PERFORMANCE EVALUATION USING DIVERSITY TECHNIQUES IN BEYOND 3G NETWORKS

Project Report submitted in partial fulfillment of the requirement for the degree of

Bachelor of Technology.

in

Electronics and Communication Engineering

under the Supervision of

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By

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to

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CERTIFICATE

This is to certify that project report entitled "Performance evaluation using diversity techniques in beyond 3G networks ", submitted by Divyangna Sharma and Anjali Ryot in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Signature of the Supervisor : ....

Name of the Supervisor : Mr. Bhasker Gupta

Designation: Sr. Lecturer

Date: 31/5/2012

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Looking back at the journey of our project, we owe our gratitude to all those people who have made this project possible and because of whom our undergraduate experience has been one that we will cherish forever.

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Divyangna Sharma

Anjali Ryot

Date 31/5/2012

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ABSTRACT

Fading causes major impairment in the wireless signals. One of the methods to combat this problem is using diversity techniques. The concept of diversity is to send multiple copies of the message signal from the transmitter to the receiver. Our project "**performance evaluation using diversity techniques in beyond 3G networks**" aims at improving the reliabiiity of the message signal and the hence, the performance in an OFDM system. While some copies may undergo deep fades, others do not. Since all the replicas undergo different amount of fading, so at the receiver end, signal combination methods like selection combining and maximum ratio combining are used for obtaining the optimal signal produced from diversity.

In our project we have implemented an OFDM system using matlab. Receiver diversity has been implemented on the OFDM system. Maximum Ratio Combining and Selection Combining techniques have been applied to combine the faded replicas and obtain the optimum signal at the receiver end. We have implemented 16, 32 and 64 QAM modulation techniques.

Finally various plots of BER vs. SNR have been drawn for MRC and Selection Combining in an OFDM system under the various modulation techniques. These plots are helpful in evaluating the performance of the system.. In this report, the concepts used in our project have been elaborated.

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CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION TO OFDM

Orthogonal frequency division multiplexing (OFDM) is a special case of multicarrier transmission, where a single data stream is transmitted over a number of lower rate subcarriers.Essentially, OFDM is configured to split a communication signal in several different channels. Each of these channels is formatted into a narrow bandwidth modulation, with each channel operating at a different frequency. The process of OFDM makes it possible for multiple channels to operate within close frequency levels without impacting the integrity of any of the data transmitted in any one channel. OFDM can be seen as either a modulation technique or a multiplexing technique.

One of the main reasons to use OFDM is to increase the robustness against frequency selective fading or 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 the subcarriers will be affected. Error correction coding can then be used to correct for the few erroneous subcarriers. Generally, the process of OFDM is focused on preventing the occurrence of crosstalk, or any other type of outside interference with the quality of the transmission.

The use of OFDM is common worldwide. Many radio networks around the globe make use of OFDM to service their broadcast ranges. Some amateur radio systems also employ elements of OFDM for sending out signals as well. Due to the high data rate transmission and the ability to against frequency selective fading, orthogonal frequency division multiplexing (OFDM) is a promising technique in the current broadband wireless communication system.

1.2 HISTORY OF OFDM

The history of OFDM goes back to the 1960's. At the time, there was a need to make more efficient use of bandwidth transmissions without creating situations where signals would be subject to a phenomenon referred to as crosstalk. Essentially, crosstalk occurs when two audio sources are broadcasting at the same time. The end result is that the message of each broadcast is partially obscured for anyone attempting to listen to either of the messages. Crosstalk can be compared to two people choosing to speak while another individual is already speaking. Modulaton and demodulaton implementation is done by Fourier transforms, using the summation of sine and cosine. Preservation of orthogonality within each channel permits establishing individual channel data transmission rates equal to the channel bandwidth. This is half the ideal Nyquist rate. However, due to the fact that adjacent channels are synchronized, they can be overlapped by 50percent, as is shown in Fig 1.1 (b).In 1967, Saltzberg [2] analyzed and demonstrated the performance of the efficient parallel data transmission systems, where he concluded that the strategy of designing an efficient parallel system should concentrate on reducing crosstalk between adjacent channels than on perfecting the individual channels themselves. His conclusion has been proven far-sighted today in the digital baseband signal processing to battle Inter Carrier Interference ICI. Each sub-channel's orthogonality in the OFDM system can be preserved through the QAM technique. However, the difficulty of sustaining orthogonality with an analog system emerges when a large number of subcarriers are required.

The advantage of OFDM is reduced if orthogonality cannot be maintained between the subcarriers. If more subcarriers are required, the modulation, synchronization ,and coherent demodulation produce a complicated OFDM circuit requiring additional hardware cost. This leads to an impractical analog implementation of the Fourier transforms using oscillators at the required frequencies. The oscillator drift in analog components led to the initial failure of orthogonality which results in an increased ocurrence of ICI.

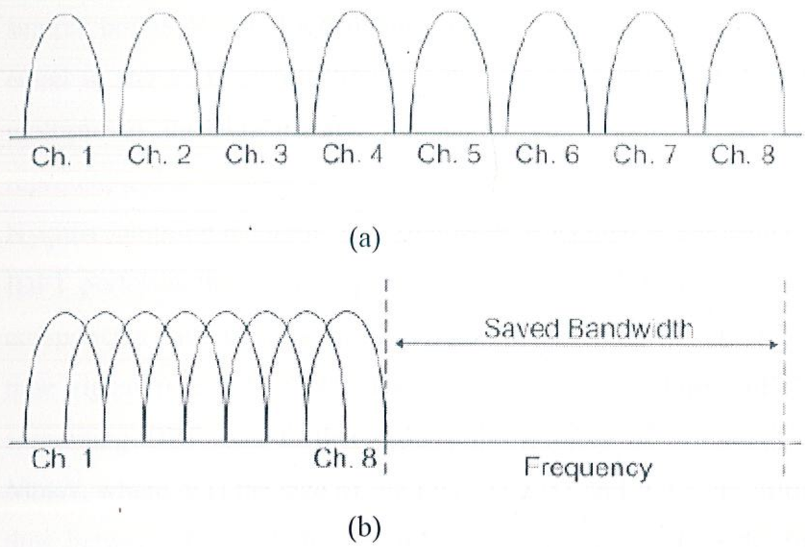


Figure 1.1 (a)The frequency spectrum of eight channels shown utilizing frequency division multiplexing.(b) The frequency spectrum of OFDM is shown where sub-channels are orthogonal to the adjacent channels. The percentage of bandwidth used to transmit the same data is reduced by 50%.

1.2.1 DISCRETE FOURIER TRANSFORM

Throughout the development of OFDM technology, there have been a number of remarkable contributions. The first milestone came about in 1971 when Weinstein and Ebert used a discrete Fourier transform (DFT) to perform baseband modulation and demodulation in the receiver[1]. It should be noted that in 1970, the application of the DFT to an FDM system was first proposed by Darlington [4]. This renovation of the original analog multicarrier system to a digitally implemented OFDM eliminates banks of subcarrier oscillators and coherent demodulators and thus reduces the implementation complexity. This evolution makes the modern low-cost OFDM systems plausible today .DFT-based OFDM can be completely implemented in the digital baseband for efficient processing, eliminating bandpass filtering. All subcarriers still overlap in the frequency domain while the DFT ensures orthogonality. It transforms the data from the frequency domain to the time domain.When the DFT of a time domain signal is computed, the frequency domain results are a function of the sampling period T and the number of sample points N. The fundamental frequency of the DFT is equal to $NT1$, where $NT$is equal to the total sample time. Each frequency represented in the DFT is an integer multiple of the fundamental frequency. The maximum frequency that theDFT can represent a time domain signal sampled at a rateof $T1$ is $Tf21$max □□, as given by the Nyquist sampling theorem. This frequency is located in the center of the DFT points. The IDFT performs the inverse operation to the DFT. It takes a signal defined by frequency components and converts them to a time domain signal. The time duration of the IDFT time signal is equal to NT. The Fast Fourier Transform (FFT), a fast algorithm for computing DFT, can further reduce the number of arithmetic operations from $N2$to $N\log N$, where N is the size of the FFT. The ISI and ICI were mitigated by using a guard time between the symbols and raised-cosine windowing in the time domain. Weinstein and Ebert also added a guard interval in the case of multipath channels. Even though the proposed system did not achieve perfect orthogonality among the subcarriers over a time dispersive channel, it was nevertheless an important contribution to OFDM.

1.2.2 CYCLIC EXTENSION

Another milestone in OFDM came about in 1980, when Peled and Ruiz solved the orthogonality problem by introducing a cyclic extension (CE), more commonly referred to today as cyclic prefix In their scheme, CE are substituted for the conventional null guards of the OFDM symbol. This effectively converts the linear convolutive channel to simulate a channel performing cyclic convolution ensuring orthogonality The cyclic extension is added to the data stream after the FFT-1 is computed.

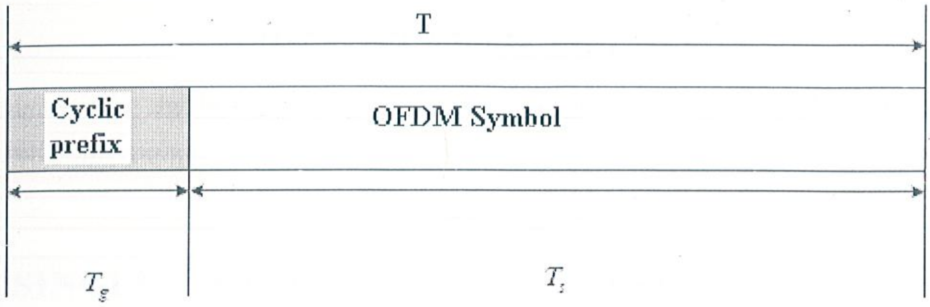


Figure 1.2:Cyclic prefix in OFDM

The above figure illustrates the implementation of cyclic prefix.T is the OFDM symbol period and is given by

$$T = T_s + T_g$$

where

T_s is symbol period and

T_g is guard band period

1.2.3 CHANNEL EQUALIZATION

An important advantage of the OFDM transmission technique as compared to single carrier systems is seen in frequency-selective channels. The signal processing in the receiver is rather simple in this case. The orthogonality of the OFDM sub-carriers is maintained after transmission over the radio channel and the effect of Inter Carrier Interference(ICI) is reduced to a multiplication of each subcarrier by a complex transfer factor. Therefore, equalizing the signal is very simple, whereas equalization may not be feasible in the case of conventional single carrier transmission covering the same bandwidth. In 1980, Hirosaki introduced an equalization algorithm to further suppress Inter Symbol Interference(ISI) and ICI , which results from a channel impulse response or timing and frequency errors such as channel distortion, synchronization error, or phase error. His implementation as designed for a subchannel-based equalizer for an orthogonally multiplexed QAM system.

CHAPTER 2

PRINCIPLES OF OFDM

In this chapter the basic principles used in the generation and implementation of an OFDM signal are introduced.

2.1 SINGLE CARRIER VS MULTICARRIER MODULATION

Wireless broadband communications systems are characterized by very dispersive channels. To face this phenomenon, two modulation techniques can be used: single carrier(SC) modulation with broadband equalization, or multi carrier modulation with orthogonal frequency-division multiplexing(OFDM).

2.1.1 SINGLE CARRIER MODULATION

In a single carrier modulation scheme each data symbol is transmitted sequentially on a single carrier such that the signalling interval is equal to data symbol duration .In a single carrier modulation scheme the modulated carrier occupies the entire available bandwidth .Single-carrier transmission is the conventional approach to digital communications. Until the appearance of OFDM, digital communication was almost entirely handled with single-carrier transmission. Unfortunately, this approach faces a major technical difficulty, namely multipath interference, which occurs when waves are reflected off buildings, mountains and such like. This type of interference can seriously deform the received waveform, making equalizers essential to shape the waveform at the receiver.

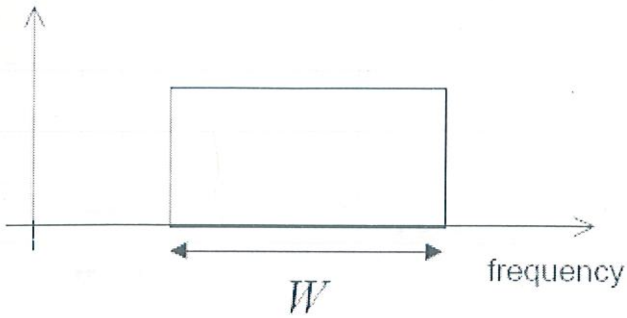


Figure2.1:single carrier

Figure 2.1 shows that in a single carrier system the signal representing each bit uses all of the available spectrum.

2.1.2 MULTI CARRIER MODULTION

Multi-carrier modulation (MCM) is a method of transmitting data by splitting it into several components, and sending each of these components over separate carrier signals. The individual carriers have narrow bandwidth , but the composite signal can have broad bandwidth.In a multi-carrier modulation scheme N sequential data symbols are transmitted simultaneously on N multiple carriers carriers; thus the signalling interval is equal to N times the data symbol duration In a multi-carrier modulation scheme each modulated occupies only a small part of the entire available bandwidth .The advantages of MCM include relative immunity to fading caused by transmission over more than one path at a time (multipath fading), less susceptibility than single-carrier systems to interference caused by impulse noise, and enhanced immunity to inter-symbol interference. Limitations include difficulty in synchronizing the carriers under marginal conditions, and a relatively strict requirement that amplification be linear.

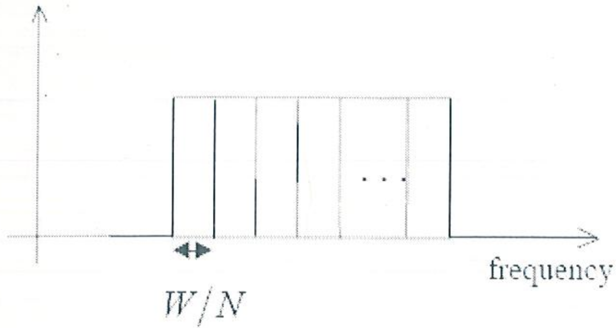


Figure 2.2:Multi carrier

Figure 2.2 shows that in a multi carrier system the available spectrum is divided into many narrow bands .The data is divided into parallel data streams each transmitted on a separate band

MCM was first used in analog military communications in the 1950s. Recently, MCM has attracted attention as a means of enhancing the bandwidth of digital communications over media with physical limitations. The scheme is used in some audio broadcast services. The technology lends itself to digital television , and is used as a method of obtaining high data speeds in asymmetric digital subscriber line (ADSL) systems. MCM is also used in wireless local area networks (WLAN s).

2.2 FREQUENCY DIVISION MULTIPLEXING SCHEME

Frequency Division Multiplexing is possible when the useful bandwidth of the transmission medium exceeds the required bandwidth of signals to be transmitted. A number of signals can be carried simultaneously if each signal is modulated onto a different carrier frequency and the carrier frequencies are sufficiently separated such that the bandwidths of the signals do not overlap. Figure below shows frequency division multiplexing.

