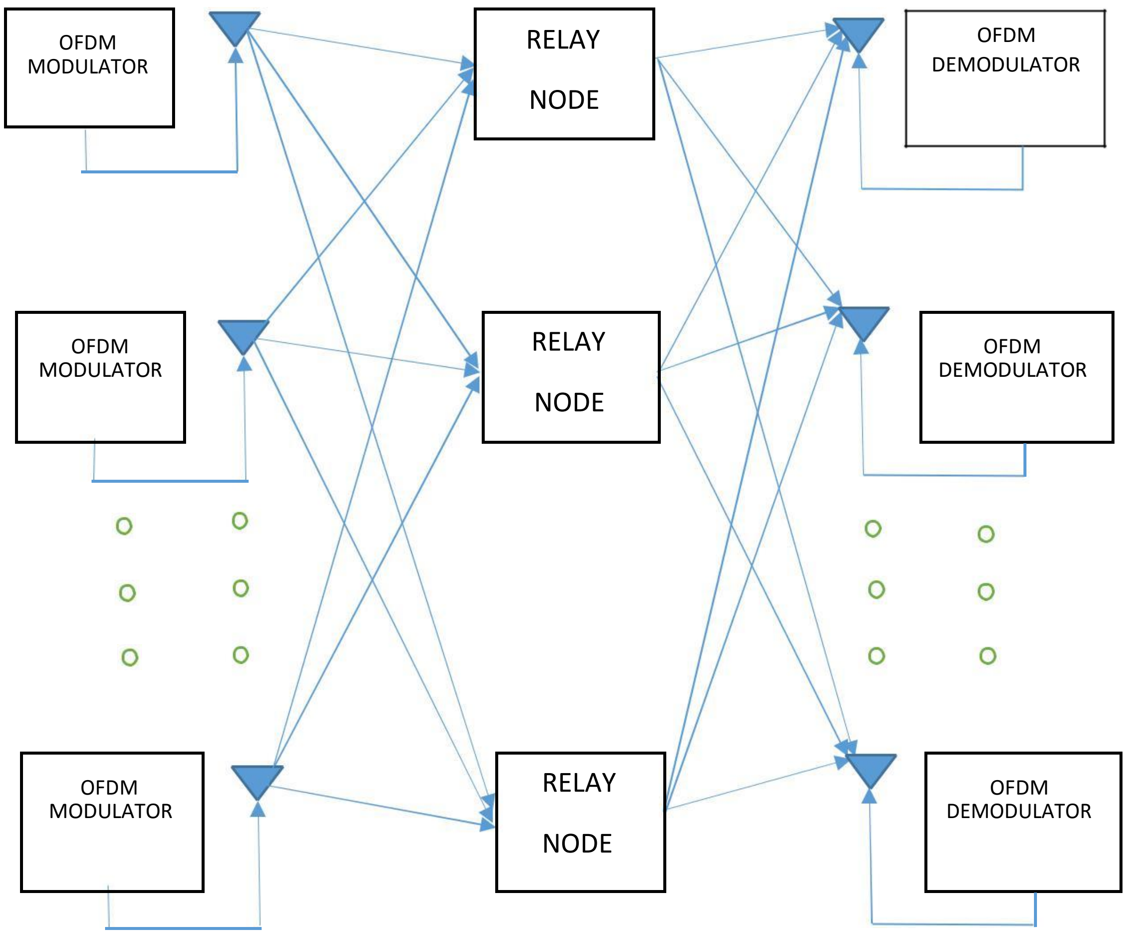


Figure 4.1 MIMO-OFDM system with relay nodes

Figure 4.1 shows the system model for MIMO-OFDM system with relay nodes. The relaying techniques are implemented on these relay nodes only. These nodes will perform amplification or decoding or both with respect to amplify and forward or decode and forward or hybrid decode and forward relaying techniques.

4.3 ANALYTICAL APPROACH

Generation of OFDM signals has been already explained in detail in section 3.3. For the relaying techniques to be added in the MIMO-OFDM system, the relay nodes are embedded within the system.

Amplify and forward relaying schemes amplify the signal which is coming to the relay nodes. This signal will comprise of useful data information and noise. The sole role of AF is to amplify what is coming from the source irrespective of its usefulness. As AF doesn't have the error detecting or correcting capability of its own so FEC control process is initiated with the help of convolutional codes.

