PERFORMANCE ANALYSIS OF MULTICARRIER CODE DIVISION MULPLE ACCESS (MC-CDMA) SYSTEMS

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Morehead State University, 2008

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In wireless communications, the Direct-Sequence Code Division Multiple Access (DS-CDMA) is affected by delay spreads and creates Inter-chip-Interference (ICI) problem. The practical implementation of the DS-CDMA is very difficult as it requires highly complex interference environment which affects on Bit Error rate (BER). Moreover, a large peak to average ratio and nonlinear amplification affects the Orthogonal Frequency Division Multiplexing (OFDM). While, Multicarrier Code Division Multiple Access (MC-CDMA) systems are being used to provide reliable communications in a various commercial applications. MC-CDMA systems combine the advantages of OFDM with the advantages of Code Division Multiple Access (CDMA). In MC-CDMA systems, the bits on each branch are transmitted on orthogonal carriers by converting a data symbol into M parallel branches to overcome the interference problem. The transmitter and the receiver of the system are implemented using the IFFT/FFT and modulation techniques. The data is modulated by an IFFT in baseband and the cyclic prefix inserted between the symbols is used to reduce the interference. The FFT operation performed at the receiver end to obtain the signal in the frequency domain. The system

can easily transmit and receive signals using the IFFT/FFT and reduces the ICI problem. The performance of the MC-CDMA outperforms the OFDM and DS-CDMA in terms of BER.

The performance of the MC-CDMA systems depends on the BER of different channels. In this thesis, the performance of the MC-CDMA systems is evaluated in an Additive White Gaussian Noise (AWGN) channel, Rayleigh Fading, and the Rician Fading channels. The central theorem is applied to derive the BER with Q-function. A Matlab simulation is performed to obtain the results of these channels in terms of BER. Equalization technique is required to achieve the effect of the channel on the final stage. In this case, the Equal Gain Combining (EGC) technique is proposed as it outperforms the MRC and the MMERC for downlink communication. In terms of BER, the performance of an AWGN channel outperforms other channels as SNR is increased. The K-factor is defined as the power of Line-of-Sight (LOS) component. The performance of Rician Fading channel increases, as the K-factor increases. The performance of the Rician Fading channel is better than the Rayleigh Fading channel due to the LOS component. The MC-CDMA systems offered better performance in an AWGN channel in terms of BER.

Accepted by: Ahmad Zayad, Chair

Issa Ahmadi

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CHAPTER I

INTRODUCTION

Many novel techniques have been invented to provide high-data rate with high quality communication services for future wireless communication systems. The applications of these systems have increased rapidly in recent years. In the near future, this technology will require very efficient bandwidth features like bandwidth options, frequency diversity, and high spectral efficiency. Because current bandwidth is limited, the services are increasing, and more demand for a higher data rate is also expected. In addition, the 4G (Fourth generation) systems must be satisfied with broadband multimedia services up to 20~100Mbps in downlink and 2~20Mbps for uplink wireless communication. This also emphasizes a higher Quality of Service (QOS) for wireless systems. This is the most predictable challenge for the wireless communication environment in upcoming years.

Lately, a narrative digital modulation technology for multiple accesses, referred to as the Multi-Carrier Code Division Multiple Access (MC-CDMA), has been proposed to support high data rate transmission; it is based on the combination of CDMA and orthogonal frequency division multiplexing (OFDM). The MC-CDMA has been shown to be an effective technique for combating multipath fading. With MC-CDMA system, a user's spreading code can be modulated on separate subcarriers, undergo frequency-flat fading channel, and can offer frequency diversity advantage.

Multicarrier CDMA systems solve the ICI (Inter-Chip-Interference) problem by transmitting the same data symbol over a large number of narrowband orthogonal carriers without spectrum spreading per carrier, and make it possible for multiple users to communicate through the same channel. It takes the leads of both OFDM and CDMA by providing an efficient transmission. The Fast Fourier Transform (FFT) is used to transmit and receive the signals. It also shows the attractive feature of high spectral efficiency due to minimizing the density of subcarrier spacing.

Moreover, MC-CDMA outperforms direct sequence CDMA (DS-CDMA) and Multicarrier direct sequence CDMA (MC DS-CDMA) by considering a factor of Bit Error Rate (BER) performance over the downlink layer. Consequently, the MC-CDMA supports multimedia services in wireless communication systems for the downlink layer. It demonstrates many advantages over widely adopted DS-CDMA systems. It provides an improvement in terms of probability of error performance.

Several papers have been published in the area of MC-CDMA system. In (Park, Kim, Lee, and Tchah, 1998), the system was mathematically evaluated over Rician fading channel in terms of BER. The system was also evaluated over AWGN to tackle interference. In (Hathi and Darwazeh), a brief overview of MC-CDMA system was done using algorithms for optimum performance. In (Osman, 2006), Multicarrier Code division multiple access (MC-CDMA) system was analyzed using ideal multipath channel. The simulations were performed on the system to test its performance. The authors did not present a detailed analysis of the system. The mathematical evaluation was not investigated in exact manner; the performance was analyzed only on limited channels, and the authors did not describe the system implementation procedure.

This thesis contains implementations of transmitter and receiver of the system. It also includes simulations performed on the MC-CDMA system to see how it behaves over different fading channels.

GENERAL AREA OF CONCERN

The rapid growth in wireless applications is likely demands for a high data rate services. The single-carrier system offers limited data rates due to the receiver complexities and multipath fading channel. In such interference limited environment, one of the ways to enhance system performance is to use diversity combining of the multipath signals at the receiver. The advantages of using diversity have long been recognized as effective means of combating the detrimental effects of fading and interference. Among the diversity techniques available, spatial diversity is one of the most attractive means of combating fading and interference impairments in the wireless mobile communication systems. MC-CDMA schemes derive complete advantages from the frequency and spatial diversities and can be reflected as strong and promising candidate for the 4G communication system. MC-CDMA is the combination of the CDMA and the OFDM, so it offers high spectral efficiency and multiple access capabilities in the data transmission. In MC-CDMA systems, the implementation of the transmitter and the receiver uses the FFT, the IFFT and the modulation techniques, so that the systems are available for the variety of applications. Due to its high bit rates, the MC-CDMA is a leading and the promising candidate for the future of wireless communication systems.

OUTLINE OF THESIS

The objective of this thesis is to study and evaluate the performance of Multicarrier Code Division Multiple Access (MC CDMA) in a variety of channels, such as the Additive White Gaussian Noise (AWGN), the Rayleigh fading, and the Rician fading channel. The thesis also focuses on implementation of the transmitter and receiver section under different channel conditions. While equalization techniques may alter the information during data transmission, it has been omitted from the implementation technique to obtain the ideal condition. This study includes Matlab simulations of wireless channel distributions. The primary objective of MC-CDMA implementation is to evaluate and improve the Bit Error Rate (BER), outage probability performance and system performance using mathematical derivations.

The first chapter of the thesis discusses the introduction part of MC-CDMA. The second chapter gives brief reviews of related work on performance analysis of MC-CDMA. The third chapter describes the methodology used in MC-CDMA systems, where the transmitter and receiver sections are implemented in Matlab over various channels. The fourth chapter contains and discusses the results from the implementation and Matlab simulations. Finally, the last chapter concludes the thesis and presents some future work in the MC-CDMA systems.

STATEMENT OF PROBLEM

The capacity limitation in direct-sequence code-division multiple-access (DS-CDMA) systems is chiefly determined by the interference level which arises from imperfect orthogonality among the spreading codes. Narrowband in DS-CDMA opposes intersymbol interference but it is susceptible to the attenuation effect caused by fading. DS-CDMA is characterized by resistance to fading by spreading the signal over the entire bandwidth. Conversely, this access technique is affected by delay spreads and thus it creates a inter-chip-interference (ICI) problem. The practical implementation of DS-CDMA is very difficult as it requires a highly complex interference environment which affects on BER .On other hand; the OFDM uses a large number of orthogonal parallel subcarriers for transmission. It also provides the improved performance against ICI at the receiver and frequency selective fading. However, the OFDM is affected by a large peak to average ratio and sensitivity to frequency offsets and nonlinear amplification. It also shows difficulty in subcarrier synchronization. The OFDM typically applies a coding technique. Therefore, the number of subcarriers needed is larger than the number of bits. The above dilemmas require improvements to wireless communication systems.

RESEARCH QUESTIONS

The convenient method for MC-CDMA implementation requires a highly effective interference environment without affecting its Bit Error Rate (BER). Due to the dispersive nature of different channels, single carrier CDMA systems are affected by Inter-Symbol-Interference (ISI). The question of how the implementation technique reduces the interference effect in Multicarrier CDMA systems will be studied. The main objective of this thesis is to implement Multicarrier CDMA system to mitigate Inter-Symbol-Interference (ISI) problem. The simulation over various fading channels enhances the average error probability of the Multicarrier system. This thesis will study how Multicarrier CDMA (MC-CDMA) systems offer improved BER by Matlab simulation. Mathematical evaluations will be conducted in terms of BER over the AWGN channel, Rician Fading Channel, and the Rayleigh Fading Channel to evaluate its performance in terms of error probability. The results will be indicated that, the MC-CDMA system offer better performance over the AWGN channel.

SIGNIFICANCE OF STUDY

In (Venakatasubramanian, 2003), using an alternative expression for the Q-function, characteristic function, and Gaussian approximation, the BER of the Multi-user MC-CDMA systems in frequency selective Nakagami-m fading channels has been calculated. In (Shiro and Milstein, 1996), the average BER performance in a frequency selective Rayleigh Fading Channels is evaluated by using the Monte-Carlo numerical computation method, the derived conditional BER, and verification by computer simulation of the signal transmission.

The rapid growth of wireless communication is needed to define the next generation (4G) broadband system. The 4G needs data transmission rates up to 200Mbps to offer quality service. This is the primary motivating feature for more investigation on Multicarrier techniques. OFDM, DS-CDMA and single carrier systems provide fine data rates but are limited in performance in fading various channels and any attempt to moderate these effects increases systems complexity. The study regarding the performance analysis of multicarrier CDMA is very significant as it will provide an insight into the theoretical as well as practical framework of working wireless communicating devices.

KEYWORDS

- Code Division Multiple Access (CDMA)
- Multicarrier Code Division Multiple Access (MC CDMA)
- Fast Fourier Transform (FFT)
- Additive White Gaussian Noise (AWGN)
- Rayleigh fading
- Rician fading
- Orthogonal Frequency Division Multiplexing (OFDM)
- Bit Error Rate (BER)
- Binary Phase Shift Keying (BPSK)
- Cyclic Prefix
- Equal Gain Combining (EGC)
- Equalization
- Signal-to-Noise (SNR) Ratio

DEFINITION OF TERMS

For clarity of understanding, the following terms will be defined.

- **CDMA** - Code Division Multiple Access: A spread spectrum air interface technology used in some digital cellular, personal communications services and other wireless networks.
- **OFDM-** It is type of Multicarrier transmission, in which a high rate data stream is transmitted in a parallel manner over a number of low rate orthogonal subcarriers.
- **MC DS-CDMA** - It is the combination of Orthogonal Frequency-division Multiplexing (OFDM) and Direct-Sequence Code division Multiple Access (DS-CDMA).
- **PERFORMANCE ANALYSIS** - Performance analysis (a field of dynamic program analysis) is the investigation of a program's behavior using information gathered as the program runs, as opposed to MATLAB code analysis.

CHAPTER II

REVIEW OF LITERATURE

Multi Carrier Code Division Multiple Access (MC-CDMA) is a modern concept in digital communication. Its development aimed to comprehend an overlay system. MC-CDMA is a modulation method that uses multi-carrier transmission or simply an OFDM of DS-CDMA signals. While the Multicarrier CDMA is another significant approach to deliberately disperse the signal over various subcarriers. It exploits the permutation of DS-CDMA, but prefers the waveform signals used by another technique known as OFDM.

This scheme was first proposed in 1993 at PIMRC in Yokohama, a great area of CDMA appliance of CDMA usage. This scheme proposed three new types of multiple access schemes based on a combination of CDMA and OFDM techniques. This arrangement consisted of Multicarrier CDMA, Multicarrier Direct-Sequence CDMA and Multitone CDMA. Linnartz and Yee, the innovators of Scheme, demonstrated that FFT and variable gain assortment combiner is used for MC-CDMA signals detection with comparatively simple receiver.

MULIPLE ACCESS SCHEMES

The frequency selective fading strictly demolishes the orthogonality of waveforms and offers Inter-Symbol-Interference (ISI). The combination of Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access (CDMA) forms three types of multiple access schemes to reduce the ISI problem. This classification is based on the spreading operation that takes place either in the time or frequency domain and it includes:

- Multitone Code Division Code Access (MT CDMA) scheme
- Multicarrier Direct Sequence Code Division Multiple Access (MC DS-CDMA) scheme
- Multicarrier Code Division Multiple Access (MC CDMA) scheme

MULTITONE CDMA (MT-CDMA)

The Multitone CDMA system is another type of multiple access schemes which can accommodate a higher number of users as compared to Multicarrier DS-CDMA, as it shows no limitations for the number of spreading codes and number of sub-carriers. In CDMA, a parallel input data streams are spread using the CDMA spreading sequence in the time domain and sub-carriers and spreading codes are arranged orthogonally to each other. The MT-CDMA is used to satisfy the orthogonality condition, which is discontented after the spreading process.

The illustration for the spreading code of Multitone CDMA for the j^{th} user is shown in Fig. 3.1

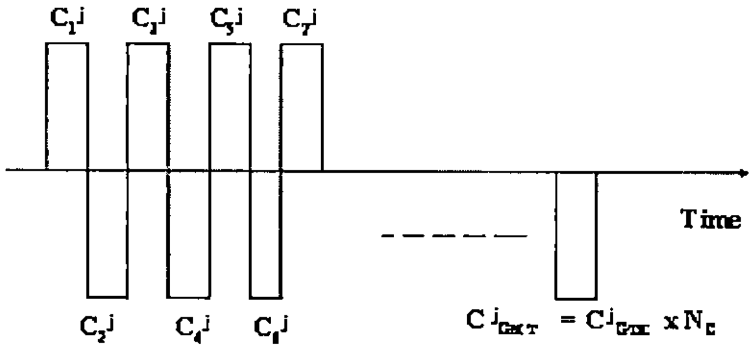

Fig. 3.1 Spreading code

MULTICARRIER DIRECT SEQUENCE CDMA (MC-DS-CDMA)

The MC DS-CDMA system extends the serial to parallel converted input stream in the time domain using the CDMA spreading code. The effective data obtained show the minimum frequency separation and is orthogonal to each other.

The transmitter model for jth user is shown in Fig. 3.2 where Nc denotes the total number of subcarriers in the MC-DS CDMA system.

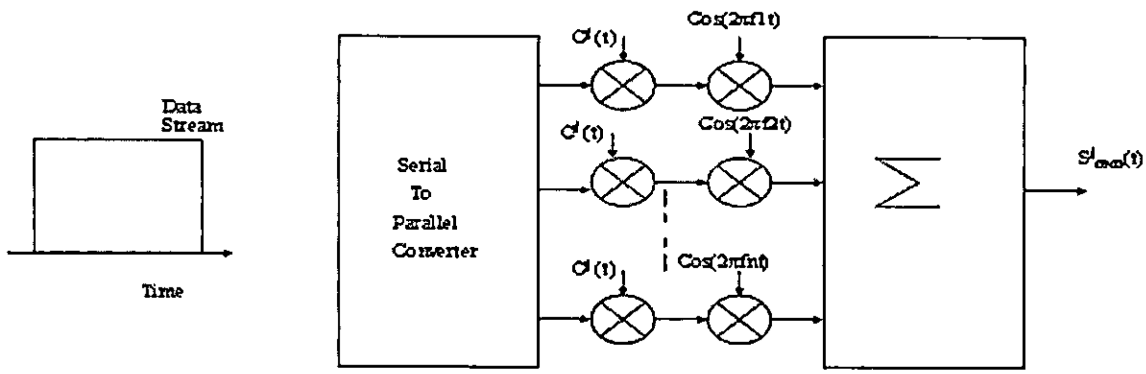

Fig. 3.2 Transmitter Model

The resulting power spectrum signal is shown in Fig. 3.3

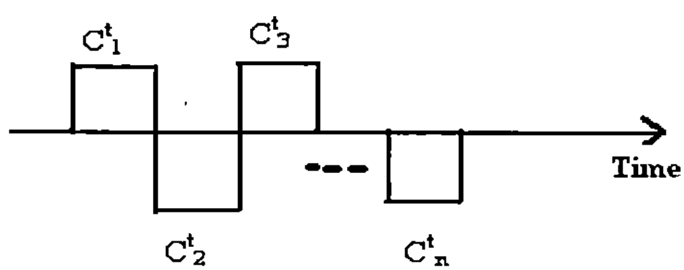

Fig. 3.3 Power Spectrum signal

MULTICARRIER CDMA (MC-CDMA)

MC-CDMA is defined as a Multicarrier Code Division Multiple Access. It is well defined digital modulation scheme, in which a data bit is transmitted through multiple narrowband sub-carriers. The sub-carrier value depends on the system requirement. Its value is either +1 or -1 depending on the spreading code and it provides phase of each sub-carrier. The frequency of sub-carriers is obtained by a factor of F/T; where F is an integer value and can be employed to find out the bandwidth efficiency of the system. The MC-CDMA has offers a maximum value of 1 for F.

