BER PERFORMANCE ANALYSIS OF A MC-DS-CDMA WIRELESS COMMUNICATION SYSTEM WITH RAKE RECEIVER EMPLOYING MRC UNDER NAKAGAMI-M FADING

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APPROVAL CERTIFICATE

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Dedicated To

My beloved Parents

And

My mentor, ***Dr. Satya Prasad Mujumder,***

Who gave me the opportunity to fulfill my father's dream.

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ABSTRACT

Multicarrier code-division multiple access is a promising spread spectrum transmission technique where each input data stream is partitioned into parallel sub streams that are modulated at different subcarriers. In MC CDMA use of orthogonal subcarriers by OFDM technique provides higher data rate which leads to improve bandwidth efficiency. In this thesis a nobel theoretical analysis is presented for a MC-DS-CDMA wireless communication system with OFDM subcarriers with Rake receivers under Nakagami-m fading environment considering maximal ratio combining (MRC) for the rake combiner. To achieve receive diversity multiple receiving antennas are used in this system. The expression for the probability density function (pdf) of the signal to noise ratio at the output of rake combiner is developed for individual sub-channels of the OFDM sub carriers. BER is then determined for each individual OFDM sub-channels and the average BER is then evaluated numerically. The results show that the BER performance improves significantly with the increase in the number of rake fingers, number of receiving antennas, processing gain etc.

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LIST OF ABBREVIATIONS

3G	Third Generation wireless technology.
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CDMA	Code division multiple access
DS-CDMA	Direct sequence CDMA
E_b/N_o	Bit Energy-to-Noise Density.
erf	Error Function.
erfc	Complementary Error function.
EGC	Equal Gain Combining
FDMA	Frequency division multiple access
ICI	Inter -Channel Interference
ISI	Inter- Symbol Interference
IS-95	EIA Interim Standard for U.S. Code Division Multiple Access.
ITU	International Telecommunication Union
MAI	Multi access interference
MC-CDMA	Multicarrier CDMA
MC-DS-CDMA	Multicarrier DS-CDMA
MRC	Maximal Ratio Combining
MT-CDMA	Multi Tone CDMA

OFDM	Orthogonal frequency division multiplexing
pdf	Probability density function
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SC	Selection Combining
SINR	Signal –to-Interference plus Noise Ratio
SNR	Signal to noise ratio
STDMA	Synchronous Time Division Multiple Access
TDMA	Time Division Multiple access
WCDMA	Wideband code division multiple access

CHAPTER 1

INTRODUCTION TO WIRELESS COMMUNICATION SYSTEM

1.1 Introduction

"Mr. Watson, come here, I want you." with these historic words Alexander Graham Bell called to his assistant Thomas Augustus Watson over the so-called "telephone". The place was at 5 Exeter Place, Boston, Massachusetts and the time was at the evening of March 10, 1876 when the history of communication began. But the ability to communicate with people on the move has evolved remarkably since Guglielmo Marconi first demonstrated radio's ability to provide continuous communication without any direct link between the communicators. Since then new wireless communication methods and services has been enthusiastically adopted by people throughout the world. Nevertheless, it was not until the 1940s when commercial mobile telephony began and then the point where we can establish the first roots of cellular communications [1].

Wireless communication is the transfer of information without the use of wires. The medium of wireless communication is the open space and information is transferred via electromagnetic waves. It is also called unguided wave propagation. Wireless transmission uses air or space for its transmission medium. Wireless communication resources are frequency, time, code, polarization, space etc. Due to the increasing demand of large number of users, resource sharing is important to optimize to upgrade the performance of wireless communication system. For optimize resource allocations multiple access techniques have been introduced. In multiple access techniques available resources are fully utilized and all resources are shared equally among users. Thus the capacity of the system is maximized and also interference is not introduced between users.

1.2 Advantages of Wireless Communication over Wired Communication

In primary periods, the communication was totally wired based. But the traditional telephone system can never be able to satisfy a growing group of users: people on the go. The demand for ubiquitous personal communications was driving the development of new networking techniques that accommodate mobile voice and data users who move throughout buildings, cities or countries. Thus concepts like cellular telephony, wireless local loop etc. were developing and the interconnection of many such systems defines a wireless network capable of providing services to the mobile users throughout a country or continent or even worldwide. In PSTN, the transfer of information takes place over landline trunked lines comprised of fiber optic cables, copper cables, microwave links etc. Here the network configuration is totally static since the network connections may only be changed when a subscriber changes residence and requires reprogramming at the local central office for that subscriber. Wireless networks, on the other hand are highly dynamic, with the network configuration being re-arranged every times a subscriber moves into the coverage region of a different base station. Where fixed networks are difficult to change and rearrangement is not appreciated, the wireless networks must re-configure themselves for the users with in very small intervals of time (on the order of seconds or fractions of seconds) to provide roaming and handoffs. The available channel bandwidth for fixed networks can be increased by installing high capacity cables, which is a difficult job. On the other hand, wireless networks are constrained by the merger RF cellular bandwidth provided for each user.