Convolutional codes [35] are a little just like the block codes. They additionally involve the transmission of parity bits that are calculated by message bits. Here the sender doesn't sends the message bits also with the parity bits; during a convolutional code, the sender sends solely the parity bits. It converts any length of message to one 'codeword'. Encoder has the memory of its own and has n outputs that at any time rely upon k inputs and 'm' previous input blocks generally represented by three parameters which are 'n' i.e. no. of bits made at encoder output at every time unit; k which is no. of bits input to encoder at every time unit

For decode and forward, the relay nodes decode the message and then forwards it to the destination. For error detection and correction the CRC is used particularly Reed-Solomon encoder and decoder. This Reed-Solomon encoder was discussed in section 1.4.2.1.

In Hybrid decode and forward relaying technique case the relay node snaps between AF and DF depending on the channel conditions. HDAF technique [19] was proposed in order to refine the amplification of noise in the AF technique and the error generation process in DF technique. In order to improve the system performance this HDAF relay switches in between the DF and the AF techniques in a manner corresponding unlike channel conditions. Other technique known as incremental HDAF was proposed in [20] to enhance the spectral efficiency of the previously discussed HDAF method. In this incremental relay, the relay may decide whether to keep the messages silent messages or transmit them in the either DF or the AF mode. This decision is entirely based on the channels conditions among the source nodes, the relays and the destination nodes. It is researched that the BER and the outage probability are improved majorly when HDAF [36] is compared with other fixed relaying techniques. To compute the BER of the system following formula were used:

- for BPSK

$$P_b = \frac{1}{2}(\sqrt{\ }\ ) \tag{8}$$

- for M- QAM

$$\frac{2(-1)}{\ }(\sqrt{\ }\ ) \tag{9}$$

Where and Q= $\frac{1}{2}$(√)

In the above mentioned formulae, P_b = error probability; = energy of signal; =noise power and M= modulation number

4.3 SIMULATION RESULTS

For amplify and forward relaying scheme, 96 data bits were taken and convolutional coding is performed. Pilot bits are bits known to receiver and sender which help in reception of signals and help in decoding process are used. In order to combat ISI in this system, 8 pilot bits were also used. For decode and forward, Reed-Solomon encoding is done and 8 pilot bits. For HDAF, first decoding then amplification is done.

Here we have used three different modulation schemes BPSK, 16QAM and 64 QAM. We have calculated BER and spectral efficiency of the system with different modulation schemes. Since spectral efficiency refers to the information rate that can be transmitted over a given bandwidth Since we have used 64QAM, 16QAM, BPSK modulation schemes then accordingly 64QAM should have higher spectral efficiency than 16QAM which in turn will have greater efficiency when compared to BPSK which is proved by the simulation results. Also BER is calculated for these three systems, which will be less in 64QAM as compared to 16 QAM, which in turn will have less error rate as compared to BPSK.

Spectral efficiency and BER of BPSK, 16QAM and 64QAM had been simulated by MATLAB and are shown below:

(1) For BPSK modulation, spectral efficiency and BER are simulated. It is evident from figure 4.2 that hybrid relaying techniques used with MIMO-OFDM has greater spectral efficiency. Also figure 4.3 depicts that hybrid relaying technique has low BER as compared to other relaying techniques.