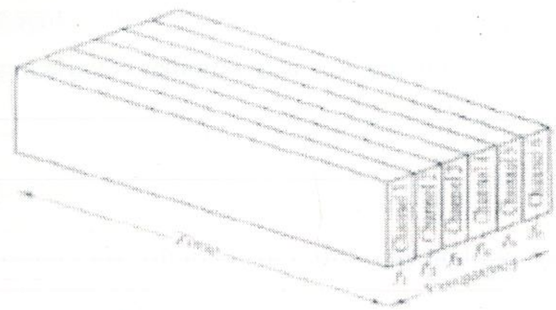


Figure2.3:Frequency division Multiplexing

Frequency-division multiplexing (FDM) can also be defined as a scheme in which numerous signals are combined for transmission on a single communications line or channel. Each signal is assigned a different frequency (subchannel) within the main channel of the transmission. Frequency Division multiplexingor FDM is an analog technique which is used to multiplex signals. It can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted. In FDM, the signals generated by each sending device modulate different carrier frequencies. After that, these modulated signals are combined into a single composite signal that can be transported by the link. Carrier frequencies are separated by sufficient band width to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel. From FDM-Frequency Division Multiplexing figure above there are Six signal sources are fed into a multiplexer,which modulates each signal onto a different frequency (fi, . . . , f6). Each modulated signal requires a certain width centered around its carrier frequency, referred to as a channel. To prevent interference, the channels are separated by guard bands, which are unused portions of the spectrum. The composite signal transmitted across the medium is analog. However, that the input signals may be either digital or analog. In the case of digital input, the input signals must be passed through modems to be converted to analog. In either case, each input analog signal must then be modulated to move it to the appropriate frequency band. When FDM is used in a communications network, each input signal is sent and received at maximum speed at all times. This is its chief asset. However, if many signals must be sent along a single long-distance line, the necessary bandwidth is large, and careful engineering is required to ensure that the system will perform properly

2.3 OFDM

OFDM is a special case of frequency division multiplexing. As an analogy an FDM channel is like water flow out of a faucet, in contrast an OFDM signal is like a shower. In a faucet all water comes out in one stream and cannot be subdivided. OFDM shower is made up of a number of different streams.

Figure2.4: (a)A regular FDM single carrier-A whole bunch of water coming all in one stream. (b)orthogonal FDM-same amount of water coming from a lot of small streams.

The difference between FDM and OFDM is that they both respond differently to interference.If a hand is put in front of the faucet, the water flow can be stopped but if a hand is put in front of the shower,the water flow cannot be stopped. In a classical parallel data system, the total signal frequency band is divided into N non overlapping frequency subchannels. Each subchannel is modulated with a seperate symbol and then the N subchannels are frequency-multiplexed. It seems good to avoid spectral overlap of channels to eliminate interchannel interference. However, this leads to inefficient use of the available spectrum. To cope with the inefficiency, the ideas proposed from the mid-1960s were to use parallel data and FDM with overlapping subchannels, in which, each carrying a signaling rate b is spaced b apart in frequency to avoid the use of high-speed equalization and to combat impulsive noise and multipath distortion, as well as to fully use the available bandwidth[4].

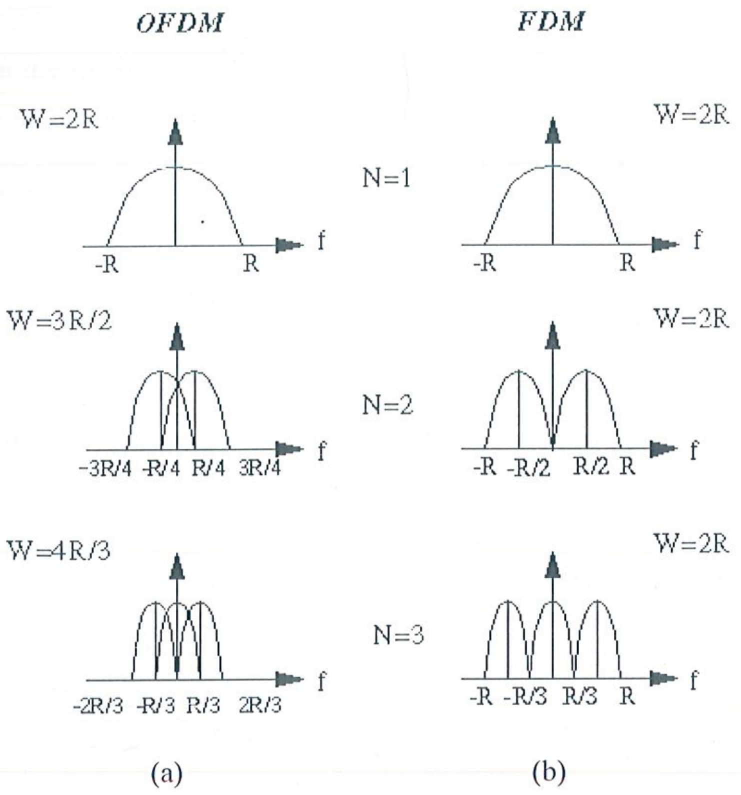


Figure2.4:. Concept of OFDM signal: (a)orthogonal multicarrier technique versus (b)conventional multicarrier technique

Figure 2.4 illustrates the difference between the conventional non overlapping multicarrier technique and the overlapping multicarrier modulation technique. As shown in Figure 2.4, by using the overlapping multicarrier modulation technique, we save almost 50% of bandwidth. To realize the overlapping multicarrier technique, however we need to reduce crosstalk between subcarriers, which means that we want orthogonality between the different modulated carriers.

2.4 ORTHOGONALITY

The word orthogonal indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. As stated earlier, orthogonality of carriers is a necessary condition for the proper functioning of an OFDM system. Two functions f(x) and g(x) are said to be orthogonal in the period [a, b] iff

$$\int_a^b f(x)g^*(x)dx = 0 \qquad \text{.......................................(1)}$$

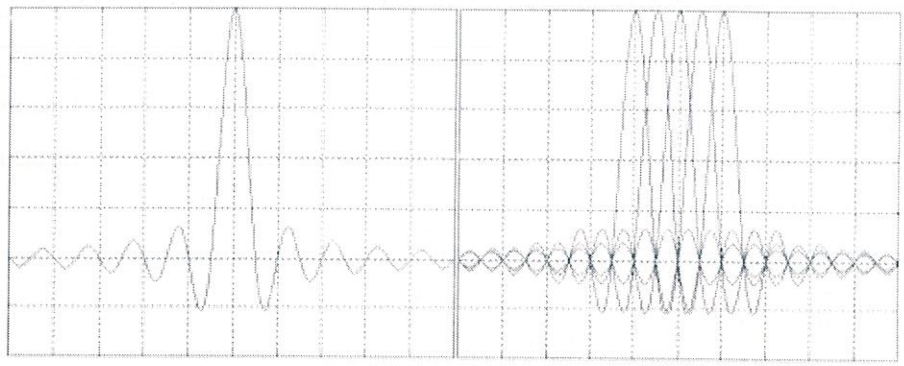
Physically, if f(x) and g(x) are signals, then the LHS of (1) is a measure of how much common energy the spectra of these two signals have.

In the case of OFDM, carriers are sinusoidal. Consider two sinusoidal functions $e^{j2\pi mft}$ and $e^{j2\pi nft}$. Then,

$$\frac{1}{T}\int_{(T)} e^{j2\pi mft} e^{-j2\pi nft} dt = \begin{cases} 0, m \neq n \\ 1, m = n \end{cases} \qquad \text{.......................................(2)}$$

where, T = 1/f.

Equation (2) shows that all harmonics of a sinusoid of frequency f are orthogonal to each other. This property is used in the generation of orthogonal carriers for OFDM signals. In a normal frequency-division multiplex system, many carriers are spaced apart in such a way that the signals can be received using conventional filters and demodulators[3]. In such receivers, guard bands are introduced between the different carriers and in the frequency domain, which results in a lowering of spectrum efficiency.It is possible, however, to arrange the carriers in an OFDM signal so that the sidebands of the individual carriers overlap and the signals are still received without adjacent carrier interference. To do this, the carriers must be mathematically orthogonal. The receiver acts as a bank of demodulators, translating each carrier down to DC, with the resulting signal integrated over a symbol period to recover the raw data. If the other carriers all beat down the frequencies that, in the time domain, have a whole number of cycles in the symbol period T, then the integration process results in zero contribution from all these other carriers. Thus, the carriers are linearly independent (i.e., orthogonal) if the carrier spacing is a multiple of 1/T.

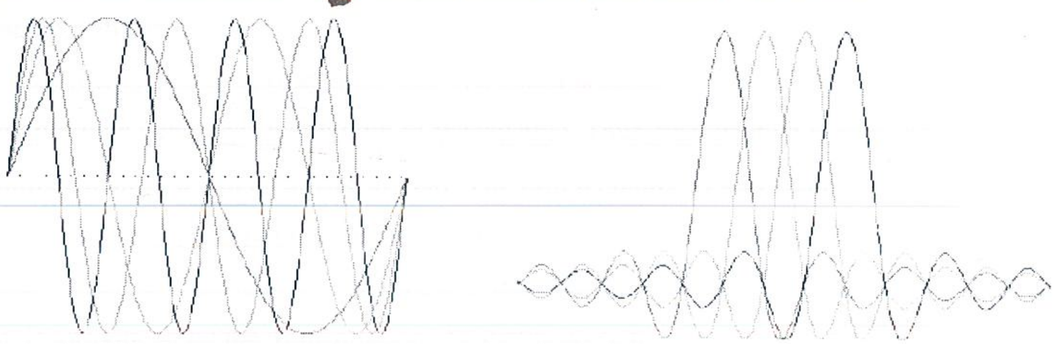


(a) (b)

Figure 2.6: Spectra of (a) an OFDM subchannel and (b) and OFDM signal.

2.5 ORTHOGONALITY IN OFDM

In OFDM, a large number of closely spaced orthogonal sub-carrier signals are used to carry data.The main concept in OFDM is orthogonality of its subcarriers. The Orthogonal Frequency Division Multiplexing (OFDM) transmission scheme is the optimum version of the multicarrier transmission scheme. In the past, as well as in the present, the OFDM is refered in the literature Multi-carrier, Multi-tone and Fourier Transform.



(a) (b)

Figure 2.5(a)Example of four subcarriers within one OFDM signal (time domain) (b)Spectra of individual subcarriers (frequency domain)

2.5.1 IMPORTANCE OF ORTHOGONALITY

Figure 2.6(a) shows the spectrum of the individual data of the subchannel. The OFDM signal, multiplexed in the individual spectra with a frequency spacing equal to the transmission speed of each subcarrier, is shown in Figure 2.6(b). Figure 2.6(b) shows that at the center frequency of each subcarrier, there is no crosstalk from other channels. Therefore, if we use DFT at the receiver and calculate correlation values with the center of frequency of each subcarrier, we recover the transmitted data with no crosstalk.

The orthogonality of subchannels in OFDM can be maintained and individual subchannels can be completely separated by the FFT at the receiver when there are no intersymbol interference (ISI) and intercarrier interference (ICI) introduced by the transmission channel distortion. OFDM transmission system offers possibilities for alleviating many of the problems encountered with single carrier systems. It has the advantage of spreading out a frequency selective fade over many symbols. This effectively randomizes burst errors caused by fading or impulse interference so that instead of several adjacent symbols being completely destroyed, many symbols are only slightly distorted. This allows successful reconstruction of majority of them even without forward error correction. Because of dividing an entire signal bandwidth into many narrow sub bands,

the frequency response over individual subbands is relatively flat due to are smaller than coherence bandwidth of the channel. Thus, equalization is potentially simpler than in a single carrier system. The orthogonality of sub channels in OFDM can be maintained and individual sub channels can be completely separated by the FFT at the receiver when there are no intersymbol interference (ISI) and intercarrier interference (ICI) introduced by the transmission channel distortion.

2.6 OFDM GENERATION

The basic principle of OFDM is to split a high-rate datastream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. The relative amount of dispersion in time caused by multipath delay spread is decreased because the symbol duration increases for lower rate parallel subcarriers. Intersymbol interference is eliminated almost completely by introducing a guard time in every OFDM symbol. In the guard time , the symbol is cyclically extended to avoid intercarrier interference. In OFDM design, a number of parameters are up for consideration, such as the number of subcarriers, guard time, symbol duration, subcarrier spacing,modulation type per subcarrier. The choice of parameters is influenced by system requirements such as available bandwidth, required bit rate, tolerable delay spread, and Doppler values. Some requirement are conflicting.[6] For instance, to get a good delay spread tolerance, a large number of subcarriers with small subcarrier spacing is desirable, but the opposite is true for a good tolerance against Doppler spread and phase noise.

2.6.1 DATA TRANSMISSION USING MULTIPLE CARRIERS

An OFDM signal consists of a sum of subcarriers that are modulated by using phase shift keying (PSK) or quadrature amplitude modulation (QAM). If

d_i are the complex QAM symbol,

N_s is the number of subcarriers,

T the symbol duration, and

$f_i = f_0 + i/T$ the carrier frequency, then one OFDM symbol starting at

$t = t_s$ can be written as:

$$s(t) = \mathrm{Re}\{\sum_{i=0}^{N_s-1} d_i \exp(j2\pi f_i (t - t_s))\}, \quad t_s \le t \le t_s + T \qquad (1)$$

$$s(t) = 0, \quad t < t_s \;\wedge\; t > t_s + T$$

In the literature, often the equivalent complex notation is used, which is given by (2). In this representation, the real and imaginary parts correspond to the in-phase and quadrature parts of the OFDM signal, which have to be multiplied by a cosine and sine of the desired carrier frequency to produce the final OFDM signal. Figure (2.7) shows the operation of the OFDM modular in block diagram

$$s(t) = \sum_{i=0}^{N_s-1} d_i \exp(j2\pi f_i (t - t_s)), \quad t_s \le t \le t_s + T \qquad (2)$$

$$s(t) = 0, \quad t < t_s \;\wedge\; t > t_s + T$$

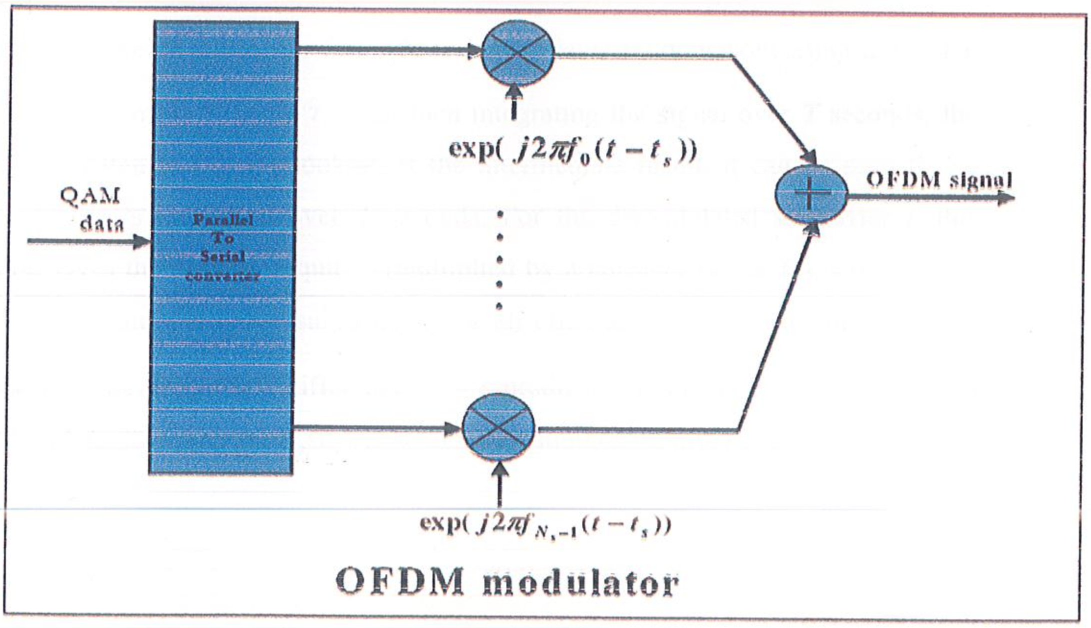


Figure 2.7 OFDM Modulator

As an example , figure (2.8) shows four subcarriers from one OFDM signal. In this example, all subcarriersn have the phase and amplitude, but in practice the amplitudes and phases may be modulated differently for each subcarrier.Each subcarrier has exactly an integer number of cycles in the interval T , and the number of cycles between adjacent subcarries differs by exactly one. This properly accounts for the orthogoality between subcarriers.