1.3 Wireless Communication Systems Based Upon Cellular Concept

The traditional wireless communication systems are structured in either a broadcast or a point-to-point fashion. In broadcast system a very powerful transmitter is placed and numerous receivers move around it. Such systems are expensive and long distance communication here is always affected by channel noises and interferences. Examples of such communication can be RF communication, satellite communication, mobile communication etc. On the other hand in point to point communication, there is always a link between the machines where bi-directional flow of information bearing signal is done. Microwave link, infrared link, different home and other small area wireless networks, paging etc. can be examples of such networks.

The broadcasting method of communication was reorganized on the basis of fixing the range of the transmitter, which was specially done for mobile communication. The concept was called the cellular concept where in place of a powerful transmitter a number of low powered transmitter so that the effects of noise and interferences. This cellular concept became very much popular as the mobile communication was increasing widely and more number of users was tentative to use the limited frequencies that can be allocated for the transmission process.

Also there remained different other wireless communication systems not using this cellular concept.

1.4 Non - Cellular Communication

Most people are familiar with a number of mobile radio communication systems used in everyday life. The term ‘mobile’ has historically been used to classify any radio terminal that could be moved during operation. Also another term ‘portable’ is used describing a radio terminal that can be hand held and used by someone at walking speed. Now except cellular services, many other wireless communication systems are present where other different techniques rather cellular concept is used. Cordless telephones, pagers, home networking systems, wireless LAN etc. can be the examples of non-cellular communications.

1.5 Multiple Access Schemes

In multiple access techniques, a large number of users share a common communication channel to transmit information to a receiver. Multiple access schemes allocate the available bandwidth or the available amount of channels to multiple users simultaneously. FDMA, TDMA and CDMA are the three major access techniques used to share the available BW in a wireless communication channel.

First generation wireless communication system experienced Frequency Division Multiple Access (FDMA) while TDMA and CDMA is used for second generation wireless communication system. TDMA and FDMA allocate a fixed capacity .Here an individual user is assigned a frequency band for FDMA and time slot for TDMA for entire duration of connection. CDMA is a spread spectrum multiple access scheme for third generation wireless communication system. These three techniques are described in the following sections and the need for MC-DS-CDMA is also described.

1.5.1 FDMA

FDMA is the first multiple access schemes implemented in mobile communication system. FDMA assigns individual channels to individual users by dividing the total frequency bandwidth into frequency channels. FDMA separates the multiple user signals spectrally along with simultaneous transmission and reception. FDMA can support narrowband only and is not suitable for multimedia communication [2].

The FDMA is relatively simple to implement. In FDMA inter modulation frequencies cause inter modulation distortion as the power amplifiers and power combiners used in FDMA are non-linear. These non-linearity also cause signal spreading in frequency domain which also results in inter channel interference (ICI) in other FDMA channels. FDMA also suffers from several limitations such as comparatively poor quality, causes a waste of bandwidth when the user is in dormant state, limited capacity as the system is limited by the number of channels available.

To achieve interference free transmission frequency allocation between the uplink and downlink channels have to be separated by a sufficient amount. This can be achieved by using two antennas operating at different frequencies or one antenna with frequency division duplexing that is uplink and downlink channels of FDMA operate at distinctly different frequency bands.

1.5.2 TDMA

TDMA system divides the radio spectrum into time slots and in each slot only one user is allowed to either transmit or receive. Here each user occupies a cyclically repeating time slot that re occurs every frame where N time slots comprise a frame. This time slot can be fixed or dynamically assigned from frame to frame. The modes of TDMA are of two different types. In synchronous TDMA (STDMA) slot assignment is fixed from frame to frame and users have to synchronize to their respective assigned slots. In asynchronous TDMA (ATDMA), the transmission slots are dynamically assigned from frame to frame.

TDMA while operating at wideband, each user uses the entire available frequency spectrum while in narrowband TDMA the total frequency spectrum is divided into a number of sub-bands and each individual user uses the allocated sub-band.

In TDMA system power consumption is less as transmission is non-continuous and occurs in burst. Although TDMA system is more flexible, it suffers from synchronization problem and ISI caused by multipath propagation.