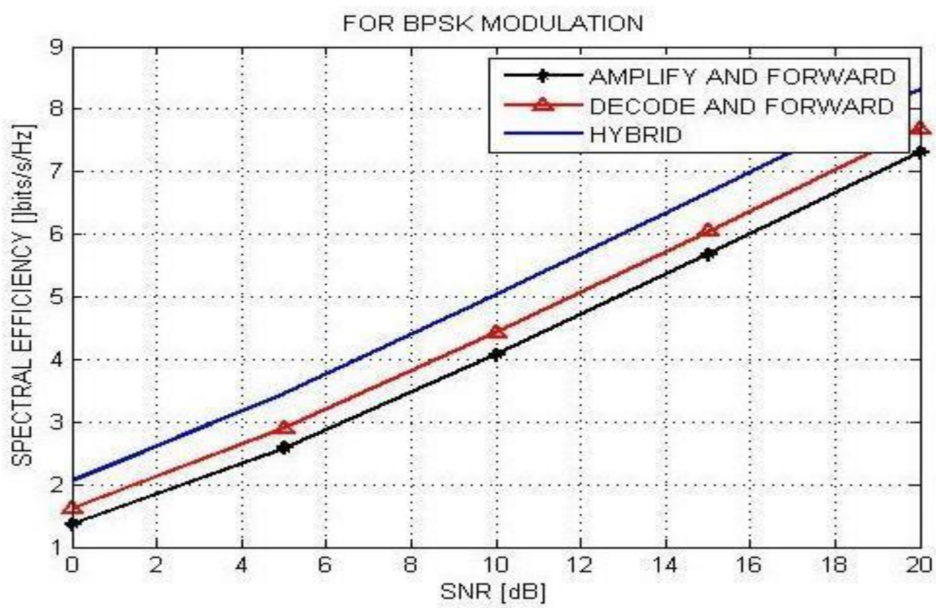


Figure 4.2: Spectral efficiency for BPSK

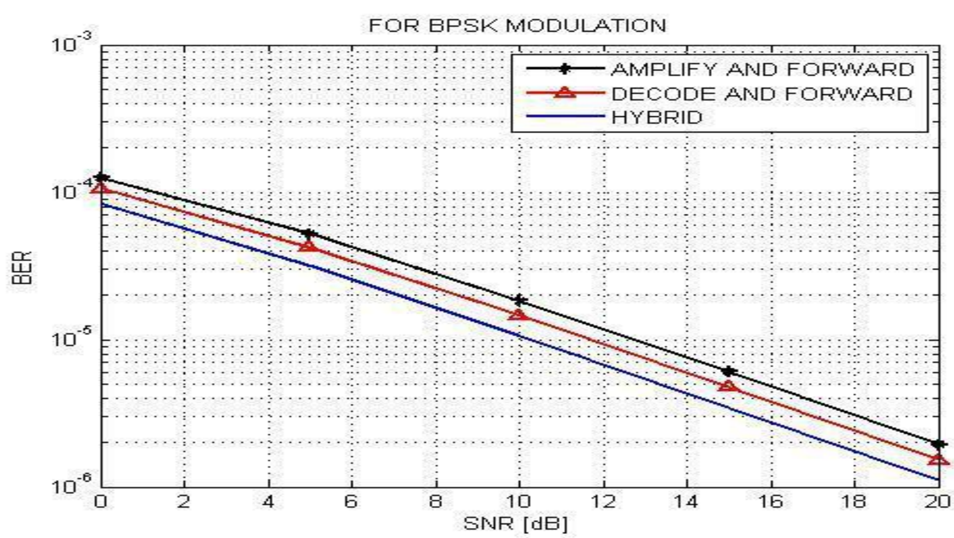


Figure 4.3: BER for BPSK

(2) For 16QAM modulation, spectral efficiency and BER are simulated. It is evident from figure 4.4 that hybrid relaying techniques used with MIMO-OFDM has greater spectral efficiency. Also figure 4.5 depicts that hybrid relaying technique has low BER as compared to other relaying techniques. As compared to BPSK, the 16 QAM modulation shows better performance in terms of spectral efficiency and BER