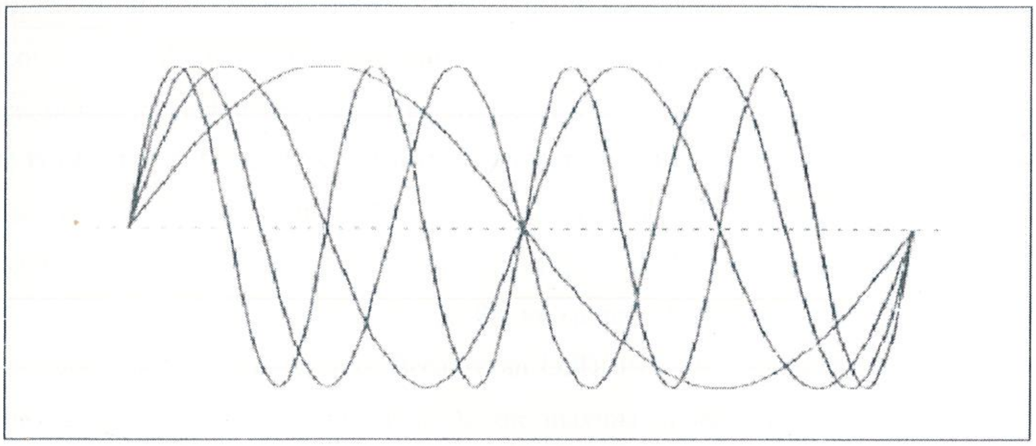


Figure 2.8:An OFDM signal comprising of four orthogonal subcarriers

For instance, if the *j*th subcarrier from (2) is demodulated by downconverting the signal with a frequency of $f_j = f_0 + j/T$ and then integrating the signal over T seconds, the result is as written in (3). By looking at the intermediate result, it can be seen that a complex carrier is integrated over T seconds. For the demodulated subcarrier *j*, this integration gives the desired output d_j (multiplied by a constant factor T), which is the QAM value for that particular subcarriers. For all other subcarriers , this integration is zero, because the frequency difference $(i-j)/T$ produce an integer number of cycles within the integration interval T ,such that the integration result is always zero.

$$\int_{t_s}^{t_s+T} \exp(-j2\pi f_j(t-t_s)) \sum_{i=0}^{N_s-1} d_i \exp(j2\pi f_i(t-t_s))dt$$
$$= \sum_{i=0}^{N_s-1} d_i \int_{t_s}^{t_s+T} \exp(j2\pi \frac{i-j}{T}(t-t_s))dt = d_j T \qquad (3)$$

The orthogonality of different OFDM subcarriers can also be demonstrated in another way. According to (1), each OFDM symbol contains subcarriers that are nonzero over a ***T*** -seconds interval. Hence, the spectrum of a single symbol is a convolution of group of Dirac pulses located at the subcarrier frequencies with the spectrum of a square pulse that is one for a ***T***second period and zero otherwise. The amplitude spectrum of the square pulse is equal to **sinc(p*fT*)** , which has zeros for all frequencies ***f*** that are an integer multiple of ***1/T*** . This effect is shown in figure which shows the overlapping sinc spectra of individual subcarriers. At the maximum of each subcarrier spectrum, all other subcarrier spectra are zero. Because an OFDM receiver calculates the spectrum values at those points that correspond to the maxima of individual subcarrier, it can demodulate each subcarrier free from any interference from the other subcarriers. Basically, Figure (2.8) shows that the OFDM spectrum fulfills Nyquist's criterion for an inter symbol interference free pulse shape. Notice that the pulse shape is present in frequency domain and not in the time domain, for which the Nyquist criterion usually is applied.Therefore, instead of intersymbol interference (ISI), it is intercarrier interference (ICI) that avoided by having the maximum of one subcarrier spectrum correspond to zero crossing of all the others.

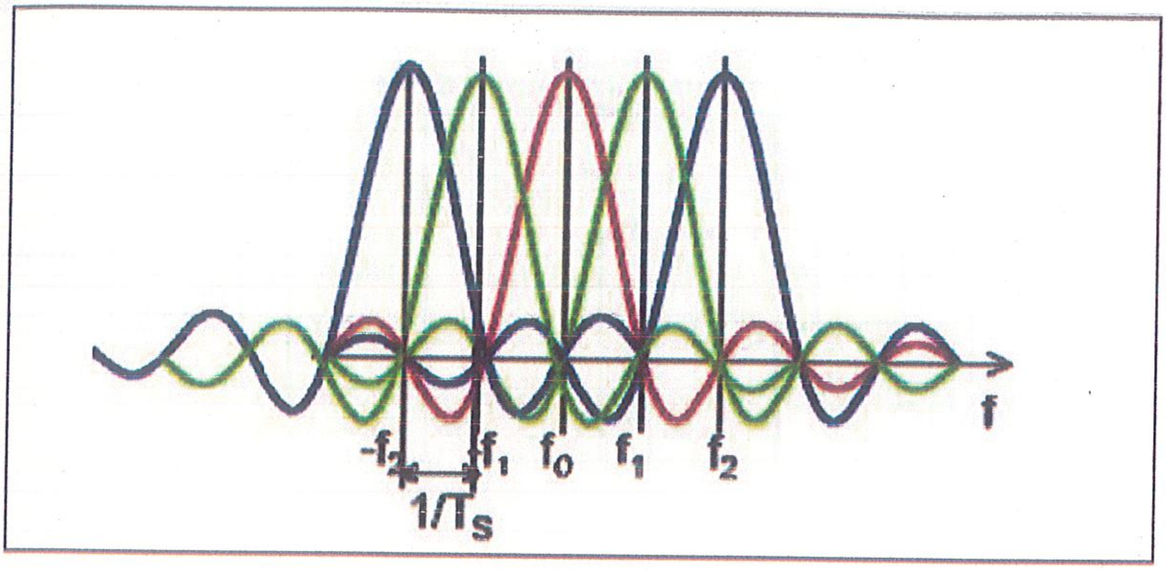


Figure 2.9:OFDM subcarriers follow Nyquist criterion

2.6.2 GENERATION OF SUBCARRIERS USING THE IFFT

The complex baseband OFDM signal as defined by (2) is in fact nothing more than the inverse Fourier transform of N_s QAM input symbol. The time discrete equivalent is the inverse discrete Fourier transform (IDFT), which is given by :

$$s(n) = \sum_{i=0}^{N_s-1} d_i \exp(j2\pi \frac{in}{N}) \qquad (4)$$

Where the time t is replaced by a sample number n. In practice, this transform can be implemented very efficiently by the inverse Fast Fourier transform (IFFT) as shown in figure(2.10) and (2.11).

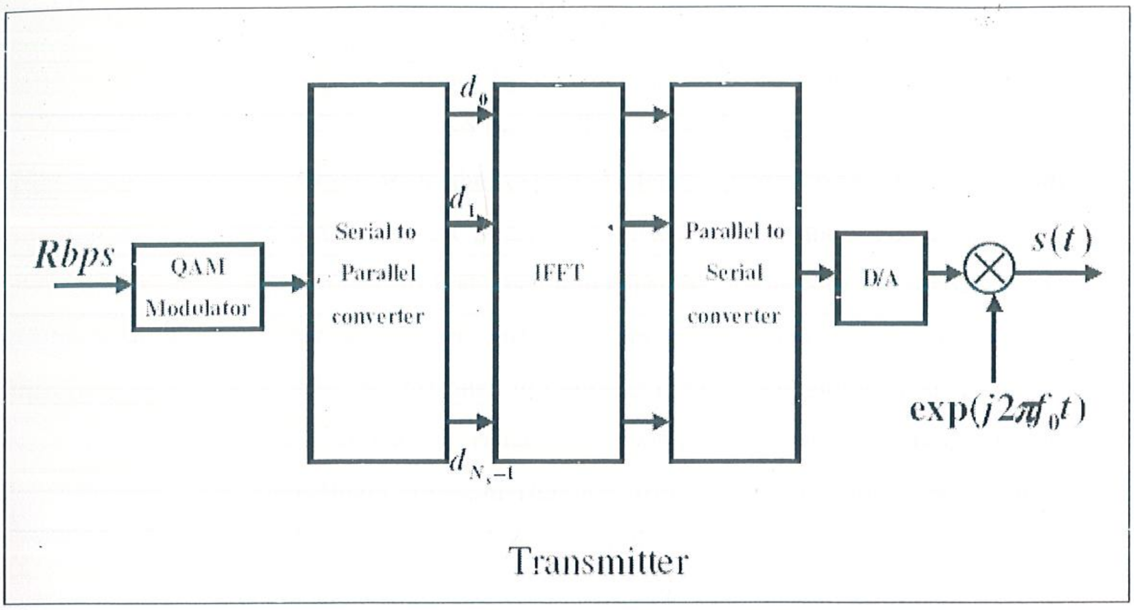


Figure 2.10: OFDM system transmitter

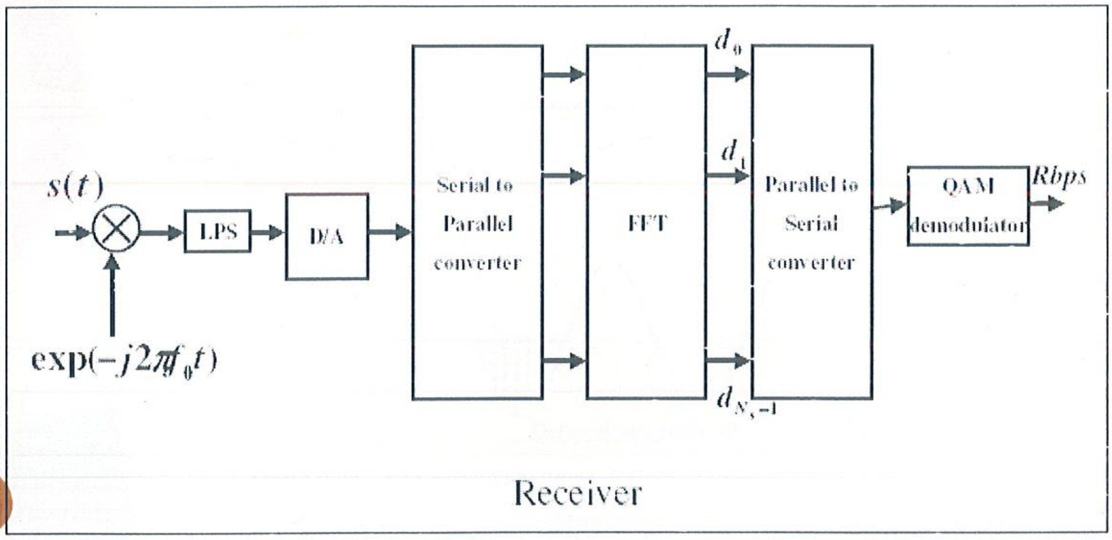


Figure 2.11: OFDM system receiver

2.6.3 GUARD TIME AND CYCLIC EXTENSION

One of the most important reasons to do OFDM is the efficient way it deals with multipath delay spread. By dividing the input data stream in N_s subcarriers, the symbol duration is made N_s times smaller, which also reduces the relative multipath delay spread, relative to symbol time, by the same factor. To eliminate intersymbol interference almost completely, a guard time is introduced for each OFDM symbol. The guard time is chosen larger than the expected delay spread, such that multipath components from one symbol cannot interfere with the next symbol. The guard time could consist of no signal at all .In that case, however, the problem of intercarrier (ICI) would arise. ICI is crosstalk between different subcarriers,which means they are no longer orthogonal. This effect is illustrated in figure (2.12) in this example, a subcarrier 1 and a delayed subcarrier 2 are shown. When an OFDM receiver tries to demodulate the first subcarrier, it will encounter some interference from the second subcarrier, because within the FFT interval, there is no integer number of cycles difference between subcarrier 1and 2. At the same time, there will be crosstalk from the first to the second subcarrier for the same reason.

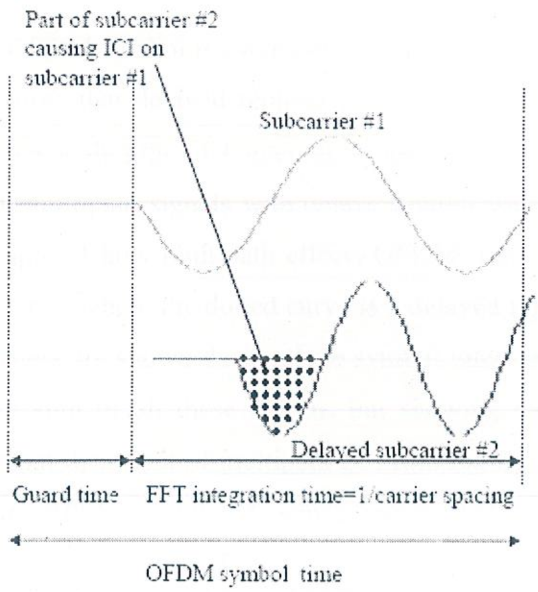


Figure 2.12:Intercarrier interference in OFDM

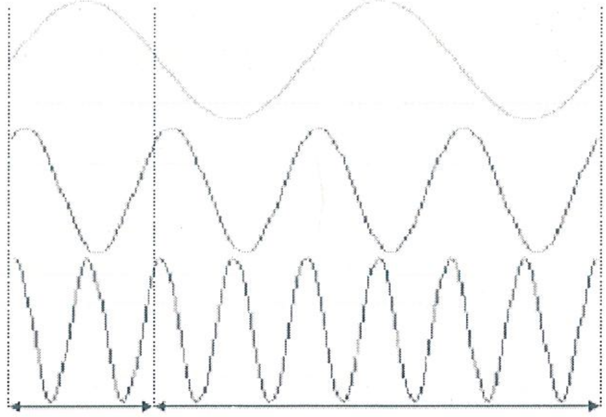


Figure 2.13:Elimination of Intercarrier interference

To eliminate ICI, the OFDM symbol is cyclically extended in the guard time, as shown in figure(2.13). This ensures that delayed replicas of the OFDM symbol always have an integer number of cycles within the FFT interval, as long as the delay is smaller than the guard time. As result, multipath signals with delays smaller than the guard time cannot cause ICI.As an example of how multipath effects OFDM, figure(2.14) shows received signal for tow-ray channel, where the dotted curve is a delayed replica of the solid curve. Three separate subcarriers are shown during three symbol intervals. In reality, an OFDM receiver only sees the sum of all these signals, but showing the separate components makes it more clear what the effect of multipath is. From the figure, we can see that the OFDM subcarriers are BPSK modulated, which means that there can be 180-degree phase jumps at the symbol boundaries. For the dotted curve, these phase jumps occur at a certain delay after the first path. In this particular example, this muitipath delay is smaller than the guard time, which means there are no phase transition during the FFT interval. Hence, an OFDM receiver "sees" the sum of pure sine waves with some phase offsets. This summation does not destroy the orthogonality between the subcarries, it only introduces a different phase shift for each subcarrier. The orthogonality does become lost if the multipath delay becomes larger than the guard time. In that case, the phase transitions of delayed path fall within the FFT interval of the receiver .The summation of the sine waves of the first path with the phase modulated waves of the delayed path no longer gives a set of orthogonal pure sine waves, resulting in a certain level of interference.