1.5.3 CDMA

CDMA is an example of multiple access where several transmitter can send information simultaneously over a single communication channel. Here the narrowband message signal is multiplied by a spreading signal having large bandwidth. The spreading signal is a pseudo noise code sequence that has a chip rate which has an order of magnitudes greater than the data rate of the message. Each user in CDMA has its own pseudorandom code word which is orthogonal to all other code words. The receiver performs a time correlation to detect only the specific desired codeword. All other code words appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the code word used by the transmitter.

In CDMA there are three ways to spread the bandwidth of the signal which leads to spread spectrum communication. They are:

- **Frequency-Hopping CDMA(FH-CDMA)**
  FH-CDMA is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels within the hopping bandwidth using a pseudorandom sequence known to both transmitter and receiver.
- **Time Hopping CDMA(TH-CDMA)**
  Here the signal is transmitted in short bursts pseudo-randomly known to both transmitter and receiver.
- **Direct-Sequence CDMA(DS-CDMA)**
  DS-CDMA is a technique to multiplex users by different codes. In this technique, the same bandwidth is used by different users. Each user is assigned with its own spreading code. The receiver knows how to generate the same code and correlates the received signal with that code to extract the data.

In DS-CDMA, RAKE receivers are often used to combine the multipath signals. A rake receiver is a radio receiver designed to counter the effects of multipath fading. It does this by using several "sub-receivers" called fingers, that is, several correlators each assigned to different multipath components.

Compare to other multiple access techniques such as TDMA and FDMA, CDMA has many advantages which includes immunity against interference, robustness against fading, soft capacity, low dropout rate, large coverage, soft handover etc. Conventional CDMA system suffers from MAI and ISI. For efficient cellular mobile radio system, it is necessary to suppress ISI which affects the capacity and MAI which affects the capacity and BER of the system. So single carrier CDMA is unable to cope with high speed wireless system. Due to high data rate, symbol duration will be shortened which leads to channel delay spread by exceeding symbol duration. Moreover data rates beyond 100 Mbps results in synchronization problem and also spectrum spreading causes frequency selective fading. Single carrier CDMA requires complex receiver design as signal energy is scattered in time domain due to multipath propagation and signals of all path cannot successfully received. To overcome this limitation of SC-CDMA, MC-CDMA is introduced. MC-CDMA is a combination of OFDM and CDMA and takes advantages of both OFDM and CDMA.

1.6 MC-CDMA

Multicarrier code-division multiple access is a promising spread spectrum transmission method where each input data stream is partitioned into parallel sub streams that are modulated at different subcarriers [3-13]. The narrowband subcarriers are generated using BPSK modulated signals, whose base-band frequencies are multiples of a fundamental frequency [14]. A MC CDMA signal is then composed of narrowband subcarrier signals each with a symbol duration [15, 16]. In MC CDMA use of orthogonal subcarriers by OFDM technique provides higher data rate which leads to improved bandwidth efficiency compared to DS CDMA. In addition MC CDMA has several other advantages such as strong immunity to noise, high spectrum efficiency, flexibility in handling multiple data rates and capacity to spread the original signal bandwidth without increasing the adverse effect of ISI [17].

Multicarrier DS-CDMA and Multi-tone MT-CDMA are two separate schemes developed by different researchers .The Multicarrier DS-CDMA transmitter spreads the S/P converted data streams using a given spreading code in the time domain so that the resulting spectrum of each subscriber can satisfy the orthogonality condition with the minimum frequency separation [4]. This scheme is proposed to achieve both frequency diversity improvement and narrow band interference suppression.

The MT-CDMA transmitter spreads the S/P converted data streams using a given spreading code in the time domain so that the spectrum of each subcarrier prior to spreading operation can satisfy the orthogonality condition with the minimum frequency separation [7]. The MT-CDMA scheme uses longer spreading codes in proportion to the number of subcarriers compared to normal DS-CDMA and accommodate more users than the DS-CDMA scheme [4].

1.7 Different Diversity Techniques and Diversity Combining Schemes in Wireless Communication

Fading environment severally degrades the average bit error rate (BER) or probability of error (P_e) performance of wireless digital communication system. In order to achieve highly reliable digital data transmission without excessively increasing both transmitter power and co-channel reuse distance, it is indispensable to adopt an auxiliary technique that can cope with the fast multipath fading effect. Diversity reception is one of the most effective techniques for this purpose.

A diversity technique requires a number of signal transmission paths, named diversity branches that carry the same information but have uncorrelated multipath fading and a circuit to combine the received signals or select one of them. Depending on the land mobile radio propagation characteristics, there are a number of methods to construct diversity branches. Generally, branches are classified into one of the following categories of diversity:

- Space
- Angle
- Polarization
- Frequency
- Time

Each of the methods will be reviewed briefly.