At the 1994^{th} PIMRC conference, the finest and most suitable gain control functions were proposed in the intellect of the Mean Square Error (MSE). Regardless of the speculative need for a full matrix inversion, it emerged that for a MC-CDMA downlink the subcarrier combiner can exist to gain control that depend only on the code phase offset and signal fading at the meticulous subcarrier. This simple subcarrier gain and phase correction combines the functions of the rake receiver and interference cancellation as used in multi-user DS-CDMA. The outcomes obtained from this scheme indicated that MC-CDMA systems have a similar number of users and spread factors that can be activated in an exceedingly time dispersive channel with accepted BER. The DS-CDMA system performance does not provide adequate behavior with large time dispersion.

Since 1993, MC- CDMA has been considered a trendy and diverse issue for research purposes. In 1996, at ISSSTA conference, Prof. Aghvami declared that the MC-CDMA is the most innovative subject in the Spread Spectrum Epoch. MC-CDMA has attracted a lot of consideration from researchers because of their observed high rate transmission capability. In the MC-CDMA system, researchers have analyzed the performance in different fading channels (Choi, 2000). In (Park, Kim, Lee, and Tchah, 1998) & (Chung and Jeong, 2002), researchers have offered many proposals to improve the system performance. They have suggested many diversity techniques (Roy and Fortier, June, 2004) to enhance the performance in a multipath propagation environment.

Parallel interference is reduced in (Park, Kim, Lee, and Tchah, 1998) by applying some diversity techniques. In (Prasad and Hara, Feb, 1996), MC-CDMA system is analyzed using various fading channels. The simulations were performed on the system to tests its performance. The research included the various channels and their structures. It also discussed the transmitter and receiver structure of the MC-CDMA system. These studies characterized the system by different channel parameters such as Delay spread, coherence bandwidth, Doppler shift, and coherence time. The work mainly discussed the three important types of distribution that are commonly required.

- Rayleigh Distribution
- Rician Distribution

- Log-normal Distribution

The transmitter model of the MC-CDMA system is implemented by converting the binary signal from serial to parallel mode which is equal to the number of subcarriers. The binary signal is then multiplied by one corresponding element of the spreading code. By modulating the signal with BPSK, it shows spectral efficiency. The transmitter then performed the IFFT of the code and multiplied it by the transmitted signal. Then the receiver takes the FFT of the received signal and multiplies it by the code. The received signal is then transformed to the frequency domain.

The AWGN test is used to show the system performance by analyzing a simulation. The data collected from the AWGN test is then compared to the theoretical records. The system was also investigated in opposition to AWGN channel and compared to the BPSK BER curve because the BPSK signal and MC-CDMA signal has the same structure. The AWGN is also analyzed in terms of Rayleigh channel as it shows good performance for the system against white noise. This simulation is compared to the equalization performance for a single user. This type of test is used to see the working performance of the system.

Rayleigh channel is analyzed to test the capacity of the system in terms of the number of users. It is very hard to simulate a system with respect to the number of users because the noise level of each user is not easily determined. Therefore, the Rayleigh Channel is analyzed in uplink and downlink simulations. In (Choi, 2000), Multi-code Multi carrier CDMA system was evaluated and compared with both single-code Multicarrier CDMA system and multi-code Multicarrier CDMA system with single carrier in a frequency selective fading channel.

In this work, the MC-CDMA system was analyzed and evaluated for various channels. The thesis implemented the transmitter and receiver model of the MC-CDMA system and it also includes simulations where some tests were executed on the system to compare its performance against different fading channels such as AWGN, Rayleigh, and Rician channel. The system was mathematically evaluated in terms of (BER) over various channels. The system showed increased spectral efficiency as compared to other modulation techniques such as BPSK or QAM. The system was able to handle N simultaneous users with good BER for various frequencies. Bandwidth options were also available for the MC-CDMA system.

CHPATER: III

METHOLOGY

INTRODUCTION

The Multicarrier CDMA system has appeared as one of the most secured multiple access schemes for high data rate applications. However the system performance is limited by the interference effect. Due to this, the suppression of interference in the Multicarrier CDMA system is essential. This part of the thesis focuses on system implementation to reduce the interference without affecting its Bit Error Rate (BER). In this part, the transmitter model and the receiver model of the system is implemented.

In the second part of this chapter, the performance of the system is evaluated in terms of error probability over various channels. The evaluation is performed with an equalization technique, mathematical analysis of each channel, and Matlab simulation.

IMPLEMENTATION

The MC-CDMA system operates on the same perception of spreading the signal's bandwidth that used in the DS-CDMA system; however MC-CDMA has a different implementation process. It uses a number of sub-carriers to occupy the bandwidth attention. In the Multitone CDMA scheme, the CDMA spreading sequence is used to spread the input data streams in the time domain; the spreading subcarriers are orthogonal to each other. Therefore, this scheme is not suited for the orthogonality condition. While Multicarrier direct sequence CDMA system is ideal for uplink transmission, its implementation is also very complex. Therefore, this thesis concentrates on the Multicarrier CDMA scheme, a new digital modulation technique for fourth generation mobile technology. It permits high capacity networks and robustness in frequency selecting channels.

The implementation of Multicarrier CDMA has been classified according to channel detection, channel estimation, interference suppression, modulation or demodulation, frequency offset and equalization. MC-CDMA is a combination of OFDM and CDMA so it offers advantages of both OFDM and CDMA. In this case, the MC-CDMA system is implemented according to interference suppression. The system is robust again frequency selective fading hence each user's data is initially spread by high rate spreading code. The small part of the symbol corresponding to the high rate spreading code is transmitted through a different subcarrier. The Multicarrier CDMA system consists of two components.

- Transmitter model
- Receiver Model

A general block diagram of Multicarrier CDMA system shown in Fig. 3.4

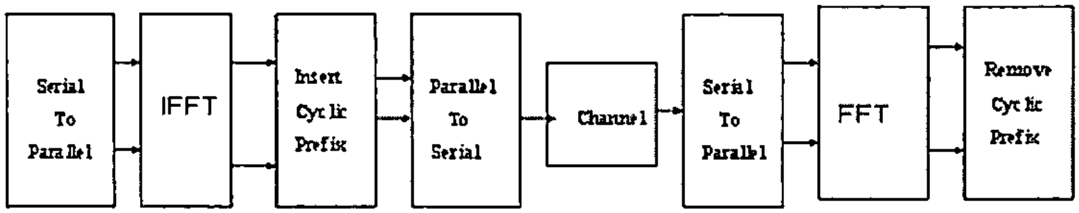

Fig. 3.4 Block Diagram of Multicarrier CDMA System

The input signals are spread using spreading sequence by cyclic prefix and the resultant chips are modulated into different subcarriers by IFFT operation. The prefix maintains orthogonality between subcarriers in a multipath channel. First, the receiver removes the cyclic prefix and then performs the FFT operation of the received symbols to bring them back to the frequency domain. The performance of Multicarrier CDMA systems reduces the interference effect using cyclic prefix operation which is introduced by using system implementation.

TRANSMITTER IMPLEMENTATION

In the transmitter model, the input signal is applied as a $a_m(k)$ which is a random binary sequence representing data. The structure of the transmitter model for MC-CDMA is shown in Fig. 3.5 Where k denotes the k^{th} bit interval.

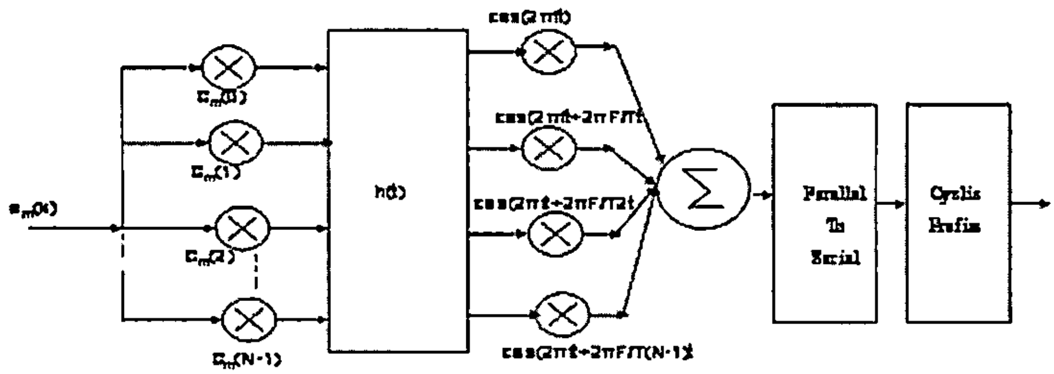

Fig. 3.5 Transmitter Model

According to the figure, The MC-CDMA system transmits the equivalent data symbol in parallel through several subcarriers. A particular data symbol is replicated into N parallel copies; a_m (k) denotes data stream. A Pseudo-random chip is multiplied with every division of the parallel stream. In this case we suppose that there are N chips per symbol, and that every user has a distinct signature sequence. $C_m(t) = [C_m^1 \, C_m^2 \ldots C_m^{(N-1)}]$ shows the spreading code of the $(N-1)^{th}$ users in frequency domain.

After passing through a chip wave-shaping filter, h(t) is denoted by (Prasad and Hara, Feb, 1996)

$$h(t) = P_{Tb}(t) = \begin{cases} 1 & 0 \le t \le T_b \\ 0 & \text{otherwise} \end{cases} \tag{3.1}$$

The signal out of the filter modulates the multiple carrier signals. The transmitted signal consists of the sum of the outputs of these branches. The transmitted signal is given by (Prasad and Hara, Feb, 1996)

$$S_m(t) = \sum_{i=0}^{N-1} C_m(i)\, a_m(k) \cos(2\pi f_c t + 2\pi i\, F/T_b\, .t) \times P_{Tb}\,(t-kT_b) \tag{3.2}$$

$$C_m(i) \in \{-1, 1\} \qquad a_m(k) \in \{-1, 1\} \tag{3.3}$$

The general block diagram of transmitter model for downlink radio systems is shown in Fig. 3.6

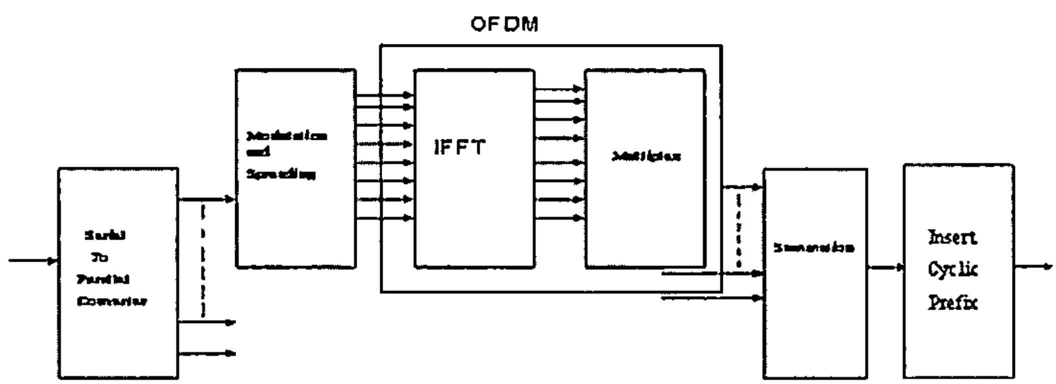

Fig. 3.6 Block diagram of Transmitter model

The transmitter model consists of an initial modulation scheme. It is simple to implement and flexible to noise. In most practical usage the Quadrature Phase Shift Keying (QPSK) modulation technique is applied; as it affects the bit error rate of output signals. In QPSK two bits of information are transmitted over every time slot.

It uses four possible phases ($\pi/4$, $3\pi/4$, $5\pi/4$ and $7\pi/4$) for the bit transmission process. It is shown in Fig. 3.7

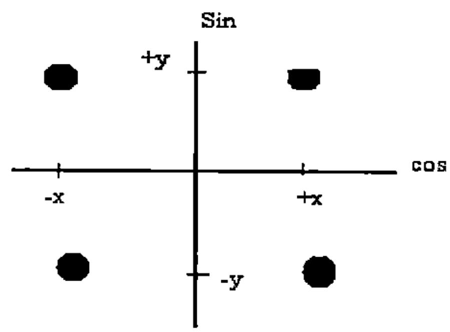

Fig. 3.7 QPSK Transmission

In Fig. 3.5 m is called as the processing gain. In Fig. 3.6 the input data stream a_m (k) is multiplied by the spreading code with length m and each chip of the code modulates one subcarrier. The number of subcarriers is equal to the number of the spreading factor. The data is modulated by an Inverse Fast Fourier Transform (IFFT) in baseband as shown in Fig.3.6 and converted back into serial data by summation. The returning prefix is used to reduce the interference problem and inserted between the symbols. The chips subsequent to Inverse Fast Fourier Transformation (IFFT) are summed and finally multiplexed to align prior to transmission through the channel.

RECEIVER IMPLEMENTATION

The receiver configuration of the MC-CDMA system is shown in Fig. 3.8. Consider the 0^{th} user is the number of required the user. The signal obtained from the transmitter is first down converted and the cyclic prefix is eliminated. The obtained signal is replicated into N parallel copies, and then multiplied with the corresponding subcarrier frequency in each branch. The signal of every branch is multiplied by a gain factor of C_0 (t). The remaining samples are serial to parallel converted to obtain the subcarriers components. The combined output signal is then integrated and sampled after adding the sub-carrier signal.

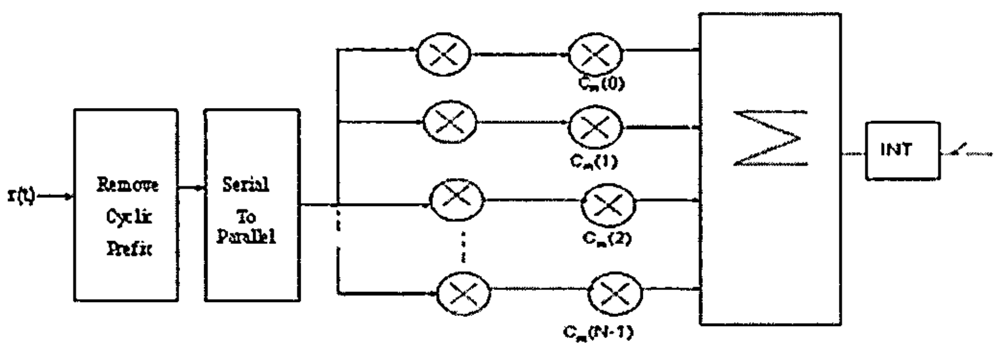

Fig. 3.8 Receiver Model

The receiver performs a reverse of the transmitter implementation for selecting an ideal channel environment. The primary blocks are arranged in a reverse manner of the OFDM transmitter section followed by the dispreading and demodulation of the output from that section. The subcarriers are first demodulated by a Fast Fourier Transform (FFT) and multiplied by the gain factor to unite the received signal in frequency domain.