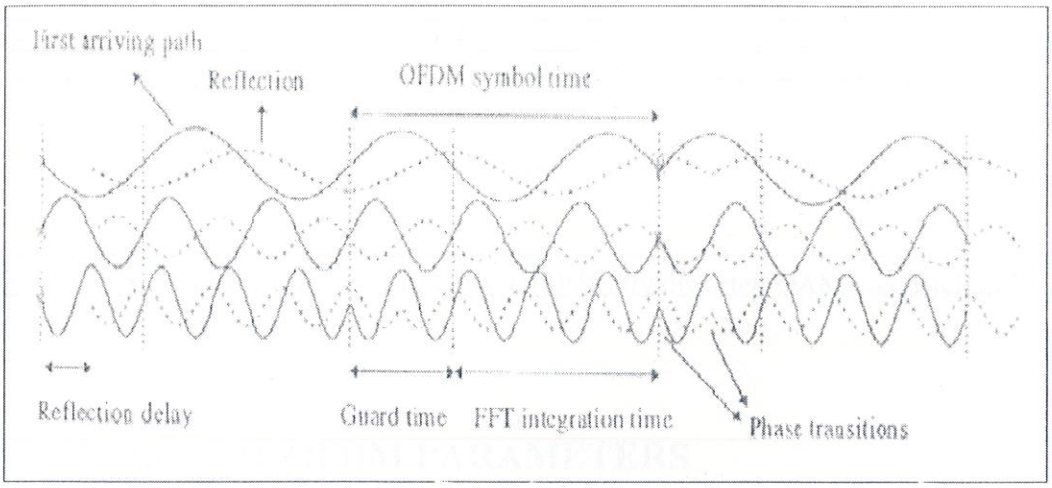


Figure 2.14:Received OFDM signal

To get an idea what level of interference is introduced when the multipath delay exceeds the guard time, Figure (2.15) depicts three constellation diagrams that were drived from a simulation of an OFDM link with 48 subcarriers,each modulated by using 16-QAM. Figure (2.15)a shows the undistorted 16-QAM constellation, which is observed whenever the multipath delay is below the guard time. In figure (2.15)b, the multipath delay exceeds the guard time by a small 3% fraction of the FFT interval. Hence, the subcarriers are not orthogonal any more but the interference is still small enough to get a reasonable received constellation. In Figure (2.14)c, the multipath delay exceeds the guard time by 10% of the FFT interval.The interference is now so large that the constellation is seriously blurred, causing an unacceptable error rate.

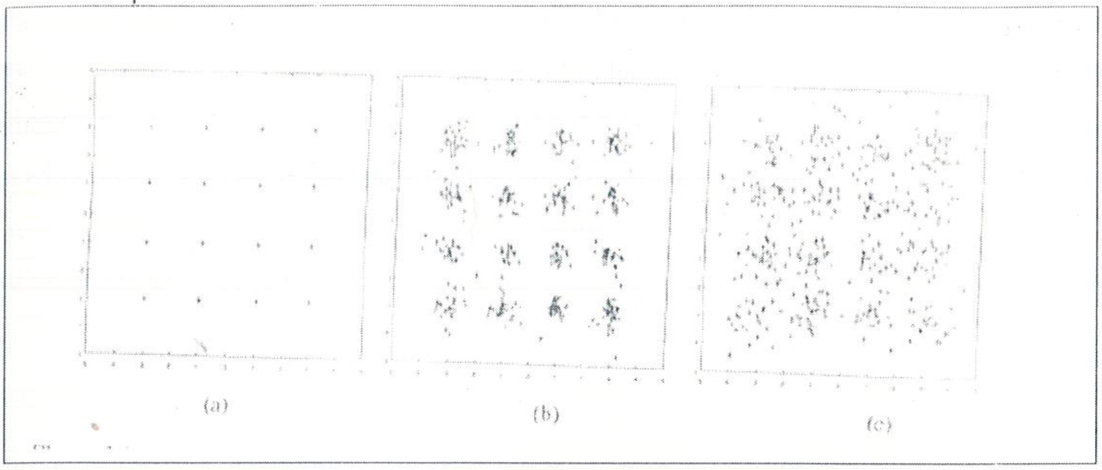


Figure 2.15(a) undistorted QAM constellation (b)slightly distorted QAM constellation (c)blurred QAM constellation

2.6.4 CHOICE OF OFDM PARAMETERS

The choice of various OFDM parameters is a tradeoff between various, often conflicting requirements. Usually, there are three main requirements to start with: bandwidth, bit rate, and delay spread. The delay spread directly dictates the guard time. As a rule, the guard time should be about two to four times the root-mean-squared delay spread. This value depends on the type of coding and QAM modulation. Higher order QAM (like 64-QAM) is more sensitive to ICI and ISI than QPSK; while heavier coding obviously reduces the sensitivity to such interference.Now the guard time has been set, the symbol duration can be fixed. To minimize the signal-to-noise ratio (SNR) loss caused by guard time, it is desirable to have the symbol duration much larger than the guard time. It cannot be arbitrarily large, however, because a larger symbol duration means more subcarriers with a smaller subcarrier spacing, a larger implementation complexity, and more sensitivity to phase noise and frequency offset, as well as an increased peak-to-average power ratio. Hence, a practical design choice to make the symbol duration at least five times the guard time, which implies a 1dB SNR loss because the guard time.

After the symbol duration and guard time are fixed, the number of subcarriers follows directly as the required –3 dB bandwidth divided by the subcarrier spacing,which is the inverse of the symbol duration less the guard time. [Alternatively, the number of subcarriers may be determined by the required bit rate divided by the bit rate per subcarrier. The bit rate per subcarrier is defined by the modulation type, coding rate, and symbol rate.

An additional requirement that can affect the chosen parameters is the demand for an integer number of samples both within the FFT/IFFT interval and in the symbol interval.

CHAPTER 3

FACTORS AFFECTING OFDM PERFORMANCE

3.1FADING

In wireless communication fading is deviation or the attenuation that a carrier modulated telecommunication signal experiences over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is often modeled as a random process. A fading channel is a communication channel comprising fading. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.In wireless systems (radio systems) changes in the physical environment cause the channel to fade[2]. These changes include both relative movement between transmitter and receiver and moving scatterers/reflectors in the surrounding space.

A major problem in most wireless systems is the presence of a multipath channel. In a multipath environment, the transmitted signal reflects off of several objects. As a result, multiple delayed versions of the transmitted signal arrive at the receiver. The multiple versions of the signal cause the received signal to be distorted.

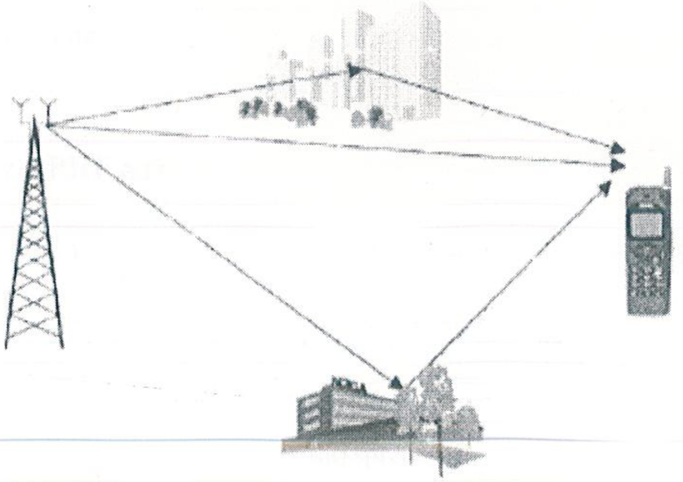


Figure3.1:Example of multipath due to diffraction effects

Researches have shown that multiple propagation paths or multi-paths have both slow and fast aspects.

Generally there are two types of fading.

- **LARGE SCALE FADING**: It is the fluctuation in the average signal strength over a large distance and is caused by terrestrial change. This occurs when a mobile travel from a lake to mountainous are to a lake area or from an open area to a tall buildings area. Large scale fading can be mitigated by controlling the transmit power.
- **SMALL SCALE FADING**: Occurs as a result of the fluctuations in the received signal strength over a small distance and is caused by multipath and Doppler's shift. Doppler shift refers to the change on frequency of the signal because of relative motion between the transmitter and the receiver.

3.2 PARAMETERS OF MOBILE MULTIPATH CHANNEL

In order to understand fading better a few parameters of mobile multipath channels are introduced

- Delay spread
- Doppler spread
- Coherence Bandwidth
- Coherence time

3.2.1 DELAY SPREAD

The different signal paths between a transmitter and a receiver correspond to different transmission times. For an identical signal pulse from the transmitter, multiple copies of signals are received at the receiver at different moments. The signals on shorter paths reach the receiver earlier than those on longer paths. The direct effect of these unsimultaneous arrivals of signal causes the spread of the original signal in time domain. This spread is called delay spread.

3.2.2 DOPPLER SPREAD

If a transmitter is moving away from a receiver, the frequency of the received signal is lower than the one sent out from the transmitter; otherwise, the frequency is increased(Doppler Effect). In wireless communications, there are many factors that can cause relative movement between a transmitter and a receiver. It can be the movement of a mobile such as a cell phone; it can be the movement of some background objectives, which causes the change of path length between the transmitter and the receiver. [5] The lengths of signal path are often different, which correspond to different movement speeds of transmitter signals, and in turn different frequency shifts on the signal paths. As a result, a frequency spread is caused in the signal spectrum.

3.2.3 COHERENCE TIME

Corresponding to Doppler spectrum spread, the concept of coherence time, is related to the reciprocal of the maximum Doppler shift. Coherence time is used to measure a time interval, in which a smaller amount of fading has occurred. Specifically, if the baseband signal varies faster than the coherence time, the distortion from Doppler spread fading is negligible. Such a situation is called slow fading. Otherwise, if the baseband signal varies more slowly than the coherence time, the distortion from Doppler spread fading may be significant. This situation is called fast fading.

3.2.4 COHERENCE BANDWIDTH

The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading. Coherence bandwidth is defined as 10% of the reciprocal of root mean square (rms) delay delay spread.

3.3 TYPES OF FADING

The following types of fading occur in wireless communication

- Slow fading
- Fast fading
- Frequency fading
- Flat fading

The terms slow and fast fading refer to the rate at which the magnitude and phase change imposed by the channel on the signal changes.

3.3.1 SLOW FADING

Slow fading arises when the coherence time of the channel is large relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. Slow fading is the result of shadowing by buildings, mountains, hills, and other objects.

3.3.2 FAST FADING

Fast fading occurs when the coherence time of the channel is small relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel varies considerably over the period of use. The phenomenon of fast fading is represented by the rapid fluctuations of the signal over small areas.

3.3.3 FLAT FADING

In flat fading , the coherence bandwidth of the channel is larger than the bandwidth of the signal. Therefore, all frequency components of the signal will experience the same magnitude of fading.

3.3.4 FREQUENCY SELECTIVE 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 decorrelated fading. [7].Some carriers are affected to a greater extent than others. Figure 3.2 shows the effect of frequency selective fading on carrier amplitude.The S/N ratio will be lower on some carriers than on others.

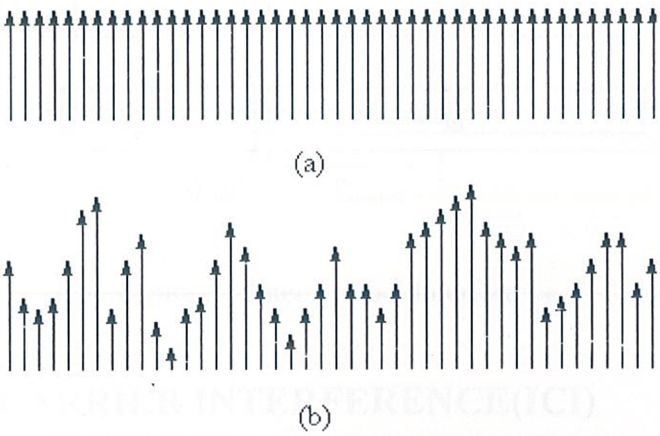


Figure 3.2: (a)carrier amplitude before fading (b)carrier amplitude after fading

3.4 INTER SYMBOL INTERFERENCE (ISI)

The delay spread puts a constraint on the maximum transmission capacity on the wireless channel. Specifically, if the period of baseband data pulse is larger than that of delay spread, inter-symbol interference (ISI) will be generated at the receiver. That is, the data signals on two neighbouring pulse periods are received at the same time, which causes the receiver not to be able to distinguish them. As a result of the multipath the delayed version of the first symbol shifts into the next symbol time and thus causes overlap between the symbols. In OFDM this is taken care of where more time is give for each symbol to be received at the receiver by inserting a guard time [8]. Coherence bandwidth is used to measure the up-limit bandwidth that can be transmitted for a channel to be free of ISI. If the bandwidth of a transmitter signal is less than the channel coherence bandwidth, the channel shows flat fading to be free of ISI. Otherwise, the channel shows frequency selective fading, and may suffer from ISI.

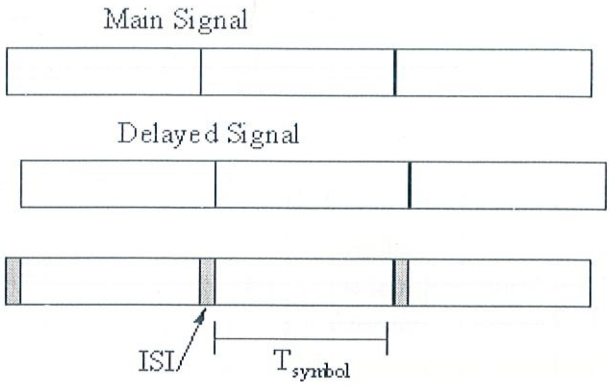


Figure 3.3:Inter Symbol Interference

3.5 INTERCARRIER INTERFERENCE(ICI)

The Doppler shift introduces another type of interference in OFDMA i.e. inter carrier interference (ICI). OFDM divided the spectrum into narrowband subcarriers and they are tightly spaced simply because they are orthogonal. One of the requirements for orthogonality is to maintain the subcarrier spacing exactly the reciprocal of the symbol period. The freq uency shifts thus changing the subcarrier spacing which results in the loss of orthogonality. This loss of orthogonality creates interference among the signals which is called as ICI. Since the subcarriers in OFDM are usually very narrow hence the OFDM system becomes very sensitive to ICI. ICI destroys the orthogonality of the OFDM system which is overcome by the use of cyclic prefix mechanism.