Space diversity, which has been widely used because it can be implemented simply & economically, has a single transmitting antenna and a number of receiving antennas. Spacing between adjacent receiving antennas is chosen so that multipath fading appearing in the diversity branches becomes uncorrelated.

Angle diversity, which is also called direction diversity, requires a number of directional antennas. Each antenna responds independently to a wave propagating at a specific angle & receives a faded signal that is uncorrelated with others.

Polarization diversity, in which only two diversity branches are available, is effective because the signals transmitted through two orthogonal polarized propagation paths have uncorrelated fading statistics in the usual VHF and UHF land mobile radio environment.

Difference in frequency and or time can also be utilized to construct diversity branches with uncorrelated fading statistics. The required frequency & time spacing can be determined from the characteristics of time delay spread and the maximum Doppler frequency. A common advantage of these two techniques compared with space, angle, & polarization diversity techniques is that the number of transmitting and receiving antennas can be to one of each, with the disadvantage that a wider bandwidth is required. Error correction coding can be regarded as a kind of time diversity technique. In time diversity, the time difference between two transmissions should be large compared to the time it takes the mobile antenna to move half a wavelength. In systems with stationary antennas, such as indoor wireless communication, time diversity will be less effective as the channel characteristics do not change very much with time. However, time diversity may be helpful if uncorrelated interference signals are experienced during successive attempts.

A number of methods have been studied for many years to combine or select uncorrelated faded signals from the diversity branches. They are usually classified into the following three categories:

- Maximum ratio combining
- Equal gain combining
- Selection combining

In Maximal Ratio Combining (MRC), receiver is able to accurately estimate the amplitude fading and carrier phase distortion for each diversity channel. Here each signal is then weighted by corresponding amplitude gain and summed together and is applied to the decision device.

In Equal Gain Combining (ECG), receiver does not estimate amplitude fading and carrier phase distortion. Here the detected signals are simply added and applied to the decision device.

In Selection Combining (SC), receiver estimates the signal to noise ratio (SNR) value of each diversity channel and chooses the one with maximum SNR value for signal detection.

In Wireless Communication systems to improve the intensity of signal in presence of fading and co-channel interference several techniques such as antenna diversity, adaptive arrays, equalization etc. can be used. Maximal Ratio Combining (MRC) and Equal Gain Combining (EGC) are the most popular diversity techniques used in wireless communication. MRC is considered as optimal combining with careful estimation of channel induced fading. The Nakagami distribution (m distribution) is a generalized distribution used to model different fading environments [17]. It has greater flexibility and accuracy in matching some experimental data than Rayleigh, Lognormal and Recian distribution [18] particularly in some urban radio multipath channels [19]. In this paper we evaluate the performance of MRC diversity reception in the Nakagami fading environment. In spite of the complexity of the MRC compared to other diversity techniques, it is worth considering because it has the maximum possible improvement that a diversity system can attain through a fading channel [20]. The received signals in MRC are weighted such that the weighted sum at the combiner output has the maximum signal to noise ratio [20]. In this thesis MC-CDMA system under Nakagami-m fading is considered.

1.8 Limitations of Wireless Communication

While wireless technology is undoubtedly an appropriate technology for many applications, it should not be regarded as a ubiquitous solution for every networking environment – despite great advances in recent years, the concept of the "wireless building" is still some way off. In every communication system, signal loss or noise effects are always a very important matter to be considered. Any communication process has some limitations due to these losses. Followings are some important reasons that create losses or disturbance in the communication process.

Adjacent channel interference

This interference is characterized by unwanted signals from other frequency channels splitting over or injecting energy into the channel of interest. The proximity with which channels can be located in frequency is determined by the modulation spectral roll-off and the width and shape of the main spectral lobe.

Co-channel interference

This interference refers to the degradation caused by an interfering waveform appearing within the signal bandwidth. It can be introduced by a variety of ways such as accidental transmissions, insufficient vertical and horizontal polarization discrimination or by radiation spillover from an antenna side lobe.

Band limiting loss

All systems use filters in the transmitter to ensure that the transmitted energy is confined to the allocated or assigned bandwidth. This is to avoid interfering with other channels and users. Such filtering reduces the total amount of energy that would otherwise have been transmitted; the result is a loss in signal.

Inter symbol interference

In such case the tail of one pulse interfere with next one during the detection process. Using different pulse shaping techniques such process can be diminished.

Local oscillator phase noise

In both receiving and transmitting side using coherent process, local oscillator is used in signal mixing. In such cases phase fluctuations or jitter adds phase noise to the signal. In case of correlator receiver such phase jitter can cause detector degradation and hence signal loss. Also at the transmitter phase jitter can cause out of band signal spreading.

Limiter loss or enhancement

A hard limiter can enhance the stronger of two signals and suppress the weaker; this can result in either a signal loss or a signal gain.