The block diagram for MC-CDMA receiver implementation is shown in Fig. 3.9

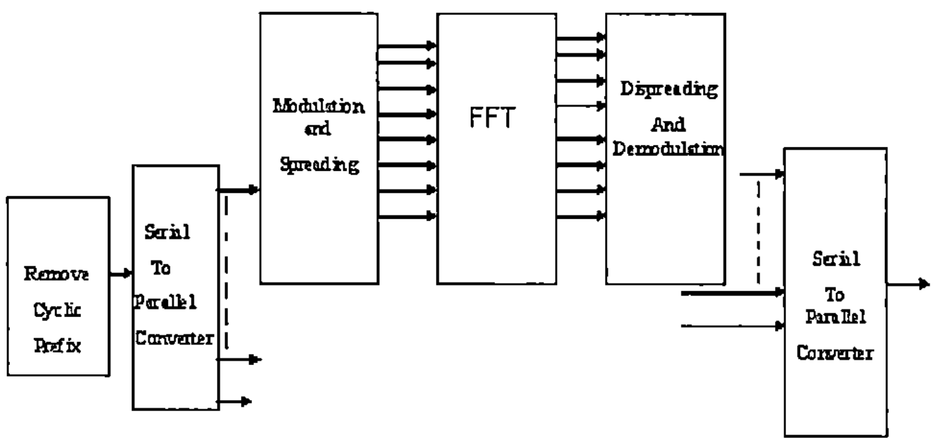

Fig. 3.9 Receiver Implementation

When the Receiver end executes an inverse operation of the transmitter, the cyclic prefix is removed and then sent to the FFT section. The FFT operation performed to obtain the signal in the frequency domain form. Therefore, in order to mitigate the interference problem of the received signal, the OFDM symbol is expanded by a cyclic prefix. At the receiver end, the data available in the cyclic prefix is avoided by synchronization. As a result, signals cannot cause Inter-Symbol-

Interference (ISI) and its bit error rate (BER) remains constant as cyclic prefix is removed at the receiver end.

SIMULATION

In this part, we perform the general Matlab simulation over various channels that we followed for the response to research questions. All simulations will be performed in the student version of MATLAB software. The first section of each channel will represent a general overview of each respective channel; then the channel is mathematically will be evaluated in terms of bit error rate (BER).

CHANNEL DISTRIBUTION

There are three essential types of channel distribution that are usually used to describe the performance of MC -CDMA. These channels are listed below.

- Additive White Gaussian Noise (AWGN) channel
- Rayleigh fading channel
- Rician fading channel

These channels are used to evaluate the error probability of Multicarrier CDMA. In the Multicarrier systems, the number of users is equal to the spread factor and can operate in a highly time dispersive channel with suitable average error probability. The performance of the system has been shown in terms of Bit Error Rate

(BER) by considering a different number of users. In this case three channels are considered with different frequency selectivity. The result shows that the Multicarrier system has a good performance with these multipath fading channels. As discussed in the first part of this chapter, the transmitter is first implemented and then the signal goes through a selected channel. The noise and interference effects are removed by system implementation. In the next part, the performance of above channels has been described.

ADDITIVE WHITE GAUSSIAN NOISE (AWGN) CHANNEL

The Additive White Gaussian Noise (AWGN) plays a vital role in the simulation of communication systems. The White Gaussian noise shows corruption in the channel. It is assumed as the fundamental type of noise that is used in many tests to show its effects on the system performance. The noise corruption is denoted by n(t) and it is known as a sample function of the Additive White Gaussian noise process with zero mean and two power spectral densities. Mathematically it is denoted by following equation (Prasad and Hara, Feb, 1996)

$$\Phi_n (t) = 1/2 \, N_0 \, W/H_z \tag{3.4}$$

In the AWGN channel, two operations are performed simultaneously. First the input signal is attenuated and delayed, and second Gaussian distributed noise is added to the attenuated output signal; this calculation is shown in Fig. 3.10.

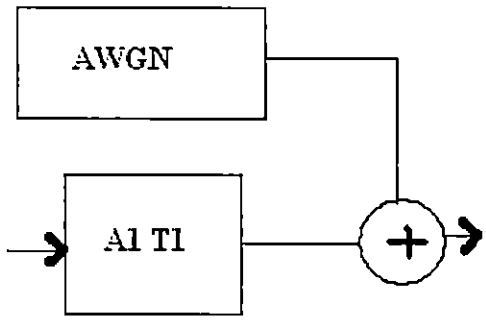

Fig. 3.10 AWGN channel

The Multicarrier CDMA system is simulated over the AWGN channel and the white noise used in simulation has approximately zero mean and unit variance. According to central limit theorem, the Gaussian distribution is also proposed for non-Gaussian independent noise sources. This characteristic of the AWGN channel allows the simple and easy analysis of communication systems.

MC-CDMA PERFORMANCE AGAINST AWGN CHANNEL

In this type of channel distribution the noise can be expressed as an additive term in the expression of received signal which is represented as (Prasad and Hara, Feb, 1996)

$$r(t) = \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} C_m(i)\, a_m(k) \cos(2\pi f_c t + 2\pi i\, F/T_b\, .t) + n(t) \tag{3.10}$$

Where r (t) is the baseband received signal and n (t) is the additive white Gaussian noise with zero mean. The transmission channel model of AWGN is shown in Fig. 3.11

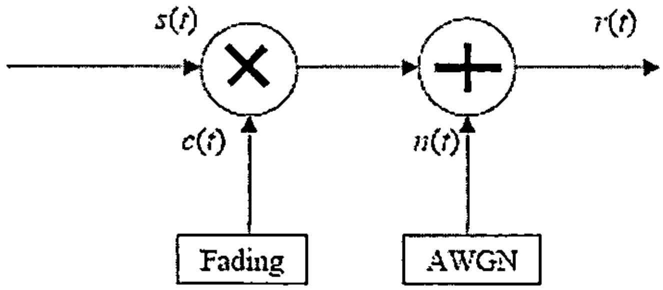

Fig. 3.11 Transmission Model of AWGN

From the receiver (Fig. 3.8), θ has a zero phase, the decision variable is

$$v_0 = \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} C_m(i)\, a_m(k) C_0(i)\, 2/T_b \int_{k\,T_b}^{(k+1)T_b} \cos(2\pi f_c t + 2\pi i\, F/T_b\,.t)\cos(2\pi f_c t + 2\pi i\, F/T_b\,.t)dt + n \qquad (3.11)$$

$$\text{Where } n = \sum_{i=0}^{N-1} \int_{k\,T_b}^{(k+1)T_b} n(t)\, 2/T_b\, C_0(i)\, \cos(2\pi f_c t + 2\pi i\, F/T_b\,.t)dt \qquad (3.12)$$

According to product of trigonometric functions,

$$v_0 = \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} C_m(i)\, C_0(i)\, a_m(k)\, 2/T_b\, 1/2 \int_{kT_b}^{(k+1)T_b} \cos(0) \cos(4\pi f_c t + 4\pi i\, F/T_b\,.t)dt + n \qquad (3.13)$$

$$= \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} C_m(i)\, C_0(i)\, a_m(k) + n \qquad (3.14)$$

$$= Na_m(k) + \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} C_m(i)\, C_0(i)\, a_m(k) + n \qquad (3.15)$$

Here the initial term represents the bit of required the k^{th} user, the second term represents the Multiple Access Interference (MAI) obtained from the (M-1) users, and the third term represents the AWGN. The interference term is expressed as (Prasad and Hara, Feb, 1996)

$$V_{int} = \sum_{m=1}^{M-1} a_m(k) \sum_{j=0}^{N/2} C_m(a_j) C_0(a_j) + \sum_{j=0}^{N/2} C_m(b_j) C_0(b_j) = 0 \qquad (3.16)$$

Where,

$$C_m(a_j)\, C_0(a_j) = 1, \qquad C_m(b_j)\, C_0(b_j) = 1 \qquad (3.17)$$

$$\{a_j\} \cup \{b_j\} = \{o, 1, \ldots. N-1\} \qquad (3.18)$$

So, $$v_0 = Na_m(k) + n \qquad (3.19)$$

Here the v_0 signify as

$$E[v_0] = Na_m(k) \qquad (3.20)$$

The variance of v_0 is given by

$$Var[v_0] = E[n^2] \qquad (3.21)$$

In the protective case of the large number of the N and by applying central limit theorem, the interference can be approximated by Gaussian random variable with a zero mean and the variance v_0. The background noise term N_0 is a random variable with a zero mean and the variance v_0 is calculated as

$$v_0 = \sum_{i=0}^{N-1} 4/T^2_b\, C^2_0(i) \int_{kT_b}^{(k+1)T_b} E[n^2(t)\cos^2(2\pi f_c t + 2\pi F(\, i/T_b).\, t)dt \tag{3.22}$$

$$= N.\, 4/T^2_b\, .\, N_0/2.\, (1/2).\, T_b = N.\, N_0/\, 4T_b \tag{3.23}$$

The relative power of noise in the AWGN channel is described by signal-to-noise ratio per sample. The error probability is calculated by using following formula (Prasad and Hara, Feb, 1996)

$$P_c = Q\,(\, \sqrt{}N/N.N_0/T_b\,) = Q(\sqrt{}T_b/N_0 \tag{3.24}$$

$$= Q \sqrt{}\, E_b/N_0 = Q(\sqrt{}SNR) \tag{3.25}$$

In other words, BER is the ratio of bit energy to power spectral density and in general it is denoted by E_b / N_0. Fig. 3.12 shows the performance of the AWGN channel as a function of signal-to-noise (SNR) ratio.

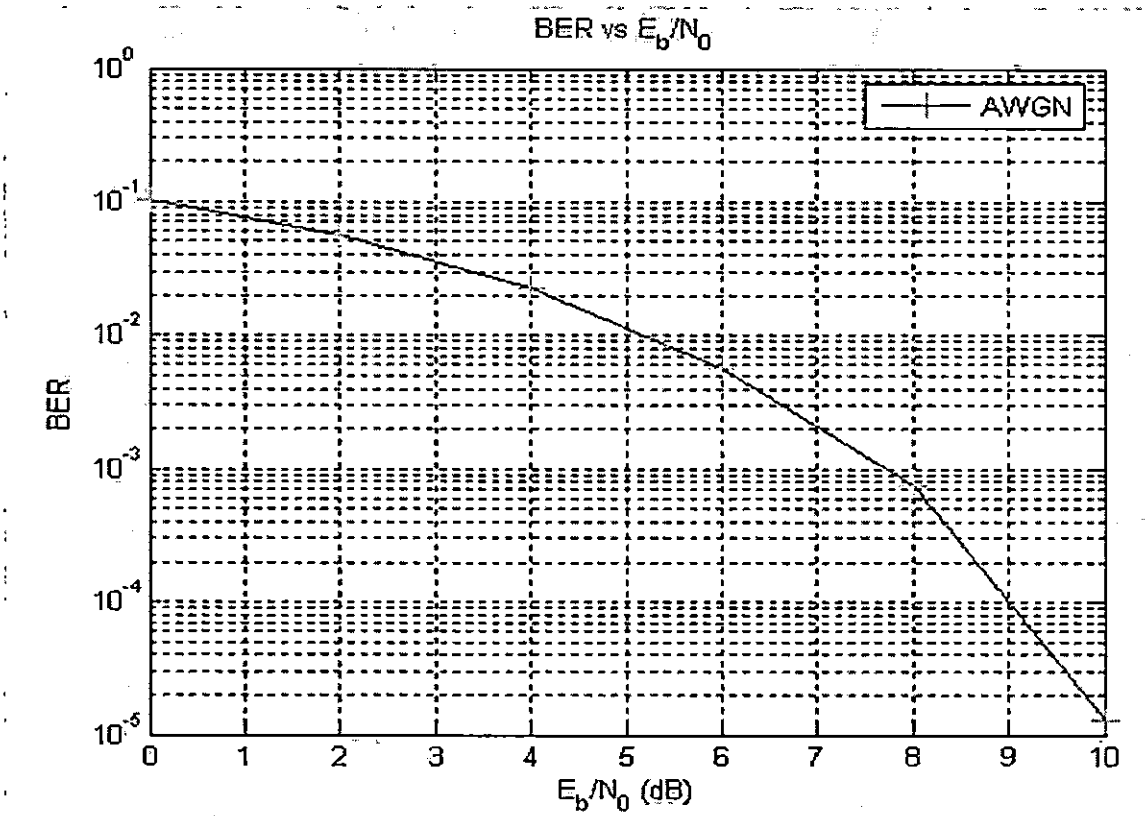

Fig. 3.12 Performance of AWGN channel

An illustration of Matlab code for error probability in the AWGN channel is shown below.

```
N=128; % # No. of subcarriers
M=38; % # No. of users
snr_db=0:8;
%% AWGN channel
p_awgn(i)=Q(sqrt(snr));
```

In this case bit error rate (BER) of the AWGN channel depends on the SNR. The local mean power of each interference signal is equal to the local mean power of desired signal.

RAYLEIGH FADING CHANNEL

A transmitted radio signal usually propagates through several paths according to surrounding environment. The attenuation coefficients corresponding to different paths are supposed to be independent and identically distributed if line-of-site between two terminals are missing. In these coefficients the path gain has a uniformly distributed phase and Rayleigh distributed magnitude. The received signal is the sum of random variables united under a particular condition to a Gaussian form. The random variable identifies as the Rayleigh distribution. In the Rayleigh Fading Channel, the transfer function assumed for the m^{th} user can be represented as (Prasad and Hara, Feb, 1996),

$$H_m[f_c + i\, F/T_b] = \rho_{m,t} e^{j\theta_{mj}} \qquad (3.5)$$

Where $\rho_{m,t}$ and $\theta_{m,j}$ are the random magnitude and phase of the channel of the m^{th} user at frequency $f_c + i{*}F/T_b$. The random magnitude $\rho_{m,j}$ is assumed to be independent and identically distributed Rayleigh random variables for all users and sub-carriers where Rayleigh distribution is represented by [13]

$$f_{\rho m,j}(\rho_{m,t}) = \rho_{m,t}/\sigma^2_{m,t}\, e^{-\rho^2_{m,j}/2\sigma^2_{m,j}} \qquad (3.6)$$

The arbitrary phase $\theta_{m,j}$ is supposed to be a identical random variable on the interval i.e. 0~2π for all users and sub-carriers.

MC-CDMA PERFORMANCE AGAINST RAYLEIGH FADING CHANNEL EQUILIZATION

The main objective of the equalization technique in the communication system is to achieve the effect of the fading channel on the conclusion stage. Multiple access tests are essential to check the equalization techniques used in simulation. There are three common types of equalization techniques named as Equal Gain Combining (EGC), Maximal Ratio Combining (MRC), and Minimum Mean Square Error Combining (MMSEC). Consider a complex variable q corresponds to the channel effect having a uniform time delay, phase shift and random amplitude. In this, q has received one sub-carrier from a multipath fading channel. As a result of this each subcarrier shows different characteristics. The various multipath channels affect on subcarriers in terms of attenuation and phase shift.

The MRC and MMERC are very difficult to implement as it requires noise power and number of users. The EGC technique does not affects the orthogonality of codes as poorly as compared to the other diversity techniques. Therefore in this part of the simulation, the standard diversity reception technique known as EGC is used.