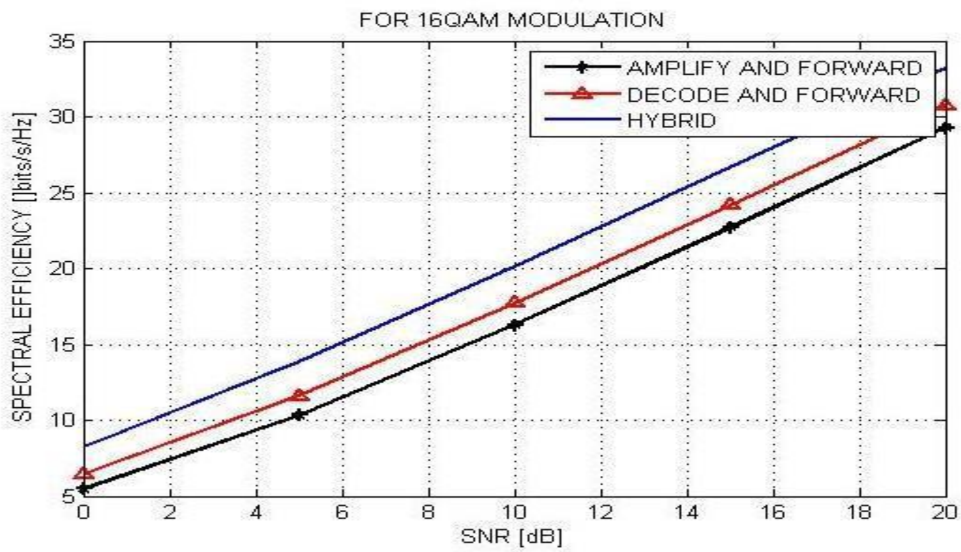


Figure 4.4: Spectral efficiency 16QAM

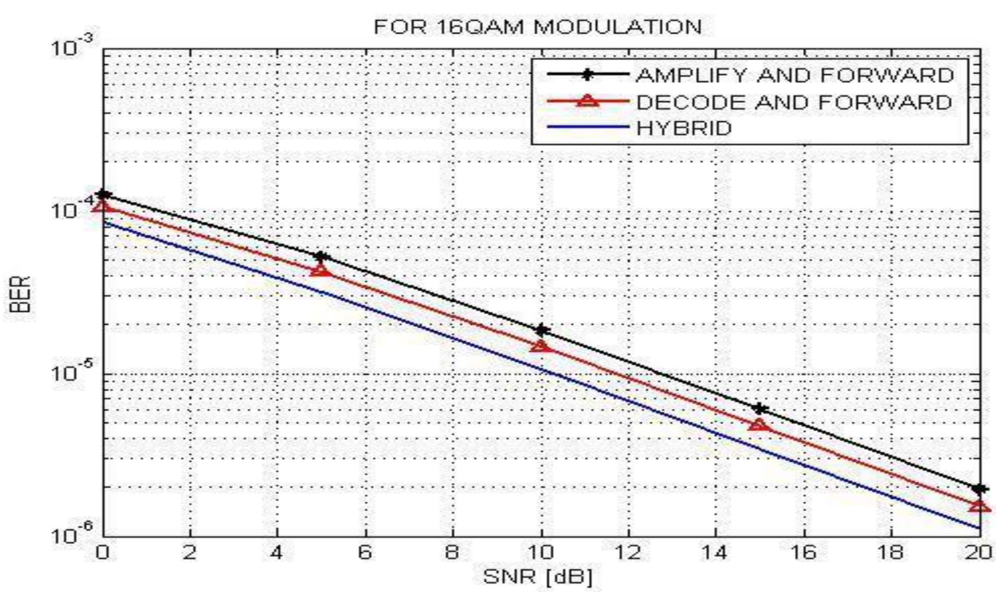


Figure 4.5: BER for16QAM

(3) For 64QAM modulation, spectral efficiency and BER are simulated. It is evident from figure 4.6 that hybrid relaying techniques used with MIMO-OFDM has greater spectral efficiency. Also figure 4.7 depicts that hybrid relaying technique has low BER as compared to other relaying techniques. As compared to BPSK and 16 QAM modulation, the 64 QAM shows better performance in terms of spectral efficiency and BER