Multiple carrier inter modulation products

When several signals having different carrier frequencies are simultaneously present in a nonlinear device. The result is a multiplicative interaction between the carrier frequencies which can produce signals at all combinations of sum and difference frequencies. The energy appointed to these inter modulation products represents a loss in signal energy. In addition if these IM products appear within the bandwidth region of these or other signals, the effect is that of added noise for those signals.

Modulation loss

The link budget is a calculation of received useful power. Only the power associated with information bearing signals is useful. Error performance is a function of energy per transmitted symbol. Any power used for transmitting the carrier rather than the modulating signal is a modulation loss.

Antenna efficiency

Antennas are transducers that convert electronic signals into electromagnetic fields and vice versa. They are also used to focus the transmitted energy in a desired direction. The larger the antenna aperture, the larger is the resulting signal power density in the desired direction. Now the antenna efficiency which is the ratio of its effective aperture to its physical aperture can be reduced by different matters such as amplitude tempering, scattering, re-radiation, spillover, edge diffraction, dissipative loss etc. typical efficiencies due to the combined effects of these mechanisms range between 50 and 80 percent.

Radome loss and noise

A radome is a protective cover used with some antennas for shielding against weather effects. The radome, being in the path of the signal will scatter and absorb some of the signal energy thus resulting in a signal loss.

Pointing loss

There is a loss of signal when either the transmitting antenna or the receiving antenna is imperfectly pointed.

Polarization loss

The polarization of an electromagnetic field is defined as the direction in space along with the field lines point. The polarization of an antenna is described by the polarization of its radiated field. There is always probability of signal loss due to any polarization mismatch between the transmitting and receiving antennas.

Atmospheric loss and noise

The atmosphere is always responsible most of the signal loss and is also a contributor of unwanted noise. An example of primary atmospheric cause of signal loss and contributor of noise is rainfall. The more intense the rainfall, the more signal it will absorb.

Space loss

There is a decrease in the electric field strength and thus in signal strength as a function of distance. Especially for a satellite communication link, the space loss is the largest signal loss in the system. It is a loss in the sense that all the radiated energy is not focused on the intended receiving antenna.

Inter-modulation (IM) noise

The IM products as described earlier, are the multiple carrier signals interacting in a non-linear device also known as active inter modes. They can either cause a loss in signal energy or be responsible for noise injected into a link.

Galactic or cosmic, star and terrestrial noise

All the celestial bodies, such as the stars and the planets, radiate energy. Such noise energy in the field of view of the antenna will degrade the SNR.

Feeder line loss

The level of the received signal might be very small as the wave-guide or cable (feeder line) between the receiving antenna and the receiver front end contributes both signal attenuation and thermal noise. This may lead the signal particularly susceptible to noise degradation.

Imperfect synchronization reference

When the carrier phase, the sub carrier phase and the symbol timing references are all diverted perfectly, the error probability is a well-defined function of signal to noise ratio. In general they are not diverted perfectly resulting in a system loss.

A typical model of a wireless communication system (let us consider mobile communication) consists of an elevated base station antenna, a relatively short distance line of sight (LOS) propagation path followed by non-line of sight (NLOS) reflected propagation paths and a mobile antenna i.e. the antenna mounted on the transceiver of the portable unit. Radio propagation in such environment is characterized by three particularly separable effects as discussed below.

Path Loss, which describes the loss in power as the radio signal, propagates in space

Shadowing, which is due to the presence of fixed obstacles in the propagation path of the radio signal

Multipath fading, which accounts for the combined effect of multiple propagation paths, rapid movements of mobile units (transmitters/receivers) and reflectors.

1.9 Various CDMA Standards

Evolution of CDMA stats through IS-95 standrad.IS-95 is a direct-sequence CDMA standard that was developed by QUALCOMM and is being put into service primarily by Bell South. It uses pseudo noise, or PN, sequences to encode channels into pairs of 1.23 MHz bands and is fundamentally different from any of the TDMA standards. Unlike the TDMA standards, call quality in an IS-95 system improves when other channels are idle, even if they are being used but have no voice activity in one direction on a channel. ECE 404 Term Project Report Page 12 Gerald S. Williams CDMA supporters frequently use theoretical calculations to show a tremendous increase in capacity, but in actuality there can never be more than 63 traffic channels per band, and the realistic limit is 45 (the true numbers will be known when a real system is operational). Thus, 900 IS-95 channels may be carried in the 50 MHz allocated to a service provider

The CDMA 2000 vision provides a seamless and evolutionary high data rate upgrade path for the users of 2G and 2.5G CDMA technology using a building block approach that centers on the original 2G CDMA channel bandwidth of 1.25 MHz per radio channel. Based upon the original IS-95 or IS-95A CDMA standards as well as the 2.5G IS-95B air interface, the CDMA2000 allows wireless carriers to introduce a family of new high data rate Internet access capabilities while assuring that such upgrades maintain backward compatibility with existing CDMA subscriber equipment.