EGC is a simplified description of MRC as it uses all the branches simultaneously. The receiver in the Rayleigh fading channel acts like a detection receiver and received signal for M active transmitters is represented as

$$r(t) = \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} \rho_{m,I}\, c(i)\, a_m(k) \cos(2pf_c t + 2piF/T_b t + \rho_{m,j}) + n(t) \tag{3.26}$$

Where n(t) is Additive White Gaussian Noise. To simplify, we assumed that the exact synchronization with the desired user (m=0) is possible and perfect phase correction can obtained. For the k^{th} bit, the decision variable is expressed as

$$V_0 = \sum^{M-1} \sum^{N-1} \rho_{n,j}\, C_m(t) C_0(t) a_m(k) 2/T_h \int_{kT_b}^{(k+1)T_b} \cos(2\pi f_c t + 2\pi F/T_h + \theta_{m,i}) \tag{3.27}$$

$$= x\cos(2\pi f_c t + 2\pi\, F/T_c\, t + \theta_{0,t})dt + n \tag{3.28}$$

$$\text{Where } n = 2/T_b \sum^{N-1} \int_{kT_b}^{(k+1)T_b} n(t) C_0(i) \cos(2\pi f_c t + 2\pi Fi/T_b t + \theta_{0,j})dt \tag{3.29}$$

Let solve the equation

$$V_0 = \{2/T_b 1/2 \sum^{M-1} \sum^{N-1} \rho_{m,j}\, C_m(t) C_0(t) a_m(k) \int_{kT_b}^{(k-1)T_b} [\cos(\theta_{0,i} - \theta_{m,j}) + (\text{Cos}\,(4\,\pi f_c t + 4\pi F/T_b + \theta_{m,j} + \theta_{0,j})dt + n)\} \tag{3.30}$$

$$= -1/T_b \sum_{m=1}^{M-1} \sum_{i=0}^{N-1} \rho_{m,j}\, C_m(i) C_0(i) a_m(k) \cos(\theta_{0,i} - \theta_{m,j}) T_b + n \tag{3.31}$$

$$= -a_0(k) \sum_{i=0}^{N-1} \rho_{0,i} \sum_{m=1}^{M-1} \sum_{i=0}^{N-1} a_m(K) C_m(i) C_0(i) \rho_{m,i} \cos(\theta_{0,i} - \theta_{m,j}) + n \tag{3.32}$$

The first term represents the k[th] bit of the required user, the second term gives the interference of the other users and last term provides the 'AWGN, which shows that the interference term has a zero mean Gaussian distribution.

The difference of the interference term is expressed as (Prasad and Hara, Feb, 1996),

$$\mathrm{var}[V_{int}] = E[\sum_{m=0}^{M-1} \sum_{i=0}^{N-1} a^2_m (k) c^2_0(i) \rho^2_{m,j} \cos^2(\theta_{0,j} - \theta_{m,j}) \quad (3.33)$$

$$= (M-1)N \,.\, E[\rho^2_{m,i}/2] \quad (3.34)$$

$$= (M-1)\, P_m \quad (3.35)$$

According to the central limit theorem for large N, the Gaussian distribution is represented as

$$\rho_c - \sum_{i=0}^{N-1} \rho_{0,i} \quad (3.36)$$

Where $\rho_{0,j}$ has a Rayleigh distribution.

So the mean and variance of Rayleigh distribution is represented as

$$E[\rho_{0,j}] = \alpha \sqrt{\pi}/2 \quad (3.37)$$

$$\mathrm{var}[\rho_{0,j}] = (2-\pi/2)\alpha^2 \quad (3.38)$$

Therefore the variance of the required data is given by

$$\mathrm{var}[\rho_j] = N(2-\pi/2)p_{0,j} = (2-\pi/2)p_0 \quad (3.39)$$

Similarly the mean can be obtained by

$$a_0(k)E[\rho_{0,j}] = \alpha_0(k)N \sqrt{\pi/2}\sqrt{p_{0,i}} = a_0(k) \sqrt{\pi/2}\, Np_0 \quad (3.40)$$

At the same time the variance for noise can represented as

$$var[V_a] - N\, N_0/T_b \quad (3.41)$$

Now the interference and noise factor has a zero mean, then the mean of v_0 is shown as

$$E[v_0]-\sqrt{\pi/2}Np_{0,i} \quad (3.42)$$

And variance for v_0 is obtained as

$$Var[V_0] = (2- \pi/2)\, P_0 + (M-1)P_m + N\, N_0/T_b \quad (3.43)$$

Now rearranging the above equation, for large values of N, the average BER for the case of a full load is represented as (Prasad and Hara, Feb, 1996),

$$P_0 = Q\ \sqrt{\pi/2}Np_0/\ (2-\pi/2)p_0 + (M-1)p_m + N\, N_0/T_b \quad (3.44)$$

$$P_0 = Q\ \sqrt{\pi/2}.(p_2\, T_b)\, /\, (2-\pi/2)p_0/\, N.T_b + (M-1)p_m/N.T_b + N_0 \quad (3.45)$$

The BER performance over the Rayleigh Fading Channel depends on its spreading factor. As the spreading factor increases, the performance improves. This is because the spreading factor is the power of the Line-Of-Sight (LOS) component. The performance of the Rayleigh fading and Rician Fading Channel is equal when the value of spreading factor is zero which minimizes the LOS. In this case, the system is simulated for different numbers of users like M = 4, 8, 64, 28. Fig. 3.13 shows a plot of average error probability versus the signal-to noise ratio (SNR in dB) in a Rayleigh

Fading Channel. The graph is plotted against 4 users. The error probability is shown by the vertical axis while SNR (dB) is given by the horizontal axis.

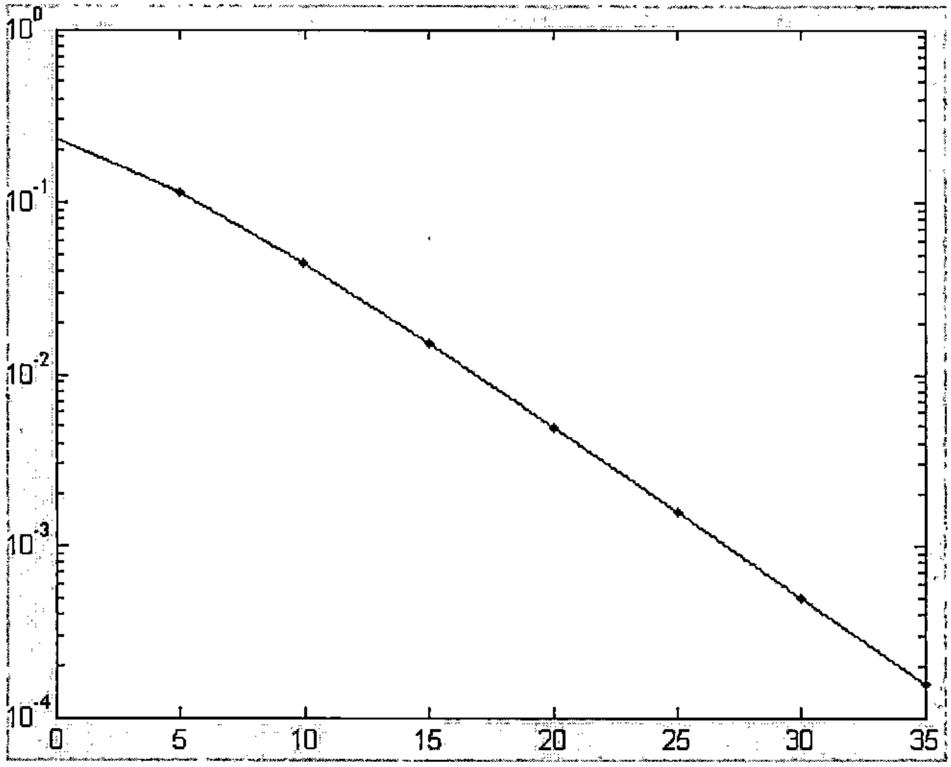

Fig. 3.13 Average Error Probability Vs SNR (dB)

As the Rayleigh Fading Channel uses the EGC equalization technique, the system shows better performance for large number of users. The EGC technique distorts the orthogonality between users and could be enhanced more by restoring the orthogonality of interfering signals. The performance of the EGC technique in the downlink communication is superior as compared to uplink communication due to its orthogonality effect. The sample of Matlab code is given below,

```
function [p_ray]=rayl(N,M);
```

```
snr_db=0:35;
%% Rayleigh fading channel
p_ray(i)=Q(sqrt((pi/2)*(snr/(((2pi/2)*snr/N)+((M1)*snr/N)+1))));
end
```

Therefore, the average BER of the downlink Multicarrier CDMA systems is improved by using the EGC equalization. The performance of EGC depends on the number of users and its SNR ratio. When the SNR and the number of users increase gradually, the synchronization error decreases. However, the other equalization techniques provide better options for performance against uplink Multicarrier CDMA systems. In this case, the simulation has been performed over downlink communications, because all users can operate on the same channel at the receiver end. Therefore, the receiver can do a phase correction to all users at one time. This will offer a better performance against interference by restoring the orthogonality.

RICIAN FADING CHANNEL

The Rayleigh Fading Channel does not offers the LOS between the transmitter and receiver, therefore it is suitable for representing urban areas, however the inhabited areas may offer LOS between the transmitter and receiver and this will propose to the Rician Fading Channel. The Rician channel considers a LOS which does not attenuate the signal and does not require a time delay. The Rician Fading Channel is characterized by the power ratio of LOS. This ratio is known as k-factor.

When $k = \infty$, there is no fading and when $k = 0$, the performance shows Rayleigh Fading. The Rician Channel is specially used for indoor wireless communication systems. In this case as orthogonality between users is not valid hence receiver only combats with noise. In downlink communication transmissions the received signals selected for other users i.e. ($m=1, 2, 3,\ldots, (M-1)$) using the same channel as the required signal i. e ($m = 0$). The transfer function assumed for the m^{th} user of the base station to user $m = 0$ can be obtained as

$$H_m[f_c + i\, F/T_b] = \rho_{m,t} e^{j\theta}{}_{m\,j} \qquad (3.46)$$

Where $\rho_{m,j}$ and $\theta_{m,j}$ are the random magnitude and phase of the channel of the m^{th} user at frequency $f_c + i*F/T_b$. The phase $\theta_{m,j}$ for $i= 0, 1, 2, \ldots N-1$ commenced by the channel are to be uniform random variables on the interval $0\sim2\pi$ for all users and sub-carriers. Due to the LOS component, the magnitude factor $\rho_{m,j}$ for $i= 0, 1, 2,\ldots, N-1$ are supposed to have the following Rician distribution (Prasad and Hara, Feb, 1996).

$$f_{\rho m,j}(\rho_{m,t}) = \rho_{m,j}/\sigma^2{}_{m,j}\, e^{\rho 2+ b2}{}_{m,j}/2\sigma^2{}_{m,j} j_{\sigma}(b_0\rho_{m,j}/\sigma^2{}_{m,j}) \qquad (3.47)$$

Where $\sigma^2{}_{m,j}$ represents the power of the scattered component, b_0 is the LOS component and $I_0(\rho)$ is the $zero^{th}$ ordered modified function, where,

$$I_0(x) = (\sum_{k=0}^{\infty} (x/2)^{2k})/\, k\pi\, (k+1) \qquad x \geq 0, \qquad (3.48)$$

MC-CDMA PERFORMAMCE AGAINST RICIAN FADING CHANNEL

The Rician Fading channel shows the basic LOS component from transmitter to receiver end with extra weaker paths obtained from reflections. The performance analysis of Multicarrier CDMA systems over the Rician Fading Channel is obtained by using the EGC equalization technique as it offers less complexity of the receiver. The decision variable for the Rician Fading Channel is shown as (Prasad and Hara, Feb, 1996),

$$V_0 = a_0(k) \sum_{i=0}^{N-1} \rho_i + \sum_{m=0}^{M-1} a_m(k) \sum_{t=0}^{N-1} C_n(i) C_0(i) \rho_{m,j} \cos(\theta_{0,i} - \theta_{n,t}) + n \tag{3.49}$$

Here $\hat{n}$ is the AWGN term and has a variance of N^*N_0/T_b and ρ_i and $\rho_{m,j}$ are Rician distribution. Due to the subcarrier orthogonality of the codes, the interference term can be expressed as (Prasad and Hara, Feb, 1996),

$$V_{int} = \sum_{m=1}^{M-1} a_m(k) \left(\sum_{j=1}^{N/2} \rho_{c,j} - \sum_{j=1}^{N/2} \rho_{b,j} \right) \tag{3.50}$$

Where

$C_m(a_j)C_0(a_j) = 1$

$C_m(b_j)C_0(b_j) = -1$

Apply the central limit theorem, the interference term as a Gaussian distribution with a mean and a variance. The Rician distribution is used to calculate the mean and variance and it is represented as

$$E[\rho_i] - e^{-k/2} \sqrt{(\pi/2.(k \mid 2))}.P_i \, [(1 \mid k) I_0 (k/2)] \mid k I_1 (k/2)] \tag{3.51}$$

From the above equation the mean of interference is calculated as a

$$E[v_{int}] = \Sigma a_m (k)\ \Sigma\ (E[\rho_{a,j}] - E[\rho_{b,j}]) = 0 \tag{3.52}$$

The variance of interference is obtained as

$$var[v_{int}] = E[v^2_{int}] \tag{3.53}$$

$$= \sum_{m=1}^{M-1} a^2_m (k) \sum_{j=0}^{N/2} E[\rho^2_{a,j}] + \sum_{m=1}^{M-1} a^2_m (k) \sum_{j=1}^{N/2} E[\rho^2_{b,j}] - 2 \sum_{m=1}^{M-1} a^2_m (k) \sum_{j=1}^{N/2} E[\rho_{a,j}]\ E[E[\rho_{b,j}]] \tag{3.54}$$

$$= 2(M-1)Np_1 - 2(M-1)N/2\ e^{-k} (\pi/2(K+1))\ p_1[(1+k)I_0 (k/2)+KI_1(k/2)]^2 \tag{3.55}$$

$$= 2(M-1)Np_1 - 2(M-1)p\ \pi/4.\ e^{-k}/[(1+k)I_0(k/2)+ KI_1(k/2)]^2 \tag{3.56}$$

$$= 2(M-1)p[1-\gamma] \tag{3.57}$$

Where $\gamma=\pi/4.(e^{-k}/k+1)[(1+k)I_0(k/2)+kI_1(k/2)]^2$ (3.58)

As the signal contains an interference term, the central limit theorem applied to the desired data term to obtain the mean given by

$$= E[v] - a_0 (k) \sum_{t=1}^{N-1} E[\rho_t] \tag{3.59}$$

$$= a_0 (k).\ N.e^{k/2}\surd\ (\pi/2(k-1)).\ p_1[(1+k)I_0(K/2)+KI_1(K/2)] \tag{3.60}$$

The mean of v_0 is represented as

$$E[v_0] = a_0 (k).\ N.\ e\text{-}^{k/2}\surd\ (\pi/2(k-1))^*\ p_1[(1+k)I_0(K/2)+KI_1(K/2)] \tag{3.61}$$

Similarly the variance of v_0 is shown as

$$Var[v_0] = (1- \gamma)p(2-M) + 2(M-1)p(1- \gamma)+ N.N_0/T_b \tag{3.62}$$

The average error probability is given by an equation

$$P_t = Q(\sqrt{\{N^2 . e^{-k} (\pi/2(K|1)).p\,[(1+K)I_0 (K/2)+ KI_1(K/2)]^2\}} / (1-\gamma)p\,(2\text{-}M) + 2(M-1)p(1-\gamma)+ N.N_0/T_b \tag{3.63}$$

$$= Q(\sqrt{(N.\gamma.p) / (p(1-\gamma).M + N.N_0/T_b)}) \tag{3.64}$$

$$= -Q(\sqrt{(\gamma.\,T_b.p) / (((p(1-\gamma).M.\,T_b\,)/N)+ N_0)}) \tag{3.65}$$

The performance of the Rician Fading channel is improved, as the value of K-factor is increased. The factor offers the power of the Line-of –Sight (LOS) component. The performance of the Rician Fading Channel and the Rayleigh Fading Channel is same the when the value of K-factor is equal to zero due to the lack of LOS path. Again the Rician Fading Channel presents a better performance than the Rayleigh Fading channel because of the LOS path. The performance of the Rician Fading channel in a downlink communication for different users shown in Fig. 3.14 The plot of the error probability was obtained for K = 10, the SNR = 15dB. In this case, the EGC equalization technique is proposed in this section because it offers improvement in the BER for increasing K-factors.