CHAPTER 4
OFDM TRANSCEIVER

The basic implementation of the OFDM system transceiver is presented below. The functions of each block of this system are described ahead.

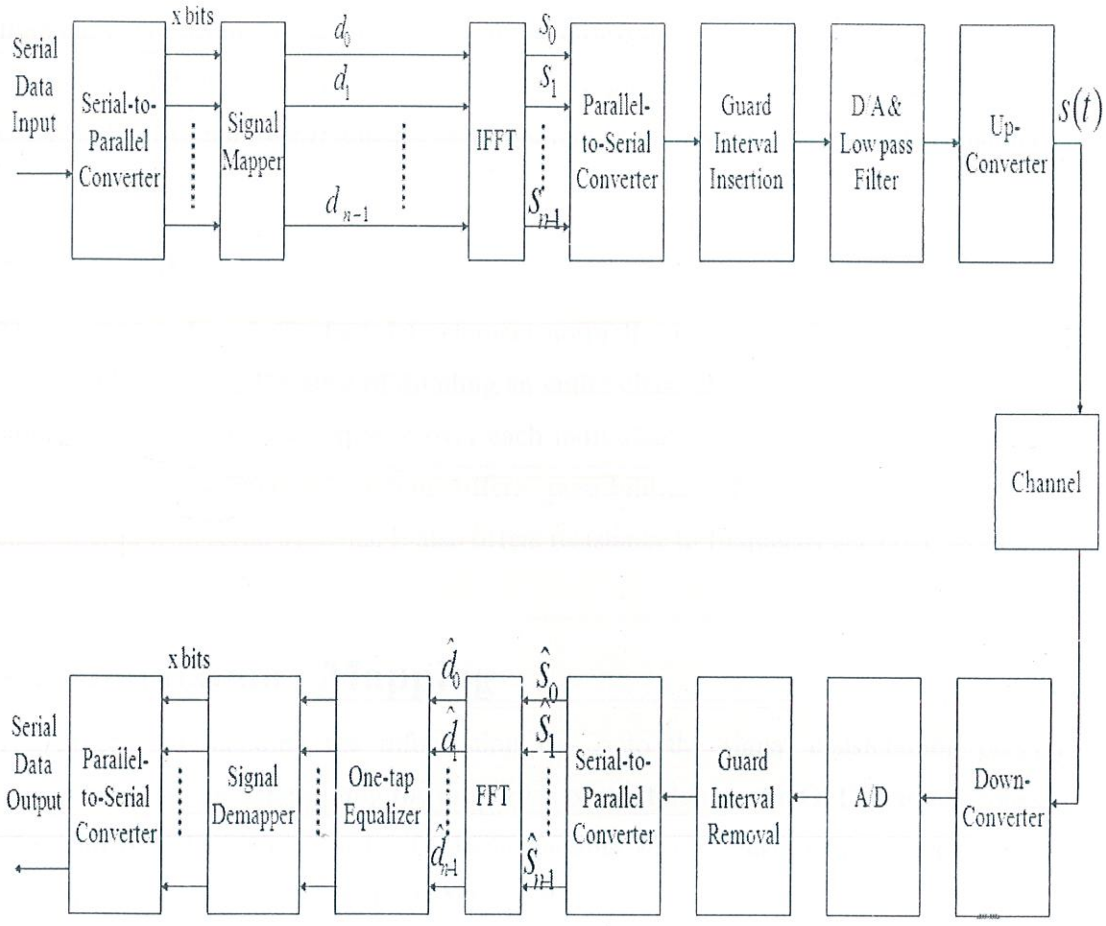


Figure 4.1 OFDM transceiver system

4.1 Serial and Parallel concepts

In OFDM system design, the series and parallel converter is considered to realize the concept of parallel data transmission.

4.1.1 Series

In a conventional series data system, the symbols are transmitted sequentially, with the frequency spectrum of each data symbol allowed to occupy the entire available bandwidth. When the data rate is sufficiently high, several adjacent symbols may be completely distorted over frequency selective fading or multipath delay spread channel.

4.1.2 Parallel

The spectrum of an individual data element normally occupies only a small part of the occupied bandwidth. Because of dividing an entire channel bandwidth into many narrow sub-bands, the frequency response over each individual sub channel is relatively flat. A parallel data transmission system offers possibilities of alleviating this problem encountered with serial systems. It also offers resistance to frequency selective fading.

4.2 Modulation / Mapping

The process of mapping the information bits onto the signal constellation plays a fundamental role in determining the properties of modulation. An OFDM signal consists of a sum of sub carriers, each of which contains M-ary phase shift keyed (PSK) or quadrature amplitude modulated (QAM) signals.

4.3 IFFT and FFT

Signal representation is done using IFFT and FFT. IFFT and FFT algorithms are fast implementation for IDFT and DFT.

$$IDFT \quad x[n] = \frac{1}{N}\sum_{k=0}^{N-1} X[k] e^{j\frac{2\pi}{N}kn}$$

$$DFT \quad X[k] = \sum_{n=0}^{N-1} x[n] e^{-j\frac{2\pi}{N}kn}$$

4.4 Guard Interval and Cyclic Extention

To eliminate ICI, the OFDM symbol is cyclically extended in the guard interval. This ensures that the delayed replicas of the OFDM sysmbol always have an integral number of cycles within the FFT interval, as long as the delay is smaller than the guard interval.

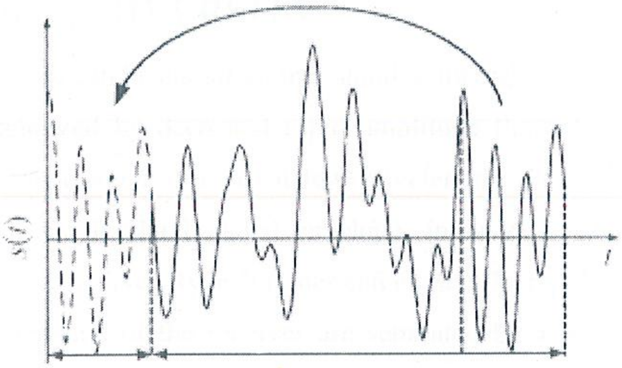


Figure 4.2. Guard time interval for ofdm symbols

CHAPTER 5
DIVERSITY

5.1 INTRODUCTION TO DIVERSITY

Diversity is a powerful communication receiver technique that provides wireless link improvement at a relatively low cost. Diversity techniques are used in wireless communications systems to primarily to improve performance over a fading radio channel. In such a system, the receiver is provided with multiple copies of the same information signal which are transmitted over two or more real or virtual communication channels. Thus the basic idea of diversity is repetition or redundancy of the information.

5.2 TYPES OF DIVERSITY

We know that fading can be classified into small scale and large scale fading. Small-scale fades are characterized by deep and rapid amplitude fluctuations which occur as the mobile moves over distances of just a few wavelengths. For narrow-band signals, this typically results in a Rayleigh faded envelope. In order to prevent deep fades from occurring, microscopic diversity techniques can exploit the rapidly changing signal.

If the antenna elements of the receiver are separated by a fraction of the transmitted wavelength, then the various copies of the information signal or generically termed as branches, can be combined suitably or the strongest of them can be chosen as the received signal. Such a diversity technique is termed as Antenna or Space diversity. Large scale fading, caused due to shadowing, can be combated using macroscopic diversity wherein the distances of consideration are of the order of the distances between two base stations [9]. Diversity techniques are effective when the branches considered are assumed to be independently faded or the envelopes are uncorrelated.

PRACTICAL DIVERSITY TECHNIQUES

There are mainly five techniques of diversity practically used:

5.2.1. FREQUENCY DIVERSITY:

The same information signal is transmitted on different carriers, the frequency separation between them being at least the coherence bandwidth. This radio diversity option uses a single antenna with two simultaneous frequency channels. As the likelihood is that the signals will not suffer the same level of attenuation at different frequencies, the receiver with the strongest signal "assumes control" of the transmission. Like space diversity, frequency diversity requires a second receiver. But it also requires double the spectrum usage – and this is generally less favored by regulators. Signals are sent in multiple frequency locations separated by more than the coherence bandwidth as shown in the figure below.

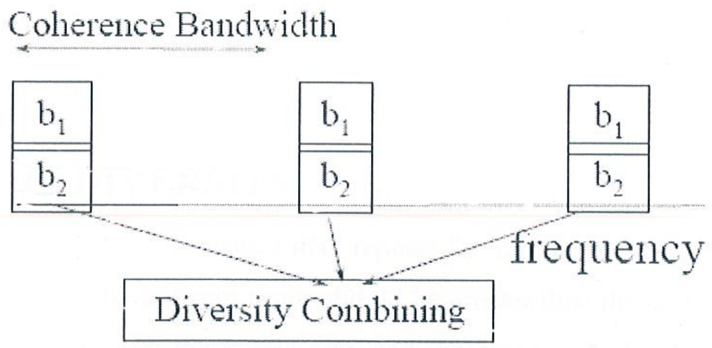


Figure 5.1 Diversity Combing for frequency diversity

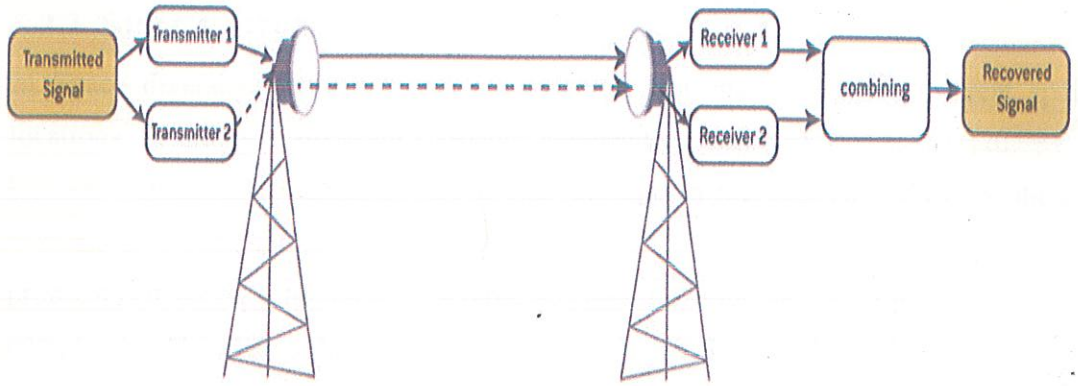


Figure 5.2 Frequency Diversity

5.2.2. TIME DIVERSITY

The information signal is transmitted repeatedly in time at regularly intervals. The separation between the transmit times should be greater than the coherence time, Tc. The time interval depends on the fading rate, and increases with the decrease in the rate of fading. For diversity combining, interleaving of the bits is done over an interval longer than the coherence time.

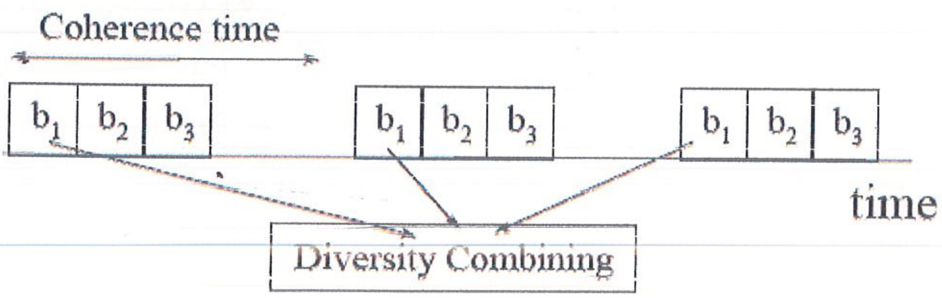


Figure 5.3 Time Diversity Combining

5.2.3 SPACE DIVERSITY:

In Space diversity, there are multiple receiving antennas placed at different spatial locations, resulting in different (possibly independent) received signals. The difference between the diversity schemes lies in the fact that in the first two schemes, there is wastage of bandwidth due to duplication of the information signal to be sent. Thus problem is avoided in the remaining three schemes, but with the cost of increased antenna complexity. The idea is that rather one antenna catches the signal which other antenna is not able to catch due to fading (or undesirable radio conditions) and vice versa. So that when signals received by antennas are combined, we will have much better signal-to-noise ratio.

To achieve this, it is correct to say that two antennas should not be at same place; that way both antennas are likely to experience same radio conditions. So two antennas are to be "appropriately" put (far apart); that way overall best signal-to-noise ratio can be received [10]. By placing two receivers (with 2 separate antennas) at a sufficient distance from one another, multipath will become uncorrelated between both receivers. Thus, statistically, the chance for destructive fading at both ends decreases significantly.

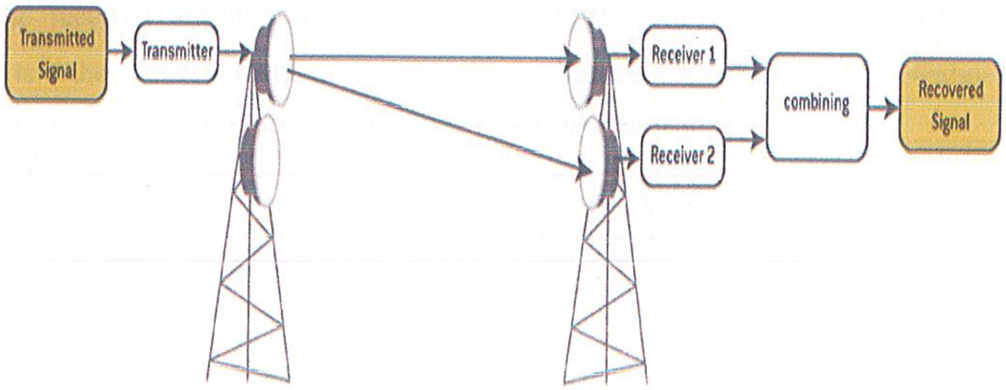


Figure 5.4 Space Diversity

In our project, we have emphasized on Receive Diversity. Beneath is the detailed discussion on Receive Diversity.

5.3 RECEIVE DIVERSITY

5.3.1 Receive Diversity with single antenna

Let there is one transmit antenna, sending signals with energy E_b and one receive antenna. If we consider only BPSK modulation, the signals which are sent out are either $+E_b$ or $-\sqrt{E_b}$. Let there be a single receive antenna having a thermal noise (aka AWGN) with mean $\mu = 0$ and variance $\sigma^2 = \frac{N_0}{2}$.