CDMA2000 supports an instantaneous data rate up to 307 Kbps for a user in packet mode and yields typical throughput rates up to 144 Kbps per user, depending on the number of users, the velocity of a user and the propagation conditions:

Wideband Code Division Multiple Access (WCDMA) was developed in order to create a global standard for real time multimedia services that ensured international roaming. With the support of ITU (International Telecommunication Union) a specific spectrum was allocated (2GHz) for 3G telecom systems. The work was later taken over by the 3GPP (3rd Generation Partnership Project), which is now the WCDMA specification body with delegates from all over the world. WCDMA is also selected as the radio transmission technology (RTT) for

UMTS (universal mobile telecommunications system) developed by ETS (European telecommunications standards institute

Code Division Multiple Access (CDMA or CDMA-one) is a multiple access technology where the users are separated by unique codes, which means that all users can use the same frequency and transmit at the same time. Then with the fast development in signal processing, it has become feasible to use this technology for wireless communication, also referred to as WCDMA and CDMA2000. In CDMA-One and CDMA2000, a 1.25 MHz wide radio signal is multiplied by a spreading signal (which is a pseudo-noise code sequence) with a higher rate than the data rate of the message. The resultant signal appears as seemingly random, but if the intended recipient has the right code, this process is reversed and the original signal is extracted. Use of unique codes means that the same frequency is repeated in all cells, which is commonly referred to as a frequency re-use of 1. WCDMA is a step further in the CDMA technology. It uses a 5 MHz wide radio signal and a chip rate of 3.84 Mcps, which is about three times higher than the chip rate of CDMA2000 (1.22 Mcps). The main benefits of a wideband carrier with a higher chip includes support for higher bit rates, higher spectrum efficiency, higher QOS etc.

1.10 Previous Works on Wireless Communication

Efficient utilization of radio frequency spectrum is vital for the design of wireless radio network because of its limitation. As a result MC CDMA technique was opted and its performance development work is still in progress.

A new spread spectrum technique called multicarrier CDMA (MC-CDMA) was analyzed by Yee, N.Linnartz,J.P. and Fettweis,G. [21].They analyzed its BER performance under Rayleigh fading channel and compared the performance of two diversity reception schemes such as ECG and MRC. They found that in uplink MRC showed better performance than ECG.

In 1991 Theodore Valachos [22] studied the performance of hybrid DS – SFH/SS communication system where this system combines the best features of pure direct –sequence (DS) and frequency–hopped (FH) SS modulation yielding high overall throughput performance levels .In 2001, Lie-Yang and Lazos Hanzo [23] introduced a slow frequency –hopping multicarrier DS-CDMA scheme for transmission over Nakagami multipath fading channels. Here nonlinear constant –codes have been introduced to control the associated FH patterns and to efficiently share the systems frequency resources by each user.

MC DS CDMA supports various types of services by combining both OFDM and DS CDMA which was proposed in 1993 [24]. This combination provides multiple access for whole bandwidth for all time as well as multi carrier transmission along with high data rate, diversity, flat fading. Different multicarrier CDMA schemes were presented by C.Reiners and H.Rohling in 1994[25]. In 1995 Douglas and Laurence [26] found less ISI, good data synchronization, less fading effect in MC CDMA as compare to SC–CDMA.A comparative study of various multicarrier CDMA such as MC CDMA,MC-DS CDMA and Multi-tone CDMA for cellular mobile radio system was presented by Shinsuki Hara Ramjee Prasad in 1995[4]. In 1999 [27] estimation of MC system capacity in terms of the number of user per unit geographical area was proposed. In 2000, Sadayuki Abeta and Fumiyuki [28] demonstrated that frequency diversity Rake receiver is efficient enough than time RAKE diversity in broad band multipath channel along with various combining technique.

In 2001 Lucy L. Chang and Laurence B. Milstein [29] find that extra order of diversity degrades the receiver performance and also they find optimal value of diversity. In 2002 [30] the effect of subcarrier spacing on the performance of multicarrier CDMA system is presented. Shingo Shuwa and Hiroyuki Atarash [31] presented a comparison with MC-CDMA system with MC-DS-CDMA on the basis of capacity, PAPR and BER. Performance evolution of MC-CDMA uplink system with diversity reception and multiuser detection was presented by Shriram and Ahemed [32].