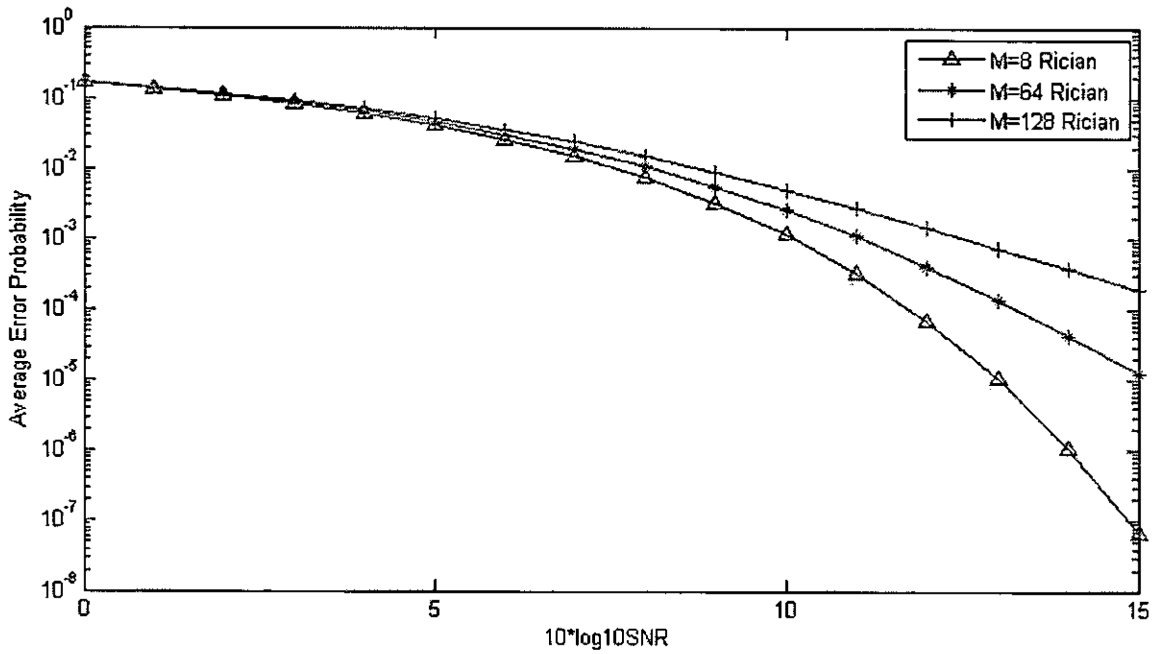

Fig. 3.14 Average Error probability Vs SNR (dB)

The sample Matlab code used for the simulation is expressed as,

```
%% in rician fading channel.
function [p_rician]=rician(N,M);
snr_db=0:15;
K=10; % The value of K-factor
r=(pi/4)*(exp(-K)/(K+1))*((1+K)*besseli(0,K/2)+K(1)*besseli(1,K/2))^2;
p_rician(i)=Q(sqrt((r*snr)/((M*(1-r)*snr)/N+1)));
```

SINGLE CARRIER SYSTEM AND MULTICARRIER SYSTEM

The single carrier system uses a RAKE receiver reception while the Multicarrier system uses the frequency diversity. The performance of the Multicarrier systems reduces the SNR of the decision state and as a result increases the BER. However, the performance of the single carrier system is difficult to implement. The Multicarrier system outperforms the single carrier system except that the bandwidth of interference covers the entire bandwidth (BW). The single carrier system waveform in the frequency domain is shown in Fig. 3.15(a) while Fig. 3.15(b) shows waveform for Multicarrier systems with M equi-width frequency bands.

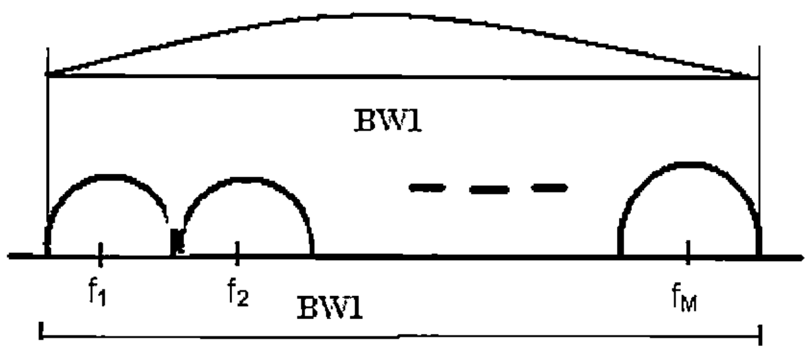

Fig. 3.15(a) Single carrier system and Multicarrier system

The central frequency of the interference overlaps the second sub-carrier frequency of the Multicarrier system, and the sub-frequency bandwidth and interference bandwidth is equal, this is shown in Fig. 3.15(b)

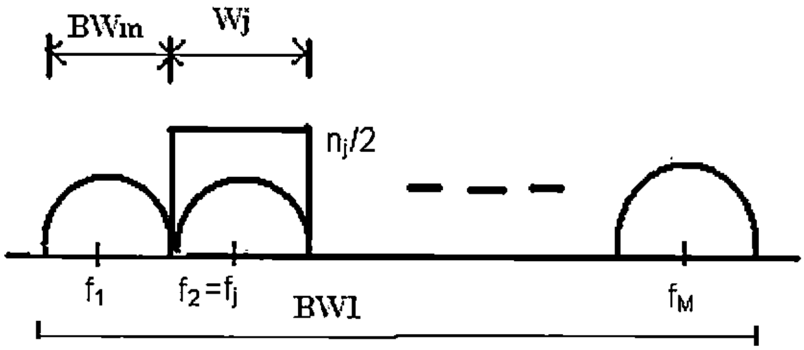

Fig. 3.15(b) Multicarrier bandwidth

Multicarrier systems do better than single carrier systems as it shows the interference only in the second band.

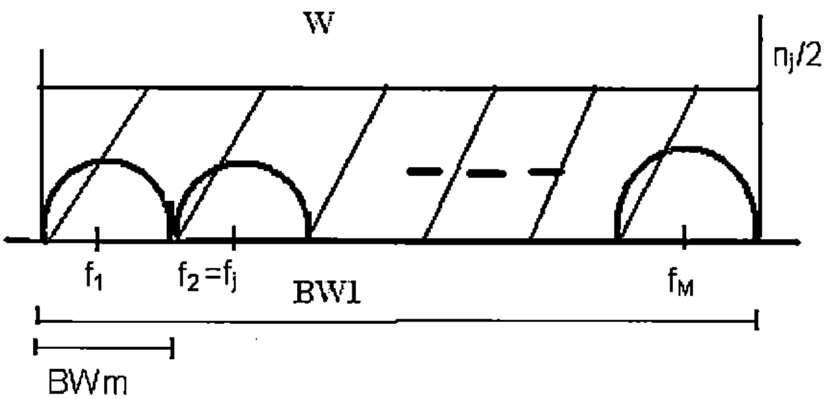

Fig 3.16

The bandwidth of the Multicarrier system is represented as (Prasad and Hara, Feb, 1996),

BW = BW/M, where all sub bands are not overlapped.

APPLICATION TO RESEARCH QUESTIONS

Question-1 asks how implementation technique reduces the interference problem in the Multicarrier CDMA systems. The frequency diversity gain in the MC-CDMA systems is limited by correlation between subcarriers; however, the cyclic prefix is introduced to minimize the correlation between subcarriers and eliminating the effect of interference. Question-2 asks how a Multicarrier system offers improved Bit Error Rate (BER) by Matlab simulation. The system is simulated over AWGN, Rayleigh Fading, and Rician Fading channels in terms of error probability. The Equal Gain Combining (EGC) equalization technique is commenced to improve the BER in downlink communication. The mathematical evaluations have been done in terms of Bit Error Rate over Transmitter and Receiver of various channels.

CHAPTER IV

FINDINGS

In this chapter the performance of MC-CDMA systems is analytically simulated over various fading channels explained in chapter three. The performance results are obtained in terms of Bit Error rate (BER). The simulation was performed using Matlab.

MC-CDMA IMPLEMENTATION

Multicarrier CDMA offers advantages of CDMA and OFDM. The MC-CDMA system reduces the interference problem by using cyclic prefix between the transmitter and the receiver. The cyclic prefix transmitting the same data for a large number of orthogonal carriers. Therefore, multiple channel users can communicate through the same channel without affecting interference. Also, the cyclic prefix reduces the transmitter and receiver complexities and offers high power spectral density. Fig. 4.1 shows the transmitter implementation output of the OFDM system.

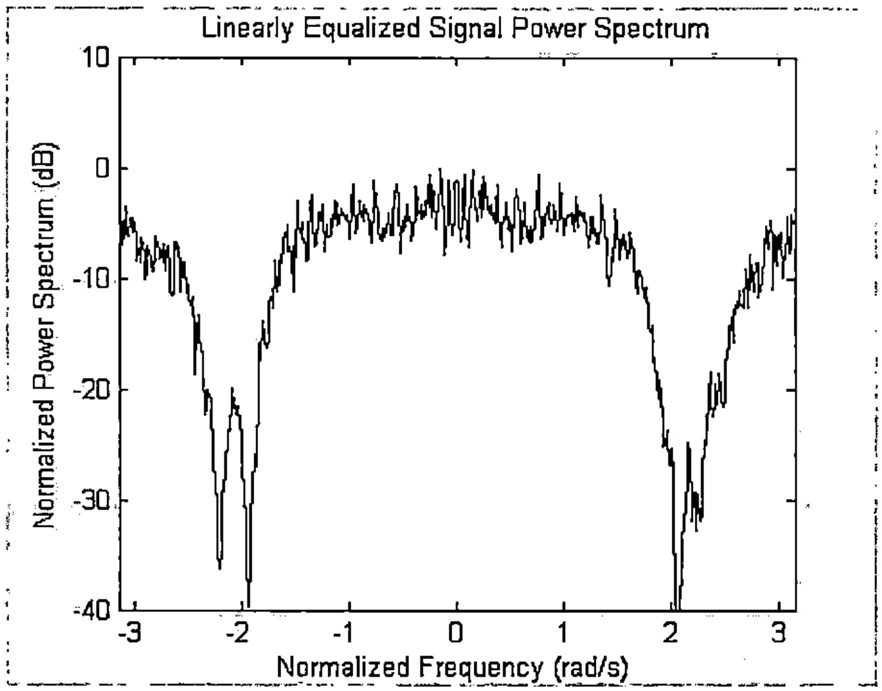

Fig. 4.1 OFDM Spectral Efficiency

The corresponding output for MC-CDMA system is shown in Fig. 4.2

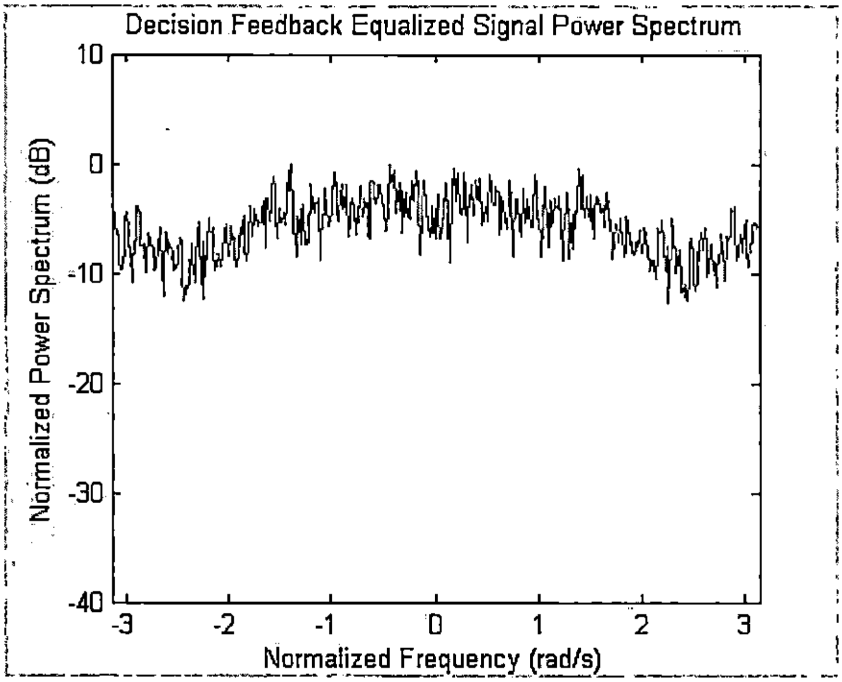

Fig. 4.2 MC-CDMA Spectral Efficiency

The figure indicates that the MC-CDMA system outperforms the OFDM in terms of spectrum efficiency (dB). The MC-CDMA uses the FFT, IFFT, and modulation/demodulation to implement a simple transmitter and receiver, so the system is capable of operating up to 100Mbps for a variety of applications. Fig. 4.3 shows that the MC-CDMA outperforms the OFDM and Direct-sequence CDMA (DS-CDMA) in terms of BER.

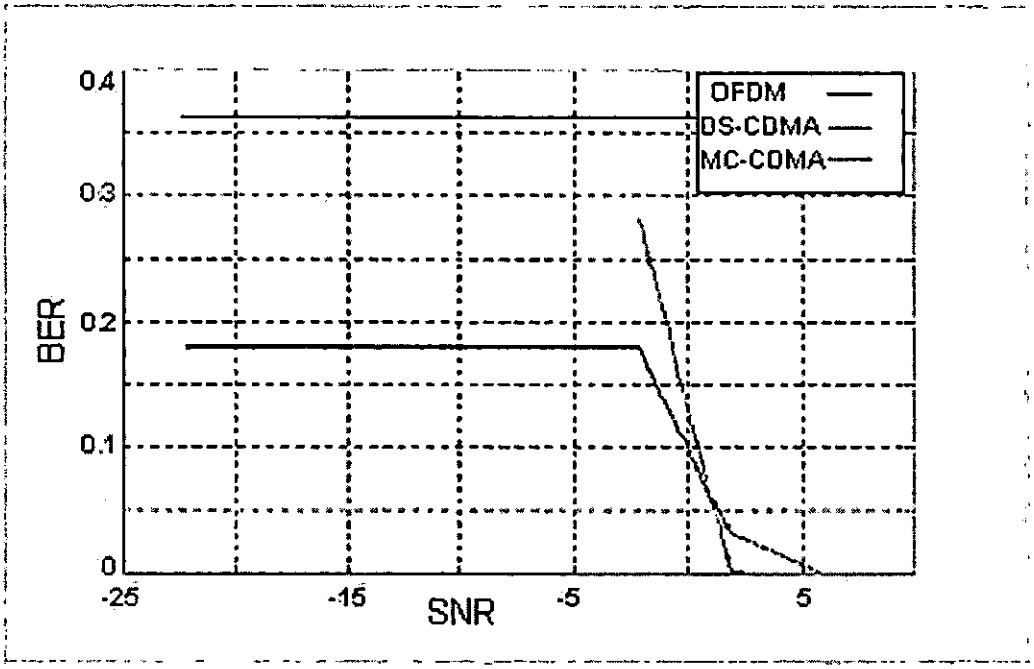

Fig. 4.3 Performance of MC-CDMA, DS-CDMA, and OFDM

PERFORMANCE AGAINST AWGN CHANNEL

Fig. 4.4 shows the performance of MC-CDMA systems in the AWGN channel, as a function of Signal-to-Noise ratio (SNR). In this case the SNR is set to be 15dB, the number of subcarriers (N) = 128, and the number of users (M) =40. The BER of the AWGN channel depends on the SNR value and outperforms the other channels. The performance of AWGN improves as the SNR is increased is shown in Fig. 4.5