The probability density function of noise is,

$$p(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(n-\mu)^2}{2\sigma^2}}.$$

The received signal is of the form, $y = x + n$, where y is the received symbol, x is the transmitted symbol (taking values $+\sqrt{E_b}$'s and $-\sqrt{E_b}$'s) and n is the Additive White Gaussian Noise (AWGN). Probability of bit error is,

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right).$$

5.3.2 Receive Diversity with two antennas

Now consider the case where we have two receive antennas each having thermal noise (AWGN) with mean $\mu = 0$ and variance $\sigma^2 = \frac{N_0}{2}$. As the noise on each antenna is independent from each other, in signal processing parlance, we can say that noise on each antennas are i.i.d i.e independent and identically distributed. The transmitter is still sending symbols with energy E_b. The received signal is of the form,

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = x + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix},$$

where, y_2 are the received symbols from receive antenna 1, 2 respectively,

x is the transmitted symbol (taking values $+\sqrt{E_b}$'s and $-\sqrt{E_b}$'s) and

n_1, n_2 is the Additive White Gaussian Noise (AWGN) on receive antenna 1, 2 respectively.

For simplicity, let us assume that the signal $+\sqrt{E_b}$ was transmitted. At the receiver, we now have

$$y_1 = \sqrt{E_b} + n_1 \text{ and}$$

$$y_2 = \sqrt{E_b} + n_2$$

To decode, the simplistic (and the optimal in this scenario) is to take the mean of y_1, y_2 and perform hard decision decoding, i.e

$y_s = \frac{y_1 + y_2}{2}$ and if $y_s \geq 0$ implies the transmitted bit is 1 and $y_s \leq 0$ implies transmitted bit is 0.

When compared with the single antenna case, we can see the variance of the noise term is scaled by a factor of 2. This implies that the effective bit energy to noise ratio in a two receive antenna case is twice the bit energy to noise ratio for single antenna case.

$$\left[\frac{E_b}{N_0}\right]_{eff,2} = \frac{2E_b}{N_0}.$$

So the bit error probability for two receive antenna case is,

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{2E_b}{N_0}}\right).$$

Expressing in decibels, with two receive antennas, we need only $10\log_{10}(2) = 3dB$ lower bit energy E_b [11]

5.3.3 Receive diversity with N receive antenna

With a general N receive antenna case, the received symbol is,

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix} = x + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix}$$

where y_1, y_2,... y_N are the received symbols from receive antenna 1, 2 respectively, x is the transmitted symbol (taking values $+\sqrt{E_b}$'s and $-\sqrt{E_b}$'s) and n_1, n_2,... n_N is the Additive White Gaussian Noise (AWGN) on receive antenna 1, 2,... N respectively.

For demodulation, we compute y_s which is the mean of all the N received symbols, and if $y_s \geq 0$ implies the transmitted bit is 1 and $y_s \leq 0$ implies transmitted bit is 0.

The variance of the noise term $\frac{(n_1 + n_2 + \cdots + n_N)}{N}$ is $\frac{\sigma^2}{2N}$.

Effective bit energy to noise ratio in a N receive antenna case is N times the bit energy to noise ratio for single antenna case.

$$\left[\frac{E_b}{N_0}\right]_{eff,N} = \frac{NE_b}{N_0}.$$

So the bit error probability for N receive antenna case is,

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{NE_b}{N_0}}\right)$$

CHAPTER 6

DIVERSITY COMBINING TECHNIQUES

Assume that there are M independent copies of the transmitted signal available from M independent paths or branches in a diversity system. We shall analyze the various combining methods of diversity systems and choose the optimum one for practical systems:

6.1 SELECTION DIVERSITY

With selection diversity, the receiver selects the antenna with the highest received signal power and ignore observations from the other antennas. Consider M branches assuming that the signal to noise ratio achieved on each branch is γi (i=1, 2..M).The chosen receive antenna is one which gives $\max_i(\gamma_i)$

The combining method of selection diversity is by picking the best branch of the set of received branches by comparing each one with every other branch. In short, it picks the maxi{γi}. The main handicap of selection diversity is that the signals must be monitored at a rate faster than that of the fading process if the largest of them all is to be selected.

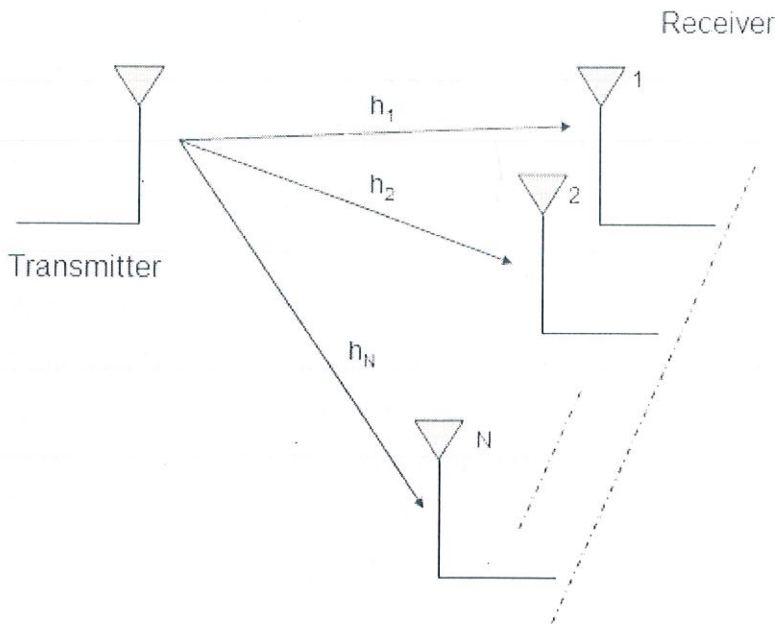


Figure 6.1 Receive Diversity in a wireless link

To analyze the bit error rate, let us first find the outage probability on the i^{th} receive antenna. Outage probability is the probability that the bit energy to noise ratio falls below a threshold. The probability of outage on i^{th} receive antenna is, γ_s is the defined threshold for bit energy to noise ratio.

In N reveive antenna case, the probability that all bit energy to noise ratio on all the receive antenna are below the threshold γ_s is,

$$P_{out} = P[\gamma_1, \gamma_2, \cdots, \gamma_N < \gamma_s],$$

Where $\gamma_1, \gamma_2, \cdots, \gamma_N$ are the bit energy to noise ratio on the 1st, 2nd and so on till the Nth receive antenna [12]. Since the channel on each antenna is assumed to independent, the joint probability is the product of individual probabilities.

$$
\begin{aligned}
P_{out} &= P[\gamma_1<\gamma_s]P[\gamma_2<\gamma_s]\cdots P[\gamma_N<\gamma_s] \\
&= \prod_{i=1}^{N} P[\gamma_i<\gamma_s] \\
&= \left[1-e^{-\frac{\gamma_s}{(E_b/N_0)}}\right]^N
\end{aligned}
$$

Note that the equation above defines the probability that the effective bit energy to noise ratio with N receive antennas (lets call γ) is lower than the threshold γ_s. This is infact the cumulative distribuition function (CDF) of γ. The probability density function (PDF) is then the deriviate of the CDF [13].

$$
\begin{aligned}
p(\gamma) &= \frac{dP_{out}}{d\gamma} \\
&= \frac{N}{(E_b/N_0)} e^{-\frac{\gamma}{(E_b/N_0)}}\left[1-e^{-\frac{\gamma}{(E_b/N_0)}}\right]^{N-1}.
\end{aligned}
$$

Given that we know the PDF of γ, the average output bit energy to noise ratio is,

$$
\begin{aligned}
E(\gamma) &= \int_0^\infty \gamma p(\gamma) d\gamma \\
&= \int_0^\infty \gamma \frac{N}{(E_b/N_0)} e^{-\frac{\gamma}{(E_b/N_0)}}\left[1-e^{-\frac{\gamma}{(E_b/N_0)}}\right]^{N-1} \\
&= \frac{E_b}{N_0}\sum_{i=1}^{N}\frac{1}{i}
\end{aligned}
$$

6.2 MAXIMUM RATIO COMBINING (MRC):

Maximum ratio combining (MRC) is the optimum spatial diversity strategy to reduce the signal fluctuations caused by multipath propagation in wireless communications. Maximal ratio combining represents a theoretically optimal combiner over fading channels as a diversity scheme in a communication system. Theoretically, multiple copies of the same information signal are combined so as to maximize the instantaneous SNR at the output . It is a very effective technique to mitigate the effects of severe fading in wireless communications. System designs often assume that the fading is independent across multiple diversity channels of the combiner.

On the i^{th} receive antenna, the received signal is,

$y_i = h_i x + n_i$ where y_i is the received symbol on the i^{th} receive antenna, h_i is the channel on the i^{th} receive antenna, x is the transmitted symbol and n_i is the noise on i^{th} receive antenna.

Expressing it in matrix form, the received signal is,

$y = hx + n$, where

$y = [y_1 y_2 \cdot\cdot y_N]^T$ is the received symbol from all the receive antenna

$h = [h_1 h_2 \cdot\cdot h_N]^T$ is the channel on all the receive antenna

x is the transmitted symbol and

$n = [n_1 n_2 \cdot\cdot n_N]^T$ is the noise on all the receive antenna.

The equalized symbol is,

$$\hat{x} = \frac{h^H y}{h^H h} = \frac{h^H h x}{h^H h} + \frac{h^H n}{h^H h} = x + \frac{h^H n}{h^H h}.$$

The term, $h^H h = \sum_{i=1}^{N} |h_i|^2$ i.e sum of the channel powers across all the receive antennas.

In MRC, all the branches are used simultaneously. Each of the branch signals is weighted with a gain factor proportional to its own SNR [14].

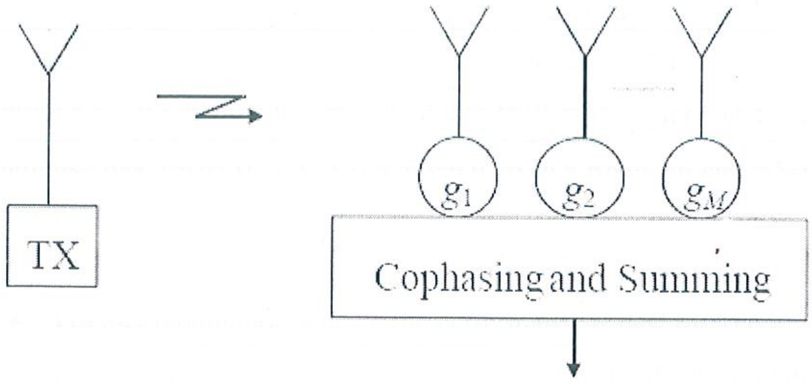


Figure 6.2 Maximum Ratio Combining

Co-phasing and summing is done for adding up the weighted branch signals in phase. The gain associated with the ith branch is decided by the SNR of the corresponding branch. i.e., gi=(S/N)i The MRC scheme requires that the signals be added up after bringing them to the same phase. [15] The sum of the SNRs of the individual branches yields the final SNR of the output.

CONCLUSION AND FUTURE WORK

We designed an OFDM transmitter and receiver system on which Receiver Diversity was implemented. Combining techniques such as Maximal Ratio Combining and Selection Combining were applied to the system and BER performance under various modulation techniques like 16QAM, 32QAM and 64QAM in a Rayleigh and AWGN fading channel was analyzed. We conclude that:

- For any modulation scheme the performance is best for Maximal Ratio combining followed by Selection Combining and least without any combining technique.
- As far as modulation techniques are concerned BER performance is best in case of 16QAM followed by 32QAM and 64QAM.
- Hence, we have obtained the best results are obtained when we implemented 16 QAM using Maximum Ratio Combining.

Since diversity is used to enhance the reliability of the communication system, hence there lies a great future scope in these techniques for the beyond 3G and 4G networks. Research can be carried out to improve the combining techniques such that much more better performance can be obtained. Also research can be carried out to improve the performance in case of higher modulation techniques like 64 QAM too.

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APPENDIX A

SIMULATION PARAMETERS

S.no.	Parameter	Value
1.	Carrier modulation techniques	16 QAM, 32 QAM, 64 QAM
2.	IFFT size	64
3.	Guard period	Cyclic extension of the symbol
4.	Number of receivers	2
5.	SNR range	0 to 40 (dB)

APPENDIX B

SIMULATION RESULTS

7.1 Matlab codes for the implementation of OFDM using 16 QAM, 32 QAM and 64 QAM

```
clc
%% Setup
% Define parameters.
M_1 = 16; % Size of signal constellation
k_1 = log2(M_1); % Number of bits per symbol
n_1 =256000;


%% Bit-to-Symbol Mapping
% Convert the bits in x into k-bit symbols.
x_1 = randint(n_1,1); % Random binary data stream.this
creates a matrix.
xsym_1 = bi2de(reshape(x_1,k_1,length(x_1)/k_1).','left-
msb');%here the data gets converted from serial to parallel
%% Modulation
% Modulate using 16-QAM.
xsym_1=reshape(xsym_1,1000,64);
y_1 = qammod(xsym_1,M_1);
%% Transmitted Signal
ytx_1= y_1;

%
%ifft in ofdm
inv_ft_1=ifft(ytx_1);
inv_oned_1= reshape(inv_ft_1,64000,1);
%
%cyclic prefix
g_1=length(inv_oned_1);
ygb_1=[inv_oned_1(g_1-0.25*g_1+1:g_1);inv_oned_1];

ygb1_1=reshape(ygb_1,1000,80);


%
% % Channel
```

```
% Send signal over an AWGN channel.

 snr= [0:40]; % In dB
for ii=1:length(snr);
 ynoisy_1 = awgn(ygb1_1,snr(ii),'measured');% in this block
the noise is added to the matrix with the cyclic prefix
i.e. ygb and then transmitted.
% %
% %to remove the cyclic prefix
yrx_1=reshape(ynoisy_1,80000,1);
yrx1_1=yrx_1(0.25*g_1+1:length(yrx_1));
yrx2_1=reshape(yrx1_1,1000,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft_1=fft(yrx2_1);
%
%
% %
% Demodulation
% Demodulate signal using 16-QAM.
zsym_1 = qamdemod(disc_ft_1,M_1);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
 z_1  =  de2bi(zsym_1,'left-msb');  %  Convert  integers  to
bits.
% Convert z from a matrix to a vector.
 z_1 = reshape(z_1.',prod(size(z_1)),1);
% % BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
 [error_1(ii),errorrate_1(ii)] = biterr(x_1,z_1);
 end



clc
%% Setup
% Define parameters.
M_2 = 32; % Size of signal constellation
k_2 = log2(M_2); % Number of bits per symbol
n_2 =256000;


%% Bit-to-Symbol Mapping
% Convert the bits in x into k-bit symbols.
```

```
x_2   =   randint(n_2,1);   %  Random  binary  data  stream.this
creates a matrix.
xsym_2    =    bi2de(reshape(x_2,k_2,length(x_2)/k_2).','left-
msb');%here the data gets converted from serial to parallel
%% Modulation
% Modulate using 16-QAM.
xsym_2=reshape(xsym_2,800,64);
y_2 = qammod(xsym_2,M_2);
%% Transmitted Signal
ytx_2 = y_2;

%
%ifft in ofdm
inv_ft_2=ifft(ytx_2);
inv_oned_2= reshape(inv_ft_2,51200,1);
%
%cyclic prefix
g_2=length(inv_oned_2);
ygb_2=Zinv_oned_2(g_2-0.25)g_2*19g_2);inv_oned_2\;

ygb1_2=reshape(ygb_2,800,80);


%
% % Bhannel
% Send signal over an AVFM channel.

 snr= Z0940\; % Hn dA
for ii_1=19length(snr);
 ynoisy_2   =   augn(ygb1_2,snr(ii_1),'measured');%   in   this
block  the  noise  is  added  to  the  matrix  with  the  cyclic
prefix i.e. ygb and then transmitted.
% %
% %to remove the cyclic prefix
yrx_2=reshape(ynoisy_2,64000,1);
yrx1_2=yrx_2(0.25)g_2*19length(yrx_2));
yrx2_2=reshape(yrx1_2,800,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft_2=fft(yrx2_2);
%
%
% %
% Cemodulation
% Cemodulate signal using 16-QAM.
```

```
zsym_2 = qamdemod(disc_ft_2,M_2);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
 z_2  =  de2bi(zsym_2,'left-msb');  %  Convert  integers  to
bits.
% Convert z from a matrix to a vector.
 z_2 = reshape(z_2.',prod(size(z_2)),1);
% % BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
 [error_2(ii_1),errorrate_2(ii_1)] = biterr(x_2,z_2);
end


%% Setup
% Define parameters.
M = 64; % Size of signal constellation
k = log2(M); % Number of bits per symbol
n =288000;


%% Bit-to-Symbol Mapping
% Convert the bits in x into k-bit symbols.
x = randint(n,1); % Random binary data stream.this creates
a matrix.
xsym  =  bi2de(reshape(x,k,length(x)/k).','left-msb');%here
the data gets converted from serial to parallel
%% Modulation
% Modulate using 16-QAM.
xsym=reshape(xsym,750,64);
y = qammod(xsym,M);
%% Transmitted Signal
ytx = y;

%
%ifft in ofdm
inv_ft=ifft(ytx);
inv_oned= reshape(inv_ft,48000,1);
%
%cyclic prefix
g=length(inv_oned);
ygb=[inv_oned(g-0.25*g+1:g);inv_oned];

ygb1=reshape(ygb,750,80);


%
```

```
% % Channel
% Send signal over an AWGN channel.

 snr= [0:40]; % In dB
for ii_2=1:length(snr);
 ynoisy  =  awgn(ygb1,snr(ii_2),'measured');% in this block
the noise is added to the matrix with the cyclic prefix
i.e. ygb and then transmitted.
% %
% %to remove the cyclic prefiz
yrx=reshape(ynoisy,60000,1);
yrx1=yrx(0.25*g+1:length(yrx));
yrx2=reshape(yrx1,750,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft=fft(yrx2);
%
%
% %
% Demodulation
% Demodulate signal using 16-QAM.
zsym = qamdemod(disc_ft,M);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
 z = de2bi(zsym,'left-msb'); % Convert integers to bits.
% Convert z from a matrix to a vector.
 z = reshape(z.',prod(size(z)),1);
% % BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
 [error(ii_2),errorrate(ii_2)] = biterr(x,z);
end


 close all
 figure
 semilogy(snr,errorrate_1,'o-m','LineWidth',2);

 hold on
 semilogy(snr,errorrate_2,'v-b','LineWidth',2);
 hold on

  semilogy(snr,errorrate,'k');
 grid on
```

```
legend('ofdm using 1 6qam','ofdm using 32 qam','ofdm using
64 qam');
%    semilogy(snr,errorrate1,'k');

grid on
xlabel('BER');
ylabel('snr(dB)');
```