Huahui Wang and Kariyan [33] demonstrate the performance analysis of an adaptive PIC m receiver for Asynchronous MC-DS-CDMA system. Adaptive minimum BER multiuser detection for Asynchronous MC-CDMA system in frequency selective Rayleigh fading channels was presented by S.J.yi and Hinten [34]. In 2008, Jianping [35] presented algorithm for Asynchronous MC-CDMA multiuser detection. Andrew and Milstein [36] studied MC-CDMA and MC-DS-CDMA system and found that the performance of a MC-CDMA degrades as compare to MC-DS-CDMA as the number of user increases and MC-CDMA system improves for high diversity. In 2010 [37] simplified Multi Access Interference (MAI) reduction for MC-CDMA with carrier frequency offset technique was illustrated.

Performance analysis of MC-DS-CDMA with fading was presented by Taher and Minhaz [38]. Here the performance is evaluated in terms of various parameters such as number of subcarrier, code length, number of RAKE finger and number of users etc.Result shows BER degraded due to fading and improved with increase in the number of subcarriers and rake fingers of rake receivers.

Several researchers have done a lot of work to enhance the performance of MC-DS-CDMA system with various diversity techniques. The MC-DS-CDMA system performance along with MRC has been studied over Nakagami-m fading channel in the paper of Simon and Alouini, 1999 [39]; Sundro and Konalavasa, 2012[40]; Hashemet. al., 2007 [41]. In 2013 Jayaraman and Pushpam analyzed the performance of this system considering both Rayleigh and Rician fading over AWGN channel using Alamoutis' Space Time Block Code (STBC) scheme [42]. Several studies have been carried out on MC-DS-CDMA over Rayleigh fading channel with MRC receiver diversity considering Rake receiver in the paper of Smidaet. al., 2007[43] and Gupta and Tiwari, 2011[44]. It showed that introducing Rake structure at the receiving end significantly improves the performance of MC system.

S.D. Paul, S.Asif and S.P. Majumder [45] presented the performance analysis of MC-DS-CDMA wireless communication system with Rake Receiver over a Rayleigh Fading Channel with Receive Diversity. The analysis is extended to RAKE receiver with Equal Gain Combining (EGC). The results are presented in terms of BER and improvement of receiver sensitivity due to diversity and multicarrier orthogonal modulation. It is noticed that there are significant improvement due to diversity as well as the number of subcarriers in MC-DS-CDMA system.

In 2013, Ibrahim Develi and Ali Akdagli [46] derived an improved expression of BER in MC-CDMA systems with Equal Gain Combining over Nakagami fading channels. A.B. Djebbar, A. Djebbar, M. Bouziani and J. M.Rouvaen [14] also derived new expressions of BER for MC-CDMA system in Nakagami fading channel where the performance is evaluated without rake receiver. After studied all these research papers, specifically the last two ones in this thesis a MC-DS-CDMA system in Nakagami fading channel is developed. Here a rake receiver is added in the receiver model and unlike EGC, here MRC as diversity technique is introduced. In our work an analytical approach has been carried out to determine the expression of SINR and BER in the presence of MAI and AWGN noises with MRC diversity under Nakagami-m fading. For this different sets of system parameters such as with and without Rake receiver, various order of receive diversity, fading order and different values of processing gain are considered and results are evaluated through simulation in terms of BER performance.

1.11 Objective of the Thesis

The objectives of this work are:

- To develop analytical approach to evaluate the bit error performance of a MC CDMA wireless communication system with OFDM subcarriers with Rake receivers under Nakagami-m fading environment considering maximal ratio combining (MRC) for the rake combiner.
- To develop the expression for the probability density function (pdf) of the signal to noise ratio at the output of rake combiner for individual sub-channels of the OFDM sub carriers.
- To evaluate the bit error rate (BER) for each individual OFDM sub-channels and the average BER numerically.

Possible outcomes of this work are:

The outcome of this research will be useful for the design of MC-DS-CDMA wireless communication system with rake receiver and receive diversity using MRC of the individual subcarriers.

1.12 Outline of the Thesis

After the introductory chapter the rest of the chapters describe the outline of the thesis. Chapter 2 presents MC-DS-CDMA system model which consists of transmitter and Rake receiver with OFDM sub-carriers considering Nakagami-m fading environment. The analysis is carried out to derive the expressions of signal to noise ratio (SINR), multi access interference (MAI), bit rate (BER) and finally average bit error rate of MC-DS -CDMA wireless communication system with RAKE receiver and diversity considering Nakagami-m fading channel. The probability density function of the output SINR will also be developed considering Nakagami–m fading environment. The average BER will be evaluated by averaging the conditional BER over the pdf of the output SINR.