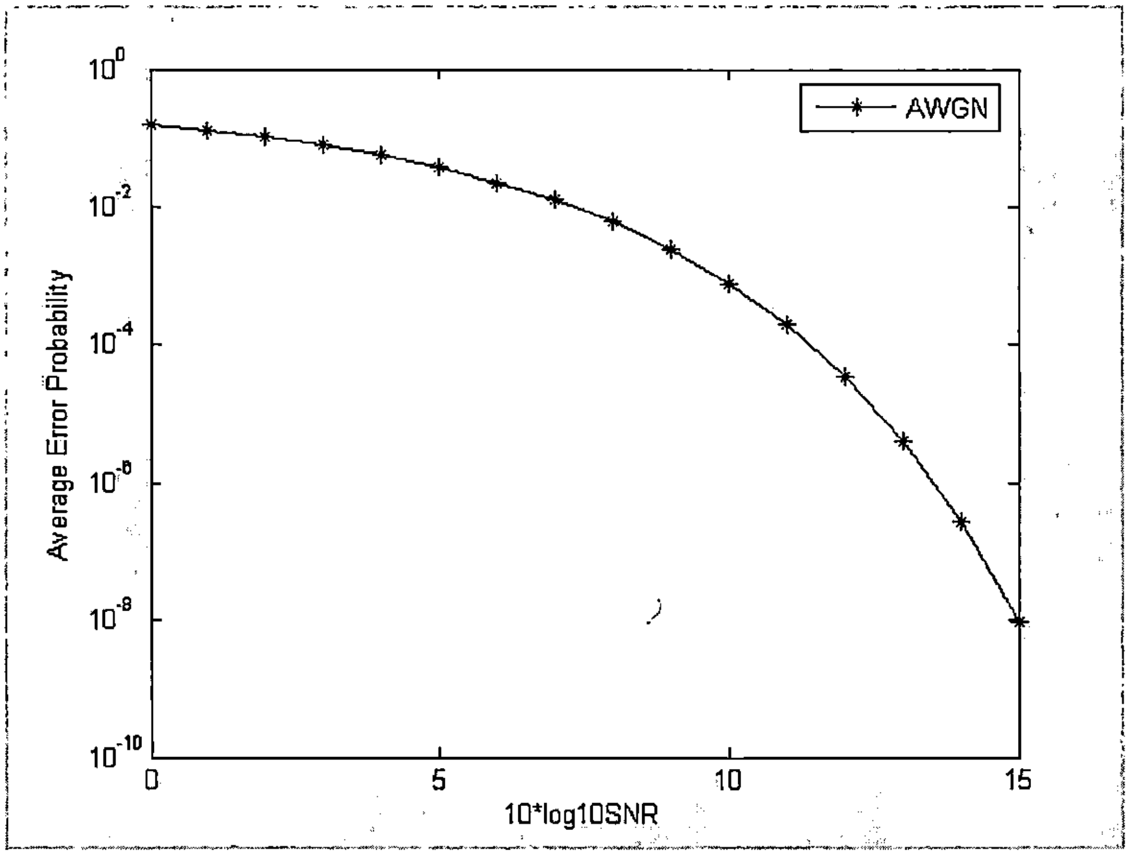

Fig. 4.4 BER vs. SNR (dB) for SNR = 15 (dB)

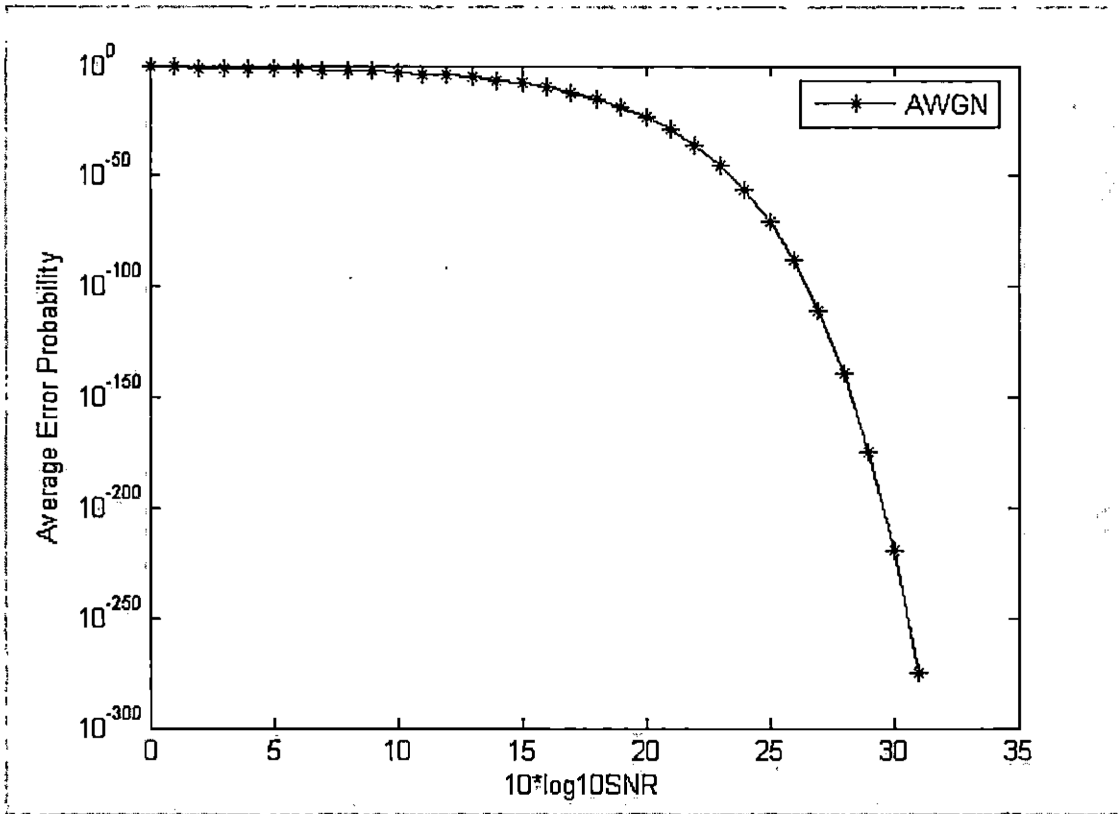

Fig. 4.5 BER vs. SNR (dB) for SNR = 35 (dB)

PERFORMANCE AGAINST RAYLEIGH FADING CHANNEL

Fig. 4.6 and Fig. 4.7 show the performance of Rayleigh Fading channel for different numbers of subcarriers (N). Both figures show that the BER reduces as the number of users increased.

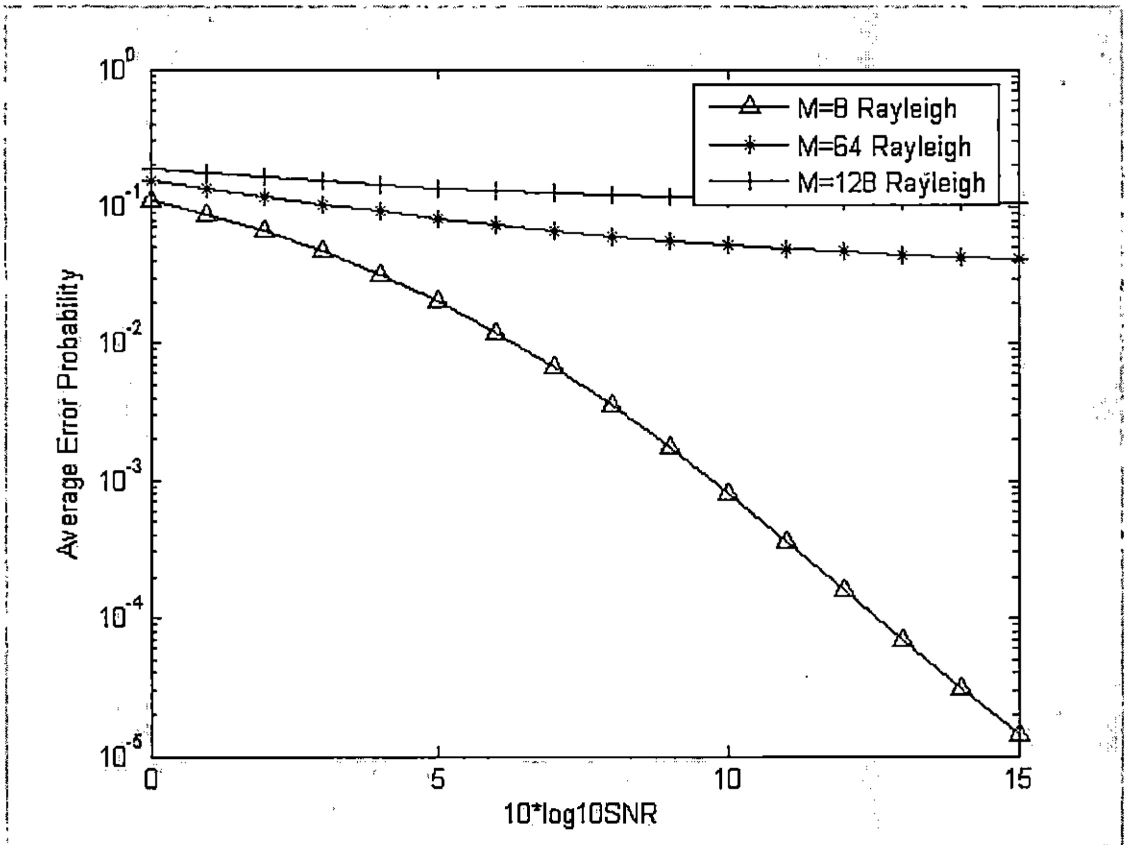

Fig. 4.6 BER vs. SNR (dB) for various values of M

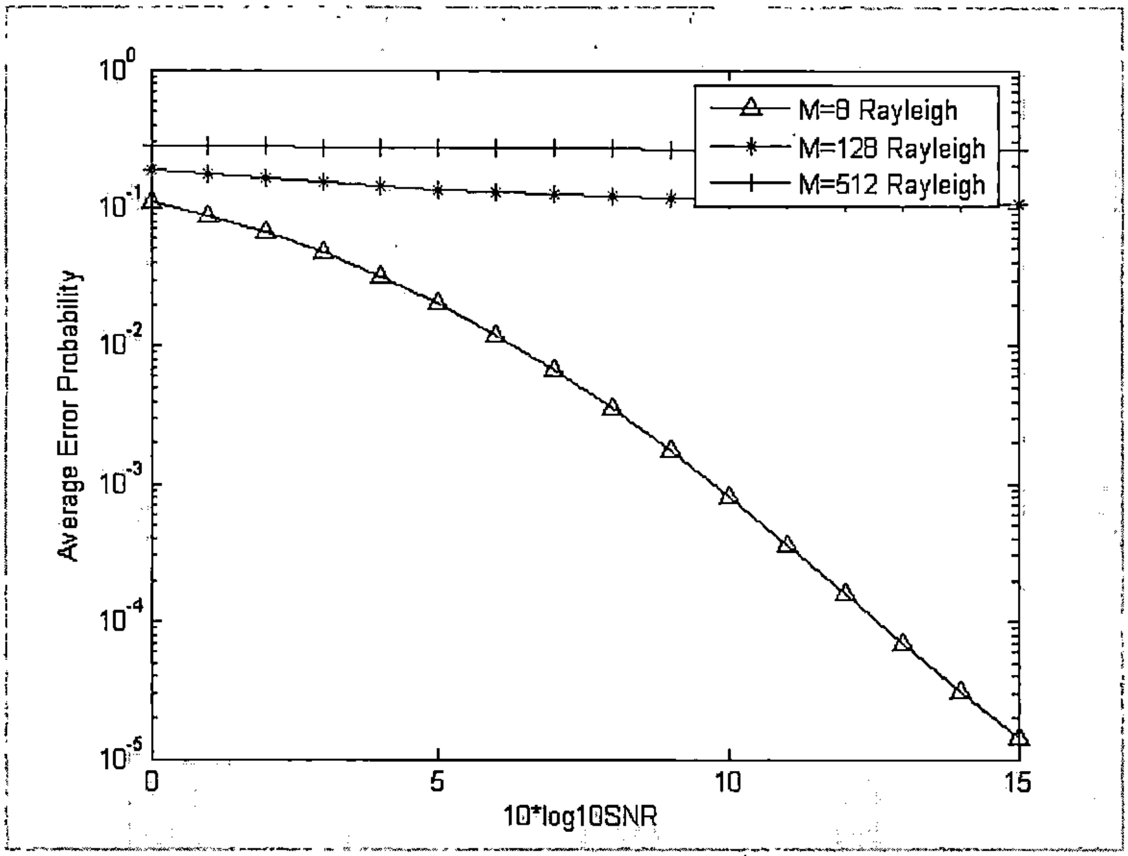

Fig. 4.7 BER vs. SNR (dB) for various values of M

The BER degrades as the SNR is increased for a higher number of users (M) due to the increased interference power shown in Fig. 4.8. In this case, the value of SNR increases from 15dB to 25dB, as a result the BER degraded.

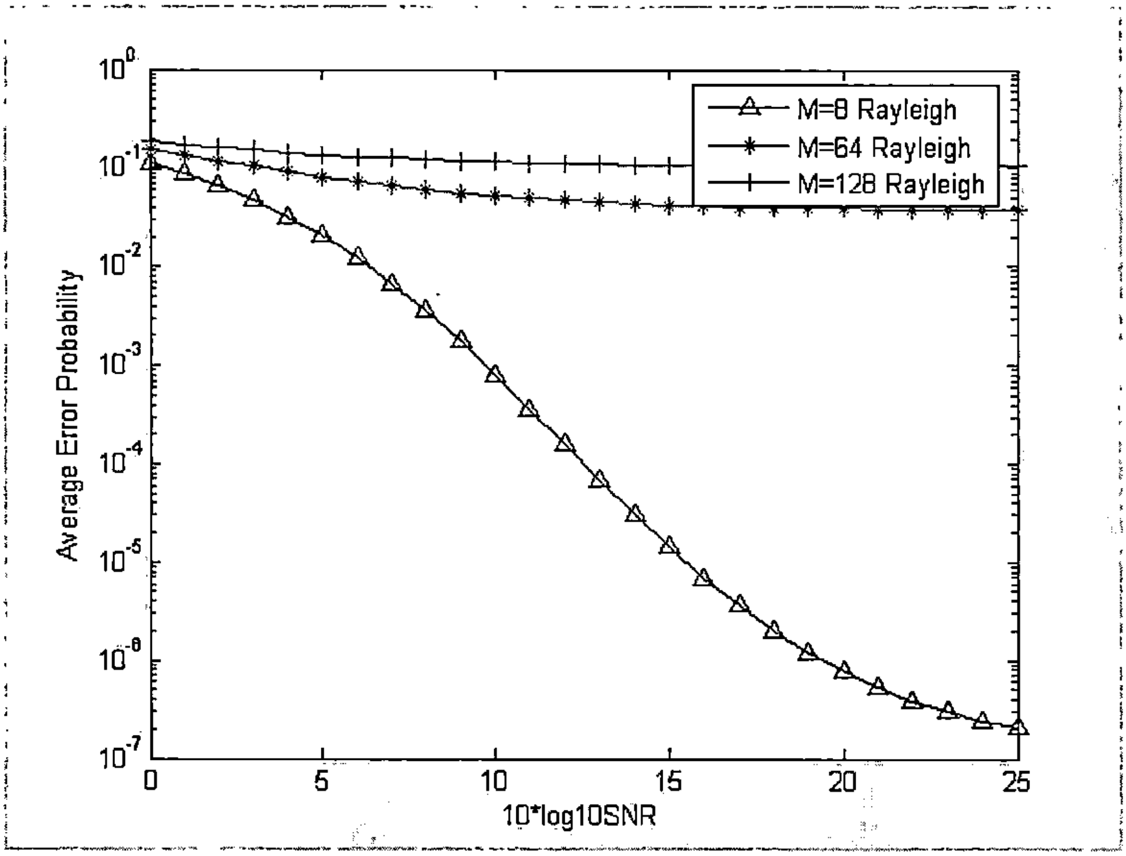

Fig. 4.8 BER vs. SNR (dB) for SNR = 25 (dB)

The equalization technique MMERC is very difficult to implement as it requires noise power and a number of users while EGC is a simplified description of MRC as it uses all the branches at a time. Moreover, the EGC technique does not affects the orthogonality of codes as poorly as compared to the other diversity techniques as described in the third chapter. Therefore, the EGC technique is proposed for the simulation. Fig. 4.9 shows the EGC improvement over MRC.