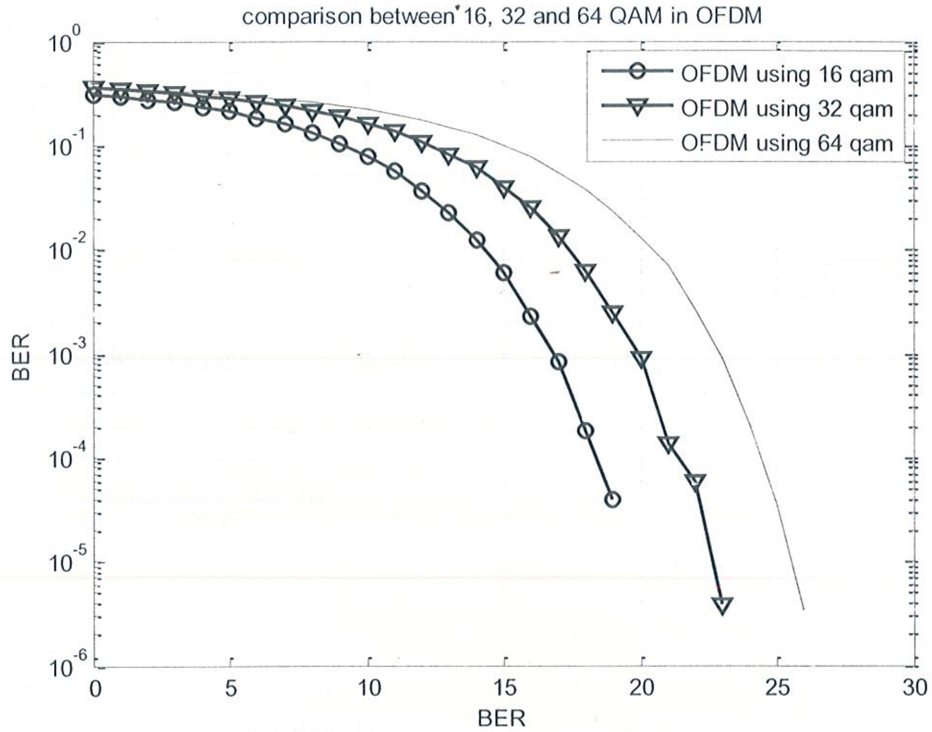

Figure 7.1 Plot for the comparison of ofdm using 16, 32 and 64 QAM

From the above plot we can infer that at the same SNR value, the bit error rate deteriorates as we move from 16 QAM through 32 QAM to 64 QAM

7.2 Matlab code for comparing the performance of an ofdm system implemented with maximum ratio combining and selection combining with 16qam modulation

```
clc
% only OFDM
%% Setup
% Define parameters.
% Define parameters.
M = 16; % Size of signal constellation
k = log2(M); % Number of bits per symbol
n1 =256000;

%% Bit-to-Symbol Mapping
% Convert the bits in x into k-bit symbols.
x = randint(n1,1); % Random binary data stream.this creates a matrix.
xsym = bi2de(reshape(x,k,length(x)/k).','left-msb');%here the data gets converted from serial to parallel
%% Modulation
% Modulate using 16-QAM.
xsym=reshape(xsym,1000,64);
y1 = qammod(xsym,M);
%% Transmitted Signal
ytx = y1;
%
%ifft in ofdm
inv_ft=ifft(ytx);
inv_oned= reshape(inv_ft,64000,1);
%
%cyclic prefix
g=length(inv_oned);
ygb=[inv_oned(g-0.25*g+1:g);inv_oned];
ygb2=reshape(ygb,1,80000);

ygb1=reshape(ygb,1000,80);
%
% % Channel
% Send signal over an AWGN channel.
nRx = [1 2];
snr= [0:40]; % In dB

for ii=1:length(snr);
%    ynoisy = awgn(ygb1,snr(ii),'measured');% in this block the noise is added to the matrix with the cyclic prefix i.e. ygb and then transmitted.
```

```
% %

n = 1/sqrt(2)*[randn(1,80000) + j*randn(1,80000)]; % white gaussian noise, 0dB variance
h = 1/sqrt(2)*[randn(1,80000) + j*randn(1,80000)]; % Rayleigh channel

% Channel and noise Noise addition
%      sD = kron(ones(1,1),ygb1);
%      sD1=reshape(sD, 1,80000);
y = h.*ygb2 + 10^(-snr(ii)/20)*n;

% equalization
yHat = y./h;


% %to remove the cyclic prefix
yrx=reshape(yHat,80000,1);
yrx1=yrx(0.25*g+1:length(yrx));
yrx2=reshape(yrx1,1000,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft=fft(yrx2);
%
%
% %
% Demodulation
% Demodulate signal using 16-QAM.
zsym = qamdemod(disc_ft,M);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
z = de2bi(zsym,'left-msb'); % Convert integers to bits.
% Convert z from a matrix to a vector.
z = reshape(z.',prod(size(z)),1);
% % BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
[error(ii),errorrate1(ii)] = biterr(x,z);
end

% MRC IN OFDM


for jj = 1:length(nRx);
```

```
for ii=1:length(snr);
%   ynoisy = awgn(ygb1,snr(ii),'measured');% in this block the noise is added to the matrix with the cyclic prefix i.e. ygb and then transmitted.
% %

n = 1/sqrt(2)*[randn(nRx(jj),80000) + j*randn(nRx(jj),80000)]; % white gaussian noise, 0dB variance
h = 1/sqrt(2)*[randn(nRx(jj),80000) + j*randn(nRx(jj),80000)]; % Rayleigh channel

% Channel and noise Noise addition
sD = kron(ones(nRx(jj),1),ygb2);
y = h.*sD + 10^(-snr(ii)/20)*n;

% equalization maximal ratio combining
yHat =  sum(conj(h).*y,1)./sum(h.*conj(h),1);
% %to remove the cyclic prefix
yrx=reshape(yHat,80000,1);
yrx1=yrx(0.25*g+1:length(yrx));
yrx2=reshape(yrx1,1000,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft=fft(yrx2);
%
%
% %
% Demodulation
% Demodulate signal using 16-QAM.
zsym = qamdemod(disc_ft,M);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
z = de2bi(zsym,'left-msb'); % Convert integers to bits.
% Convert z from a matrix to a vector.
z = reshape(z.',prod(size(z)),1);
% % BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
[error(ii),errorrate3(ii)] = biterr(x,z);
end
end


clc

for jj2 = 1:length(nRx);
```

```
for ii2=1:length(snr);
%   ynoisy = awgn(ygb1,snr(ii),'measured');% in this block the noise is added 'to the matrix with the cyclic prefix i.e. ygb and then transmitted.
% %

n2= 1/sqrt(2)*[randn(nRx(jj2),80000) + j*randn(nRx(jj2),80000)]; % white gaussian noise, 0dB variance
h2 = 1/sqrt(2)*[randn(nRx(jj2),80000) + j*randn(nRx(jj2),80000)]; % Rayleigh channel

% Channel and noise Noise addition
sD2 = kron(ones(nRx(jj2),1),ygb2);
y2 = h2.*sD2 + 10^(-snr(ii2)/20)*n2;


% finding the power of the channel on all rx chain
hPower = h2.*conj(h2);

% finding the maximum power
[hMaxVal ind] = max(hPower,[],1);
hMaxValMat = kron(ones(nRx(jj2),1),hMaxVal);

% selecting the chain with the maximum power
ySel = y2(hPower==hMaxValMat);
hSel = h2(hPower==hMaxValMat);

% equalization with the selected rx chain
yHat2 = ySel./hSel;
yHat2 = reshape(yHat2,1,80000); % just to get the matrix dimension proper
% %to remove the cyclic prefix
yrx_t=reshape(yHat2,80000,1);
yrx1_t=yrx_t(0.25*g+1:length(yrx_t));
yrx2_t=reshape(yrx1_t,1000,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft2=fft(yrx2_t);
%
%
% %
% Demodulation
% Demodulate signal using 16-QAM.
zsym2 = qamdemod(disc_ft2,M);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
```

```
z_t = de2bi(zsym2,'left-msb'); % Convert integers to bits.
% Convert z from a matrix to a vector.
z_t = reshape(z_t.',prod(size(z_t)),1);
%% BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
[error(ii2),errorrate2(ii2)] = biterr(x,z_t);
end
end
close all
figure
semilogy(snr,errorrate1,'o-m','LineWidth',2);
hold on
semilogy( snr,errorrate3,'s-r','LineWidth',2);
hold on
semilogy(snr,errorrate2,'v-b','LineWidth',2);
hold on
axis([10 40 0.00001 1])
legend('only ofdm','ofdm using MRC','using selection combining');
%   semilogy(snr,errorrate1,'k');
grid on
grid on
xlabel('BER');
ylabel('snr(dB)');
```

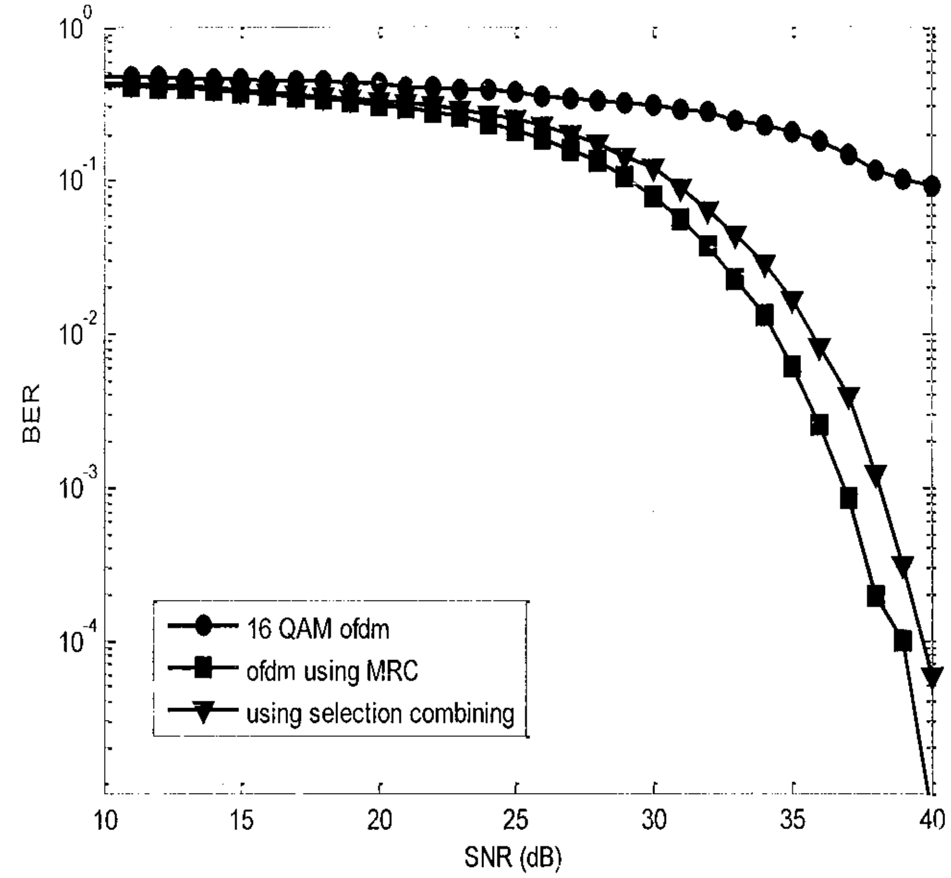

Figure 7.2 BER vs SNR plot for 16 QAM OFDM, MRC and Selection Combining

From the above plot we can infer that at the same SNR value, the bit error rate is maximum for 16 QAM ofdm system on which no combination technique has been applied. The bit error rate decreases ie. improves for Selection Combining and is best for signals combined through Maximum Ratio Combining