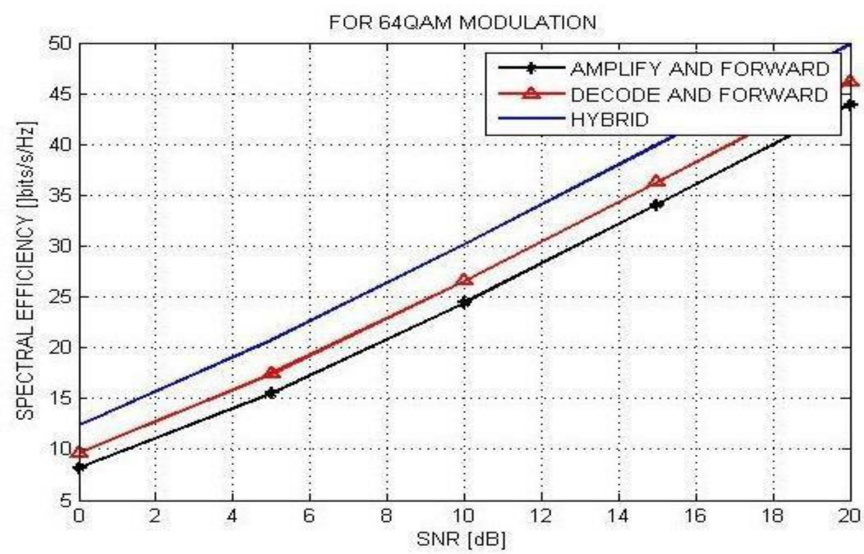


Figure 4.6: Spectral efficiency for 64QAM

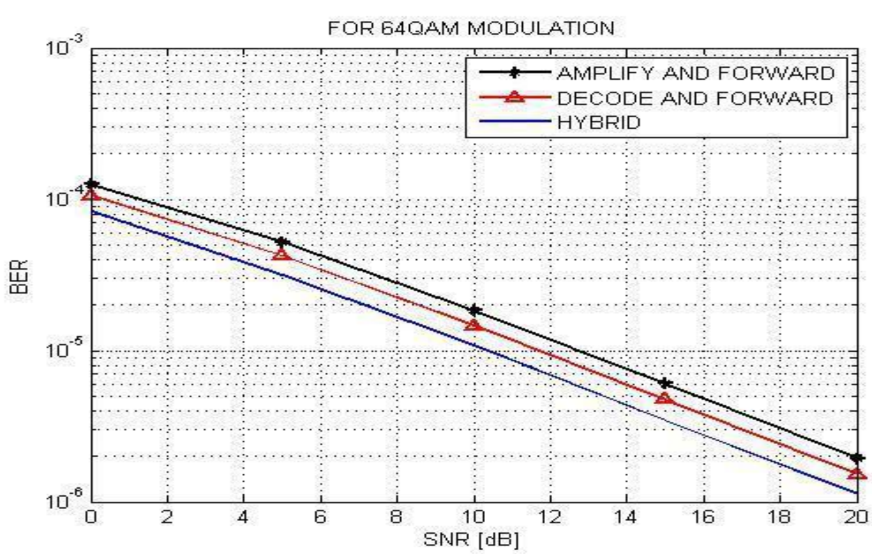


Figure 4.7: BER for 64QAM

From the above simulations, it can be concluded that using 64QAM modulation with hybrid decode amplify and forward relaying technique gives better spectral efficiency and low BER than any other modulation technique (i.e. BPSK and 16QAM) and relaying technique (amplify and forward; and decode and forward) used.

CHAPTER 5
CONCLUSION

In this thesis titled 'Performance analysis of MIMO-OFDM systems in fading channels using relaying techniques ' till date we have tried to give the analytical results of BER and spectral efficiency of OFDM signal in Rayleigh channel and AWGN channel. To improve the BER and the spectral efficiency of the system we have collaborated the system with different relaying techniques. Amplify and forward, decode and forward and hybrid relaying techniques were some of the relaying techniques which we have worked with. Also we compared the performance of the system under different modulation techniques like BPSK, 16 QAM and 64 QAM. It was concluded that the BER performance was good in case of hybrid relaying technique in BPSK modulation and for spectral efficiency performance 64 QAM hybrid relaying technique was optimum.

5.1 FUTURE WORK

Further, more simulations and analyzation could be done to analyze and simulate BER and spectral efficiency of MIMO-OFDM system in Rician channel as well. In order to get more satisfying results other relaying techniques can be used as well. Other relaying techniques are demodulate and forward, best relay selection and incremental relay selection. The use of relaying techniques would possibly decrease BER to a great extent and will also have positive effect on spectral efficiency of the system. Hence relaying techniques will affect performance analysis of the MIMO-OFDM system in a positive way.

Also different MIMO-OFDM Research ideas include

Adaptive MIMO antenna selection algorithms

MIMO channel estimation technique developments

Frequency hopping in the presence of frequency selective channels.

OFDMA

Noise tolerance and interference cancellation

Application of CMDA in MIMO-OFDM

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