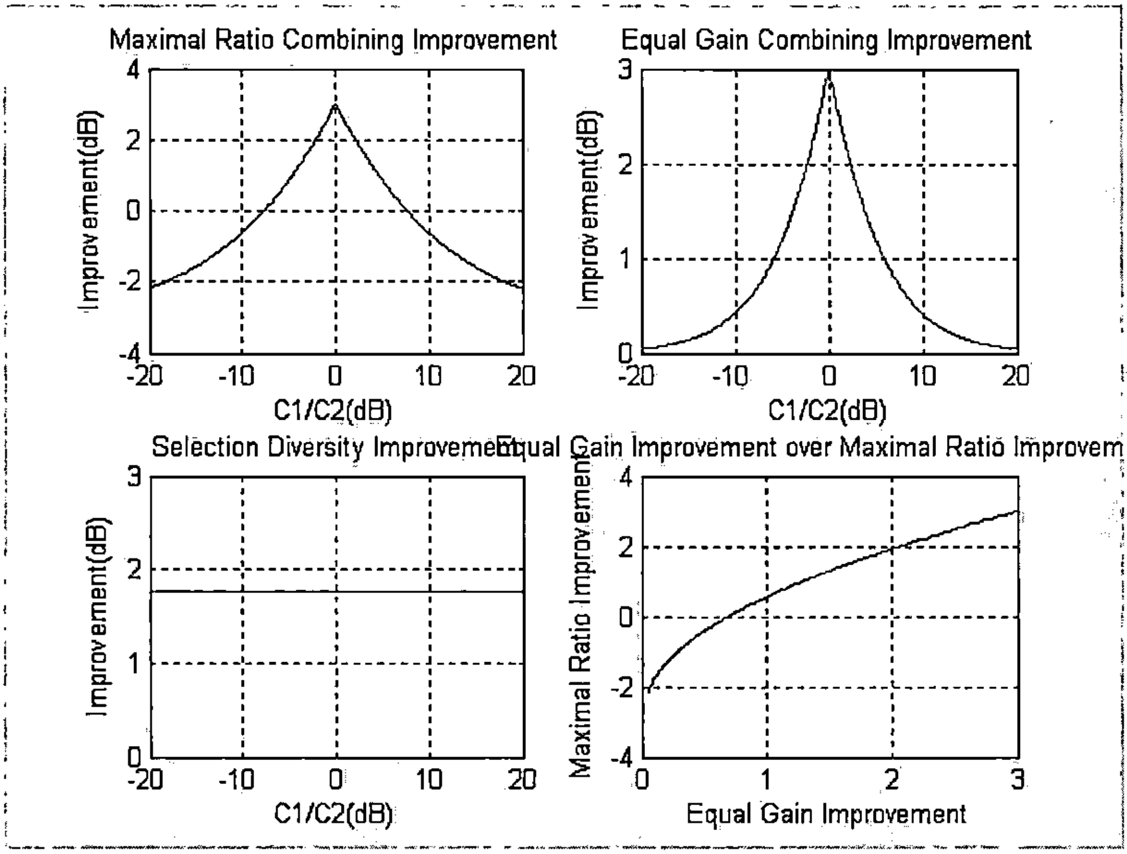

Fig. 4.9 EGC vs. MRC

PERFORMAMCE AGAINST RICIAN FADING CHANNEL

The performance of the Rician Fading channel improves as the K-factor is increased as shown in Fig. 4.10, because the K-factor is the power of Line-of-Sight component.

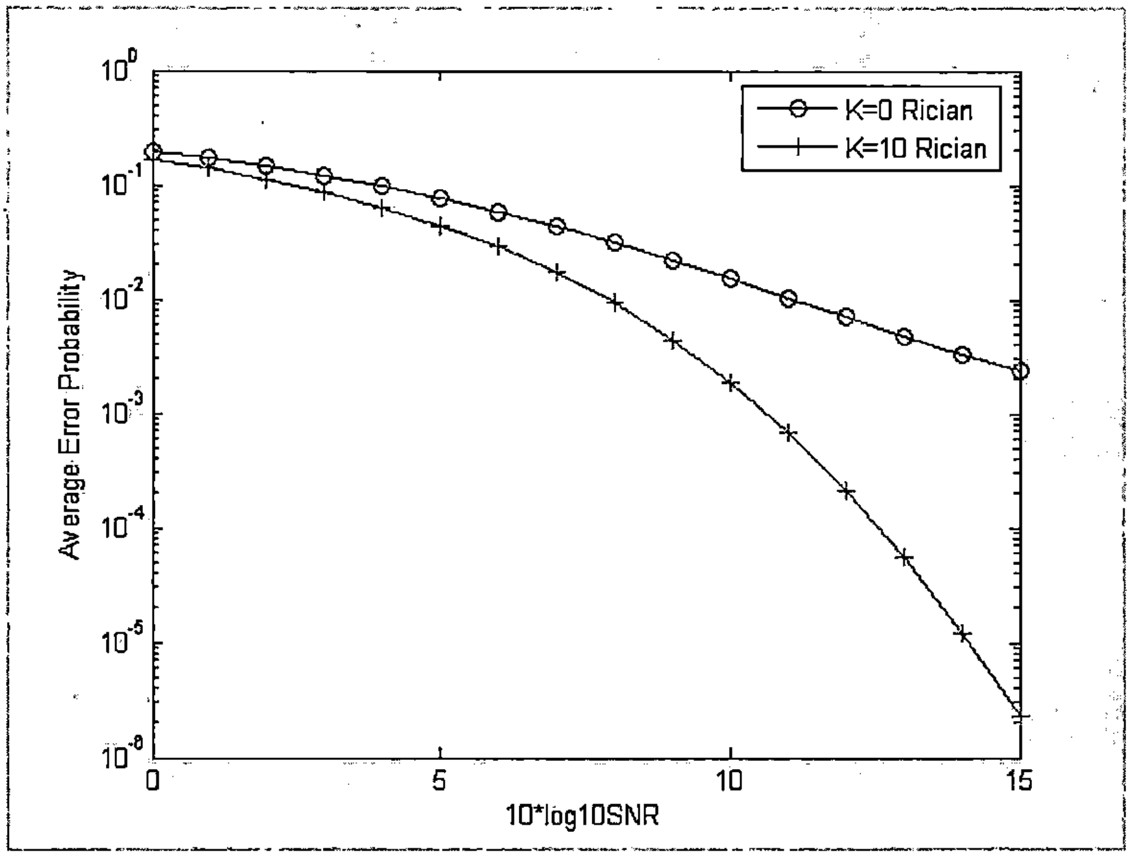

Fig. 4.10 BER vs. SNR (dB) for K = 0 and 10

The BER of the Rician Fading channel increases as the number of users is increased, as shown in Fig. 4.11. The graph shows that for M =8, the BER is ~10^{-7} and for M = 128, the BER is ~10^{-4}

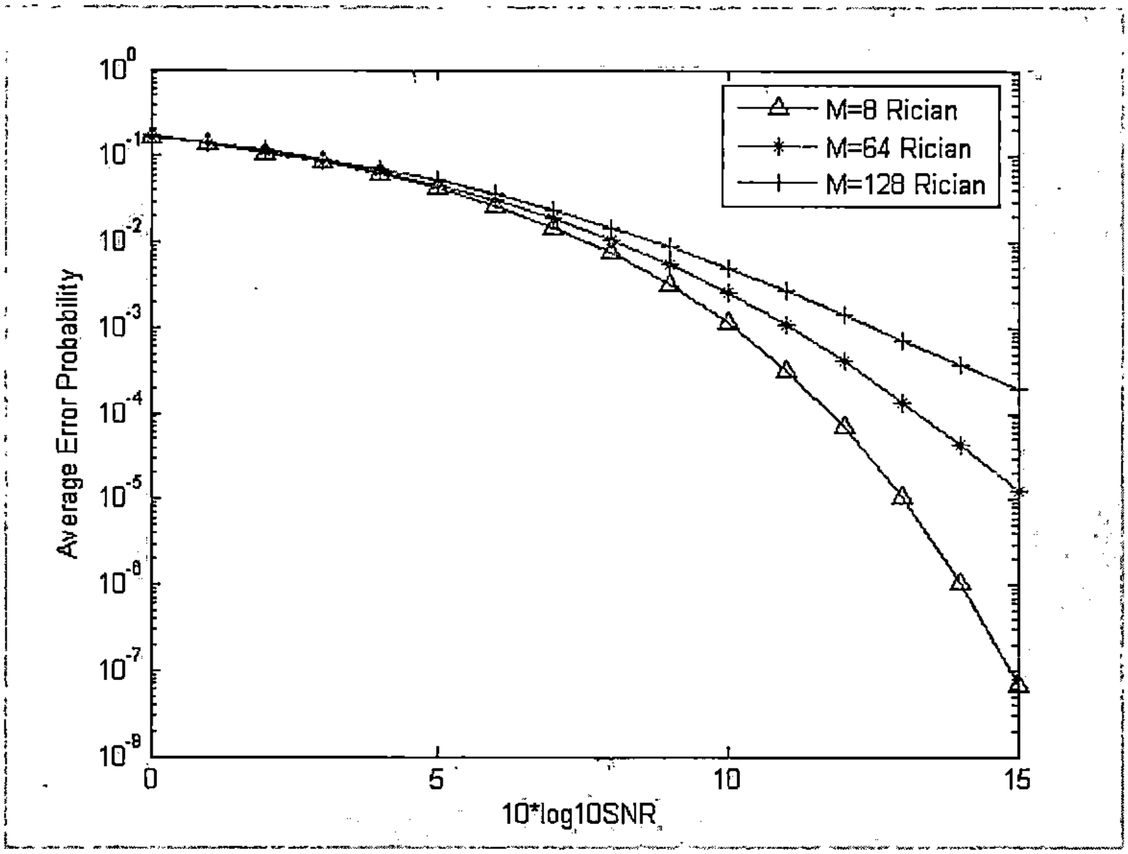

Fig. 4.11 BER vs. SNR (dB) for various values of M

In the Rician Fading channel the BER rises as the number of subcarriers increases, as shown in Fig. 4.12 In this case the number of subcarriers (N) is increased from 128 to 512 and the BER increased from ~10^{-7} to ~10^{-5}.

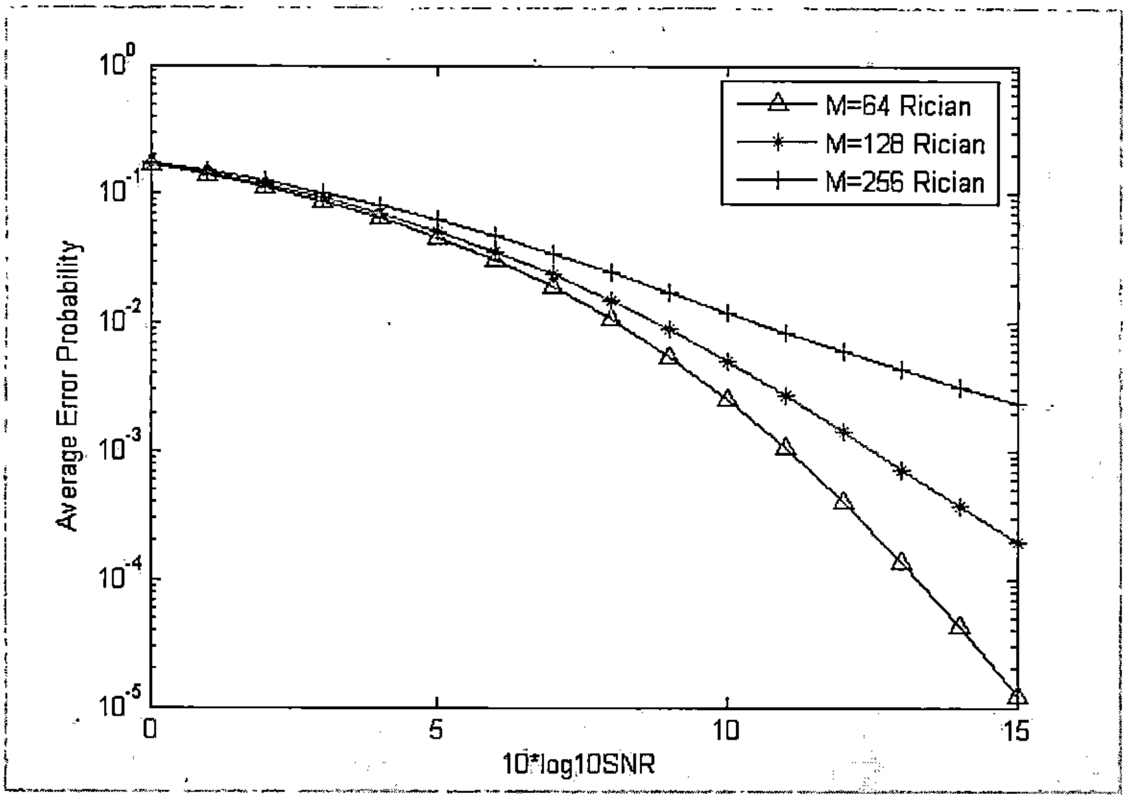

Fig. 4.12 BER vs. SNR (dB) for N = 512

The performance of the Rician Fading channel is better than Rayleigh Fading channel as shown in fig.4.13 (for K=0) and fig.4.14 (for K=10), due to the presence of the Line-of-Sight component.