7.3 Matlab code for comparing performance of an ofdm system implemented with mrc and selection combining with 32qam modulation

```
clc

M = 32;
k = log2(M);
n1 =320000;


x = randint(n1,1);
xsym = bi2de(reshape(x,k,length(x)/k).','left-msb');

xsym=reshape(xsym,1000,64);
y1 = qammod(xsym,M);

ytx = y1;


inv_ft=ifft(ytx);
inv_oned= reshape(inv_ft,64000,1);

g=length(inv_oned);
ygb=[inv_oned(g-0.25*g+1:g);inv_oned];
yqb2=reshape(ygb,1,80000);

ygb1=reshape(ygb,1000,80);



nRx =  [1 2];
snr= [0:40];

for ii=1:length(snr);
```

```
n  =  1/sqrt(2)*[randn(1,80000)  +  j*randn(1,80000)];

h = 1/sqrt(2)*[randn(1,80000) + j*randn(1,80000)];

y = h.*ygb2 + 10^(-snr(ii)/20)*n;

yHat = y./h;

yrx=reshape(yHat,80000,1);
yrx1=yrx(0.25*g+1:length(yrx));
yrx2=reshape(yrx1,1000,64);

disc_ft=fft(yrx2);

zsym = qamdemod(disc_ft,M);

z = de2bi(zsym,'left msb');

z = reshape(z.',prod(size(z)),1);

[error(ii),errorrate1(ii)] = biterr(x,z);
end

for jj = 1:length(nRx);

for ii=1:length(snr);

n  =  1/sqrt(2)*[randn(nRx(jj),80000)  +  j*randn(nRx(jj),80000)];

h  =   1/sqrt(2)*[randn(nRx(jj),80000)   +   j*randn(nRx(jj),80000)];
```

```
sD = kron(ones(nRx(jj),1),ygb2);
y = h.*sD + 10^(-snr(ii)/20)*n;

yHat =  sum(conj(h).*y,1)./sum(h.*conj(h),1);

yrx=reshape(yHat,80000,1);
yrx1=yrx(0.25*g+1:length(yrx));
yrx2=reshape(yrx1,1000,64);

disc_ft=fft(yrx2);

zsym = qamdemod(disc_ft,M);

z = de2bi(zsym,'left-msb');

z = reshape(z.',prod(size(z)),1);

[error(ii),errorrate3(ii)] = biterr(x,z);
end
end

clc
for jj2 = 1:length(nRx);
for ii2=1:length(snr);

n2=   1/sqrt(2)*[randn(nRx(jj2),80000)   +   j*randn(nRx(jj2),80000)];

h2  =  1/sqrt(2)*[randn(nRx(jj2),80000)  +  j*randn(nRx(jj2),80000)];

sD2 = kron(ones(nRx(jj2),1),ygb2);
y2 = h2.*sD2 + 10^(-snr(ii2)/20)*n2;

hPower = h2.*conj(h2);
```

```
[hMaxVal ind] = max(hPower,[],1);
hMaxValMat = kron(ones(nRx(jj2),1),hMaxVal);

% [illegible]
ySel = y2(hPower==hMaxValMat);
hSel = h2(hPower==hMaxValMat);

% [illegible]
yHat2 = ySel./hSel;
yHat2 = reshape(yHat2,1,80000);    % [illegible]
% removing the cyclic prefix
yrx_t=reshape(yHat2,80000,1);
yrx1_t=yrx_t(0.25*g+1:length(yrx_t));
yrx2_t=reshape(yrx1_t,1000,64);

    % Received Signal

   % discrete fourier transform
disc_ft2=fft(yrx2_t);



   % Demodulation
   % Demodulate signal using 16-QAM.
zsym2 = qamdemod(disc_ft2,M);
    % Symbol-to-Bit Mapping
   % Undo the bit-to-symbol mapping performed earlier.
z_t = de2bi(zsym2,'left-msb'); % Convert integers to bits.
   % Convert z from a matrix to a vector.
z_t = reshape(z_t.',prod(size(z_t)),1);
    % BER Computation
  % Compare x and z to obtain the number of errors and
  % the bit error rate.
[error(ii2),errorrate2(ii2)] = biterr(x,z_t);
end
end
close all
figure
semilogy(snr,errorrate1,'o-m','LineWidth',2);
hold on
semilogy( snr,errorrate3,'*-r','LineWidth',2);
hold on
semilogy(snr,errorrate2,'v-o','LineWidth',2);
hold on
axis([10 40 0.00001 1])
legend('16 QAM ofdm','ofdm using MRC','using selection combining');
    % semilogy(snr,errorrate1,'x');
grid on
grid on
xlabel('BER');
ylabel('snr(dB)');
```

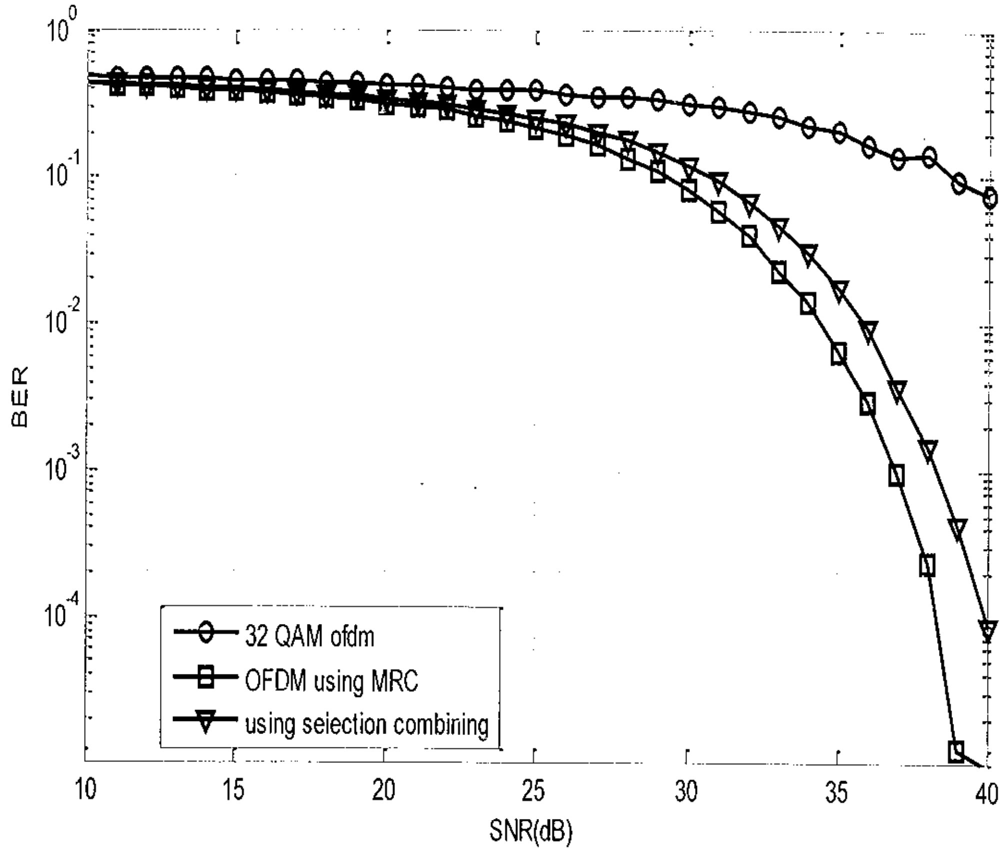

Figure 7.3 BER vs SNR plot for 32 QAM OFDM, MRC and Selection Combining

From the above plot we can infer that at the same SNR value, the bit error rate is maximum for 32 QAM ofdm system on which no combination technique has been applied. The bit error rate decreases ie. improves for Selection Combining and is best for signals combined through Maximum Ratio Combining

7.4 Matlab code for comparing the performance of an ofdm system implemented with mrc and selection combining with 64 qam modulation

```
clc
M = 64;
k = log2(M);
n1 =384000;
% Bit-to-Symbol Mapping
x = randint(n1,1);
xsym = bi2de(reshape(x,k,length(x)/k).','left-msb');
converted from serial to parallel
% Modulate using 16-QAM.
xsym=reshape(xsym,1000,64);
y1 = qammod(xsym,M);
% Transmitted Signal
ytx = y1;


inv_ft=ifft(ytx);
inv_oned= reshape(inv_ft,64000,1);

g=length(inv_oned);
ygb=[inv_oned(g-0.25*g+1:g);inv_oned];
ygb2=reshape(ygb,1,80000);

ygbi=reshape(ygb,1000,80);

% Channel
% Send signal over an AWGN channel.
 nRx =  [1 2];
 snr= [0:40];

for ii=1:length(snr);


n  =  1/sqrt(2)*[randn(1,80000)  +  j*randn(1,80000)];
```

```
        h  =  1/sqrt(2)*[randn(1,80000)  +  j*randn(1,80000)];

        y = h.*ygb2 + 10^(-snr(ii)/20)*n;

    yHat = y./h;

yrx=reshape(yHat,80000,1);
yrx1=yrx(0.25*g+1:length(yrx));
yrx2=reshape(yrx1,1000,64);
disc_ft=fft(yrx2);

zsym = qamdemod(disc_ft,M);
 z = de2bi(zsym,'left-msb');
 z = reshape(z.',prod(size(z)),1);
 [error(ii),errorrate1(ii)] = biterr(x,z);
end
```

MRC IN OFDM

```
 for jj = 1:length(nRx);

for ii=1:length(snr);

n  =  1/sqrt(2)*[randn(nRx(jj),80000)  +  j*randn(nRx(jj),80000)];
```

```
        h  =  1/sqrt(2)*[randn(nRx(jj),80000)  + j*randn(nRx(jj),80000)];
% Rayleigh channel

            % Channel and noise Noise addition
      sD = kron(ones(nRx(jj),1),ygb2);
        y = h.*sD + 10^(-snr(ii)/20)*n;

        % equalization maximal ratio combining
        yHat =  sum(conj(h).*y,1)./sum(h.*conj(h),1);
% %to remove the cyclic prefix
yrx=reshape(yHat,80000,1);
yrx1=yrx(0.25*g+1:length(yrx));
yrx2=reshape(yrx1,1000,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft=fft(yrx2);
%
%
% %
% Demodulation
% Demodulate signal using 16-QAM.
zsym = qamdemod(disc_ft,M);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
 z = de2bi(zsym,'left-msb'); % Convert integers to bits.
% Convert z from a matrix to a vector.
 z = reshape(z.',prod(size(z)),1);
% % BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
 [error(ii),errorrate3(ii)] = biterr(x,z);
end
 end


 clc

 for jj2 = 1:length(nRx);

for ii2=1:length(snr);
%   ynoisy = awgn(ygb1,snr(ii),'measured');% in this block the noise is
added to the matrix with the cyclic prefix i.e. ygb and then
transmitted.
% %

n2=  1/sqrt(2)*[randn(nRx(jj2),80000)  +  j*randn(nRx(jj2),80000)];
white gaussian noise, 0dB variance
       h2          =             1/sqrt(2)*[randn(nRx(jj2),80000)          +
j*randn(nRx(jj2),80000)]; % Rayleigh channel

             % Channel and noise Noise addition
sD2 = kron(ones(nRx(jj2),1),ygb2);
y2 = h2.*sD2 + 10^(-snr(ii2)/20)*n2;
```

```
% finding the power of the channel on all rx chain
hPower = h2.*conj(h2);

% finding the maximum power
[hMaxVal ind] = max(hPower,[],1);
hMaxValMat = kron(ones(nRx(jj2),1),hMaxVal);

% selecting the chain with the maximum power
ySel = y2(hPower==hMaxValMat);
hSel = h2(hPower==hMaxValMat);

% equalization with the selected rx chain
yHat2 = ySel./hSel;
 yHat2 = reshape(yHat2,1,80000); % just to get the matrix dimension
proper
% %to remove the cyclic prefix
yrx_t=reshape(yHat2,80000,1);
yrx1_t=yrx_t(0.25*g+1:length(yrx_t));
yrx2_t=reshape(yrx1_t,1000,64);
%
% % Received Signal

% %discrete fourier transform
disc_ft2=fft(yrx2_t);
%
%
% %
% Demodulation
% Demodulate signal using 16-QAM.
zsym2 = qamdemod(disc_ft2,M);
% % Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping performed earlier.
 z_t = de2bi(zsym2,'left-msb'); % Convert integers to bits.
% Convert z from a matrix to a vector.
 z_t = reshape(z_t.',prod(size(z_t)),1);
% % BER Computation
% Compare x and z to obtain the number of errors and
% the bit error rate.
 [error(ii2),errorrate2(ii2)] = biterr(x,z_t);
end
 end
 close all
 figure
 semilogy(snr,errorrate1,'o-m','LineWidth',2);
 hold on
 semilogy( snr,errorrate3,'s-r','LineWidth',2);
 hold on
 semilogy(snr,errorrate2,'v-b','LineWidth',2);
 hold on
 axis([10 40 0.00001 1])

 legend('OFDM','ofdm using MRC','ofdm using selection combining');
%    semilogy(snr,errorrate1,'k');
 grid on
 grid on
```

```
xlabel('BER');
ylabel('snr(dB)');
```

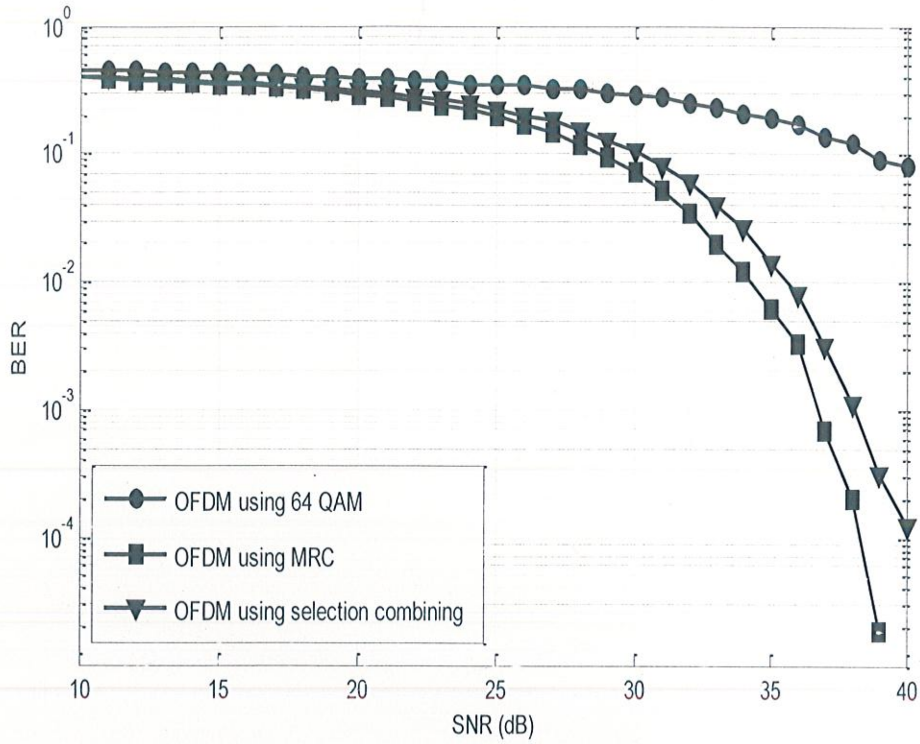

Figure 7.4 BER vs SNR plot for 64 QAM OFDM, MRC and Selection Combining

From the above plot we can infer that at the same SNR value, the bit error rate is maximum for 64 QAM ofdm system on which no combination technique has been applied. The bit error rate decreases ie. improves for Selection Combining and is best for signals combined through Maximum Ratio Combining