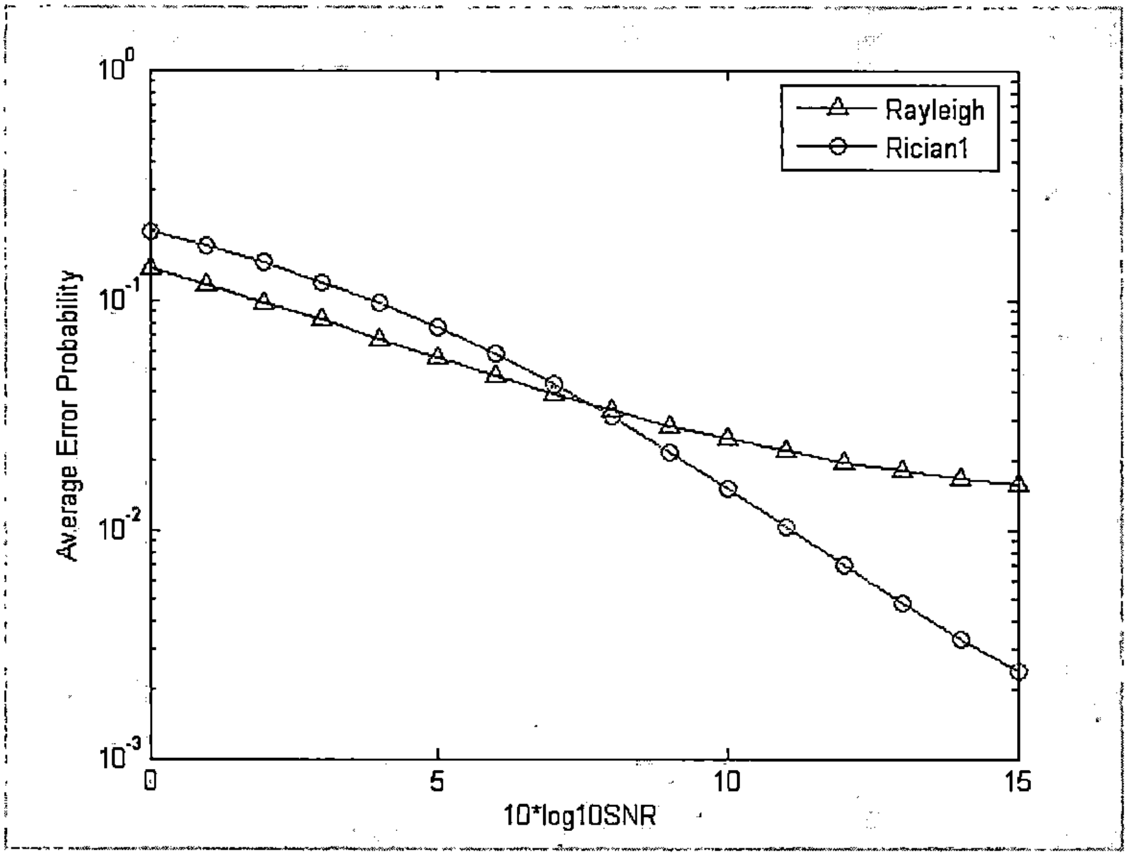

Fig. 4.13 Rayleigh Fading channel vs. Rician Fading channel for K = 0

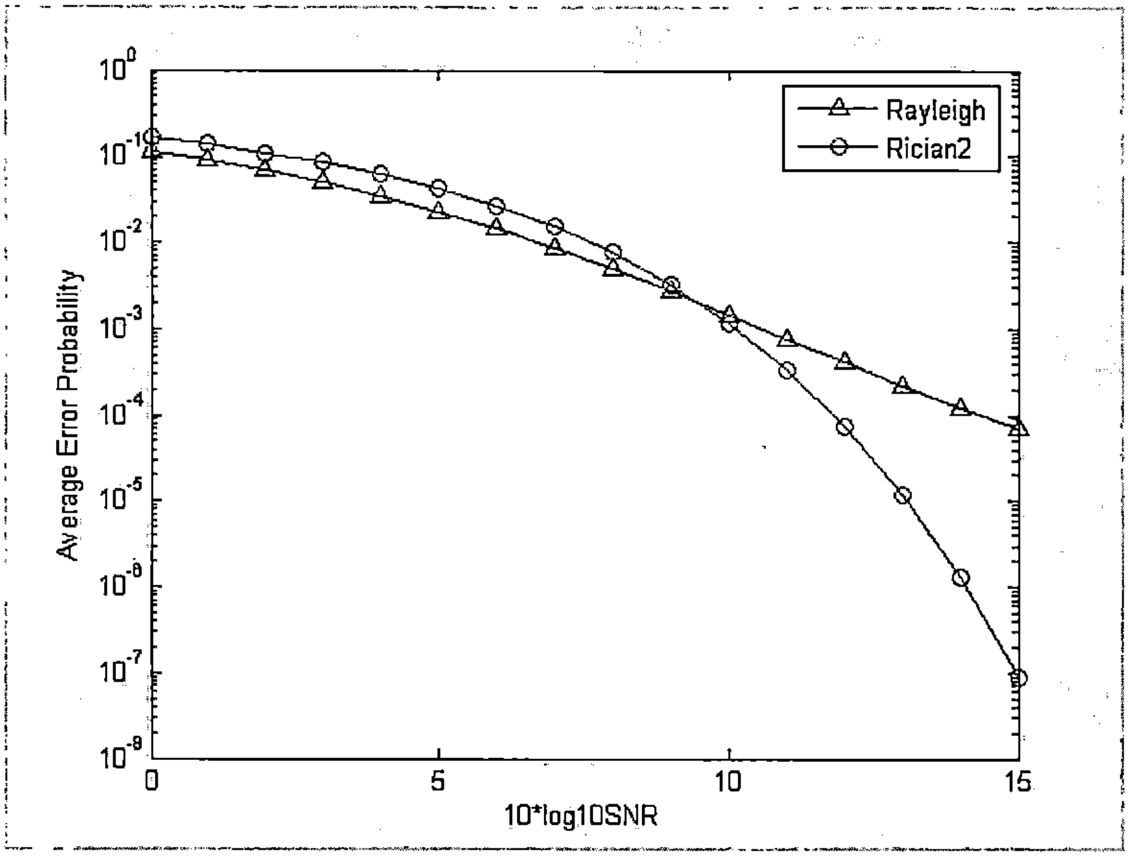

Fig. 4.14 Rayleigh Fading channel vs. Rician Fading channel for K = 10

Fig. 4.15 shows the performance of the AWGN, the Rayleigh Fading, and the Rician Fading channels. The BER of the AWGN outperforms the other two channels in terms of SNR. The following graph of BER verses SNR (dB) indicates that the AWGN has the minimum BER of 10^{-8}, while the Rayleigh Fading channel has the BER of 10^{-2}. Therefore, the performance of the MC-CDMA in the AWGN channel is better than the other channels.

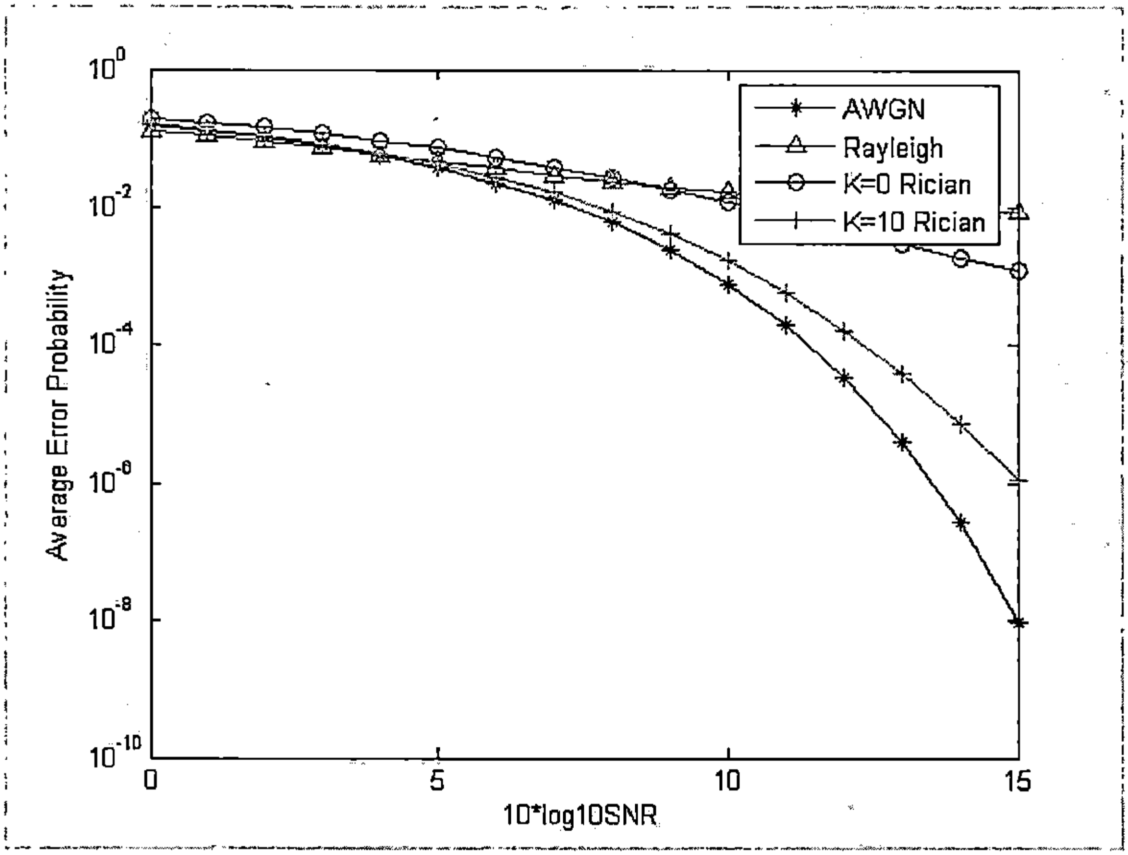

Fig. 4.15 The Performance of AWGN, Rayleigh Fading, and Rician Fading channel

SUMMARY OF RESULTS

The MC-CDMA systems was implemented IFFT/FFT. A data symbol was converted into M parallel branches and the bits on each branch were transmitted on orthogonal carriers. The system mitigated the ICI problem by using the cyclic prefix. FFT was minimizing the subcarrier spacing and offered the high spectral efficiency. The performance of MC-CDMA systems has been obtained in terms of BER. Here, the BER of AWGN channel depends on SNR. The performance of Rician Fading channel was improved as the K-factor is increased due to LOS component. The performance of Rayleigh Fading channel was depends on the number of users (M) and the number subcarriers (N). The performance of an AWGN channel outperformed other channels in terms of BER. Therefore, MC-CDMA system offered better performance in an AWGN channel.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF THESIS

This thesis focuses on the implementation and simulation of MC-CDMA systems in terms of its performance. Chapter 1 was an introduction to MC-CDMA system in which the requirement of the system was discussed. Chapter 2 provided brief reviews of previous work on MC–CDMA systems. Chapter 3 dealt with the implementation of the transmitter and the receiver of the system. The MC-CDMA system was mathematically evaluated over various fading channels in terms of BER. Chapter 4 presented the results obtained from the system implementation and the channels simulation in Matlab. The channels performance has been compared with each other in terms of BER.

CONCLUSIONS

In this thesis, we described new multiple access techniques based on a combination of CDMA and Multicarrier modulation techniques. The implementation of the MC-CDMA system has been done and the simulation of the system has been performed in terms of Bit Error Rate (BER). The performance analysis of the system has been done over various channels, and the answers to the research questions should now be presented. To begin with, the transmitter and receiver of the MC-

CDMA system have been implemented using the cyclic prefix. The cyclic prefix was inserted to minimize the Inter-Symbol-Interference (ISI) problem by making multiple users communicate through the same channel so that the same data symbol was transmitted over a large number of narrowband orthogonal carriers. The implementation has been done by using the FFT algorithm, as a result the transmitter and receiver complexities were reduced and the system offered high bit rate for transmission.

The MC-CDMA system has been mathematically evaluated in three channels, such as the Additive White Gaussian Noise (AWGN), the Rayleigh Fading, and the Rician Fading channel in terms of BER. The central limit theorem was used to derive the BER with Q-function. According to the simulation results, BER in an AWGN channel outperforms Rayleigh Fading and Rician Fading channel as Signal-to-Noise (SNR) was increased. The performance of the Rician Fading channel depends on the K-factor, the number of users, and the number of subcarriers. The performance was improved by increasing the K-factor and the number of subcarriers while degraded by increasing the number of users. The performance of the Rayleigh Fading channel was same as the Rician Fading channel when K=0; however for the other values of K, the performance of the Rician Fading channel was better than the Rayleigh Fading channel due to the LOS. The EGC equalization technique has been proposed in the Rayleigh Fading and Rician Fading channel. In downlink communications, the EGC distorted the orthogonality between users and enhanced performance by restoring the orthogonality of interfering signals. The CDMA spreading and OFDM modulation were used by MC-CDMA to implement the transmitter and the receiver of the system. As MC-CDMA system can hold N simultaneous users on the same set of channels, the system can be easily implemented with good BER. In conclusions, the MC-CDMA system for downlink communication is more efficiently implemented by using the IFFT/FFT and inserting the cyclic prefix. The performance of the MC-CDMA systems in an AWGN channel is better than the Rayleigh Fading and the Rician Fading channel as an AWGN offered low BER.

RECOMMNEDATIONS

The Multicarrier CDMA system is one of the promising technologies for future in the wireless communication applications. The MC-CDMA system offers bandwidth efficiency and ISI suppression in a high data rate of the wireless transmission by reducing the spectral efficiency. The system needs more advanced research and work to overcome some of the problems. In the near future, it is necessary to propose the MC-CDMA system without using cyclic prefix in frequency domain to avoid the spectral efficiency loss. The frequency offset is very responsive in the MC-CDMA systems so is very hard to use the system for high speed vehicles as it reduces the performance of the transmitter and the receiver. The system requires concentrated work to solve the problem of high Peak-to-Mean Envelope Power ratio (PMEPR), which is responsible for nonlinear amplification in the transmitter. The MC-CDMA system has a limited frequency reuse feature so in the near future it would be important to eliminate this effect. An advanced research is necessary to reduce the complexities in the equalization techniques. Perfect and suitable diversity techniques will also improve the performance of the system by canceling the ICI effect caused by Doppler spread. The most suggested work for the MC-CDMA future would be the design of self ICI cancellation schemes in the system by using the bandwidth efficiently without affecting BER.

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=akron1101937252

APPENDIX

ERROR PROBABILITY CODES IN AWGN, RAYLEIGH, AND RICIAN CHANNEL

```
%% Error probability in AWGN, Rayleigh, and Rician channel
%% as function of SNR
clear all;
N=128; % # of subcarriers
M=32; % # of users
snr_db=0:15;
K=[0 10]; % The value of K-factor
r1=(pi/4)*(exp(-
K(1))/(K(1)+1))*((1+K(1))*besseli(0,K(1)/2)+K(1)*besseli(1,K(1)/2))^2;
r2=(pi/4)*(exp(-
K(2))/(K(2)+1))*((1+K(2))*besseli(0,K(2)/2)+K(2)*besseli(1,K(2)/2))^2;
for i=1:length(snr_db)
snr=10^(snr_db(i)/10);
%% AWGN channel
p_awgn(i)=Q(sqrt(snr));
%% Rayleigh fading channel
p_ray(i)=Q(sqrt((pi/2)*(snr/(((2-pi/2)*snr/N)+((M-1)*snr/N)+1))));
%% Rician channel with K=0
p_rician1(i)=Q(sqrt((r1*snr)/((M*(1-r1)*snr)/N+1)));
%% Rician channel with K=10
p_rician2(i)=Q(sqrt((r2*snr)/((M*(1-r2)*snr)/N+1)));
end
figure(1);
semilogy(snr_db,p_awgn,'-*',snr_db,p_ray,'-^',snr_db,p_rician1,'-
o',snr_db,p_rician2,'-+');
xlabel('10*log10SNR');
ylabel('Average Error Probability');
legend('AWGN','Rayleigh','K=0 Rician','K=10 Rician')
%% To compare BER as the number of interfereces
%% in Rayleigh fading channel.
clear all;
snr_db=0:15;
p_ray1=rayl(128,8); % M=8
p_ray2=rayl(128,64); % M=64
p_ray3=rayl(128,128); % M=128
```

```
figure(2);
semilogy(snr_db,p_ray1,'-^',snr_db,p_ray2,'-*',snr_db,p_ray3,'-+');
xlabel('10*log10SNR');
ylabel('Average Error Probability');
legend('M=8 Rayleigh','M=64 Rayleigh','M=128 Rayleigh');
%% To compare BER as the number of interfereces
%% in Rician fading channel.
clear all;
snr_db=0:15;
p_rician1=rician(128,8); % M=8
p_rician2=rician(128,64); % M=64
p_rician3=rician(128,128); % M=128
figure(3);
semilogy(snr_db,p_rician1,'-^',snr_db,p_rician2,'-*',snr_db,p_rician3,'-+');
xlabel('10*log10SNR');
ylabel('Average Error Probability');
legend('M=8 Rician','M=64 Rician','M=128 Rician');

clear all;
snr_db=0:15;
p_rician1=rician(128,64); % M=8
p_rician2=rician(128,128); % M=64
p_rician3=rician(128,256); % M=128
figure(4);
semilogy(snr_db,p_rician1,'-^',snr_db,p_rician2,'-*',snr_db,p_rician3,'-+');
xlabel('10*log10SNR');
ylabel('Average Error Probability');
legend('M=64 Rician','M=128 Rician','M=256 Rician');
%% This is a function file of BER
%% in rayleigh fading channel.
% function [p_ray]=rayl(N,M);
% snr_db=0:15;
% for i=1:length(snr_db)
% snr=10^(snr_db(i)/10);
% %% Rayleigh fading channel
% p_ray(i)=Q(sqrt((pi/2)*(snr/(((2-pi/2)*snr/N)+((M-1)*snr/N)+1))));
% end
% %% This is a function file of BER
% %% in rician fading channel.
% function [p_rician]=rician(N,M);
% snr_db=0:15;
% K=10; % The value of K-factor
% r=(pi/4)*(exp(-K)/(K+1))*((1+K)*besseli(0,K/2)+K(1)*besseli(1,K/2))^2;
```

```
% for i=1:length(snr_db)
% snr=10^(snr_db(i)/10);
% p_rician(i)=Q(sqrt((r*snr)/((M*(1-r)*snr)/N+1)));
% end
%%This is a function file to generate Q-function
% function [qfcn]=Q(x);
% qfcn=0.5*erfc(x/sqrt(2));
```

Q-function FILE

```
function [qfcn]=Q(x);
qfcn=0.5*erfc(x/sqrt(2));
```

RAYLEIGH FADING CHANNEL

```
function [p_ray]=rayl(N,M);
snr_db=0:15;
for i=1:length(snr_db)
snr=10^(snr_db(i)/10);
%% Rayleigh fading channel
p_ray(i)=Q(sqrt((pi/2)*(snr/(((2-pi/2)*snr/N)+((M-1)*snr/N)+1))));
end
```

RICIAN FADING CHANNEL

```
%% This is a function file of BER
%% in rician fading channel.
% N=5;M=7;
function [p_rician]=rician(N,M);
snr_db=0:15;
K=10; % The value of K-factor
r=(pi/4)*(exp(-K)/(K+1))*((1+K)*besseli(0,K/2)+K(1)*besseli(1,K/2))^2;
for i=1:length(snr_db)
snr=10^(snr_db(i)/10);
p_rician(i)=Q(sqrt((r*snr)/((M*(1-r)*snr)/N+1)));
end
```