Chapter 3 presents the outcome of numerical analysis. Here, the BER performance results will be numerically evaluated for several system parameters and improvement in system performance due to rake receiver with MRC will be determined for a given BER. Optimum system design parameters (such as code length, number of users, number of rake fingers etc.) will then be determined for a given data rate.

Conclusions and the scope of the future work on this relevant field are described in chapter 4.

CHAPTER 2

SYSTEM ANALYSIS

2.1 Introduction

In this chapter a MC-DS-CDMA wireless communication system is considered using multicarrier BPSK modulation with orthogonal subcarriers where the input data stream is converted into parallel sub streams. At the receiver, a rake receiver having individual correlators for each subcarrier channel is considered. A noble theoretical analysis is presented for a MC-DS-CDMA wireless communication system with OFDM subcarriers with Rake receivers under Nakagami - m fading environment considering maximal ratio combining (MRC)for the rake combiner. The expression for the probability density function (pdf) of the signal to noise ratio at the output of rake combiner is developed for individual sub-channels of the OFDM sub carriers. The bit error rate (BER) is then determined for each individual OFDM sub-channels and the average BER is then evaluated numerically.

2.2 Transmitter Model

The Transmitter model of MC-DS-CDMA with OFDM modulator is described in this section where Fig. 2.1 shows the Transmitter model. In transmitter block, it shows MC-DS-CDMA with OFDM modulator where input data stream is converted into N_c parallel data streams having bit duration, T_b. Parallel data symbols of each data stream of jth user are coded by the pseudo random noise (PN) sequence having chip duration (T_c) and processing gain, G_p. Thus each data symbol is spread in the time domain. In each OFDM modulator there is sub carrier of respective channel which modulates the coded symbol of each data stream. MC-DS-CDMA signal is then transmitted through a multipath Nakagami-m fading wireless channel.

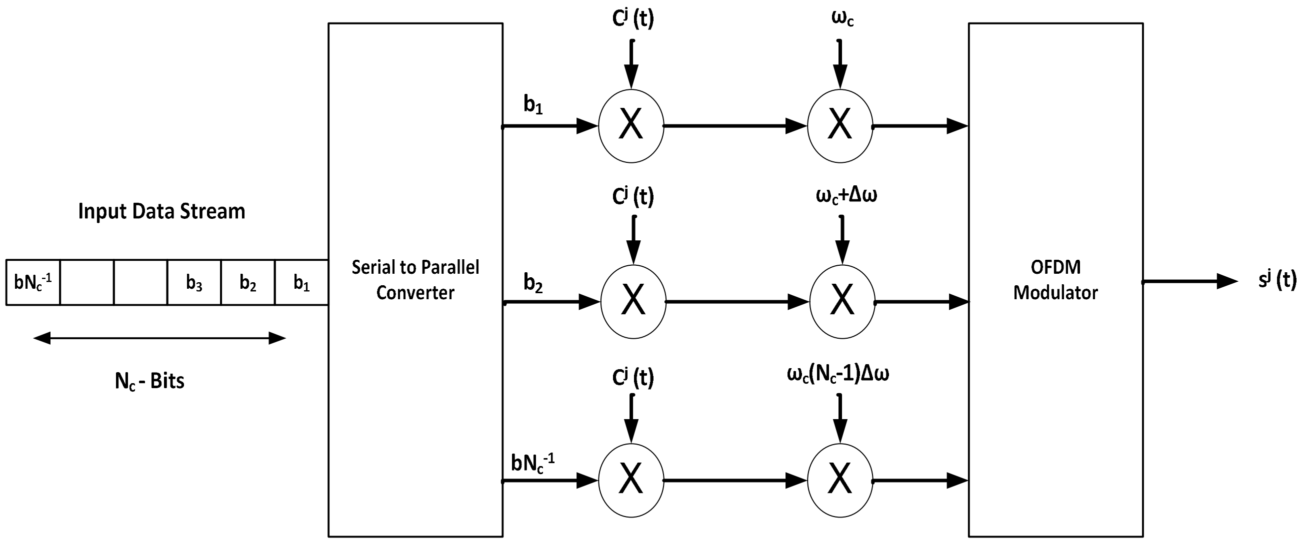

Fig. 2.1 Block diagram of a MC-DS-CDMA Transmitter Model

2.3 Receiver Model

The Receiver model of a MC-DS-CDMA with OFDM demodulator is described in this section and Fig.2.2 shows the receiver model. Receiver block mainly consists of OFDM demodulator, Rake Receiver with L_r branches, Integrators and Maximal ratio combiner (MRC). During reception the receiver of the j-th user receives all the signals transmitted by K no of users. Each receiver is equipped with Rake fingers and the output of the Rake fingers are combined by Maximal ratio combiner.

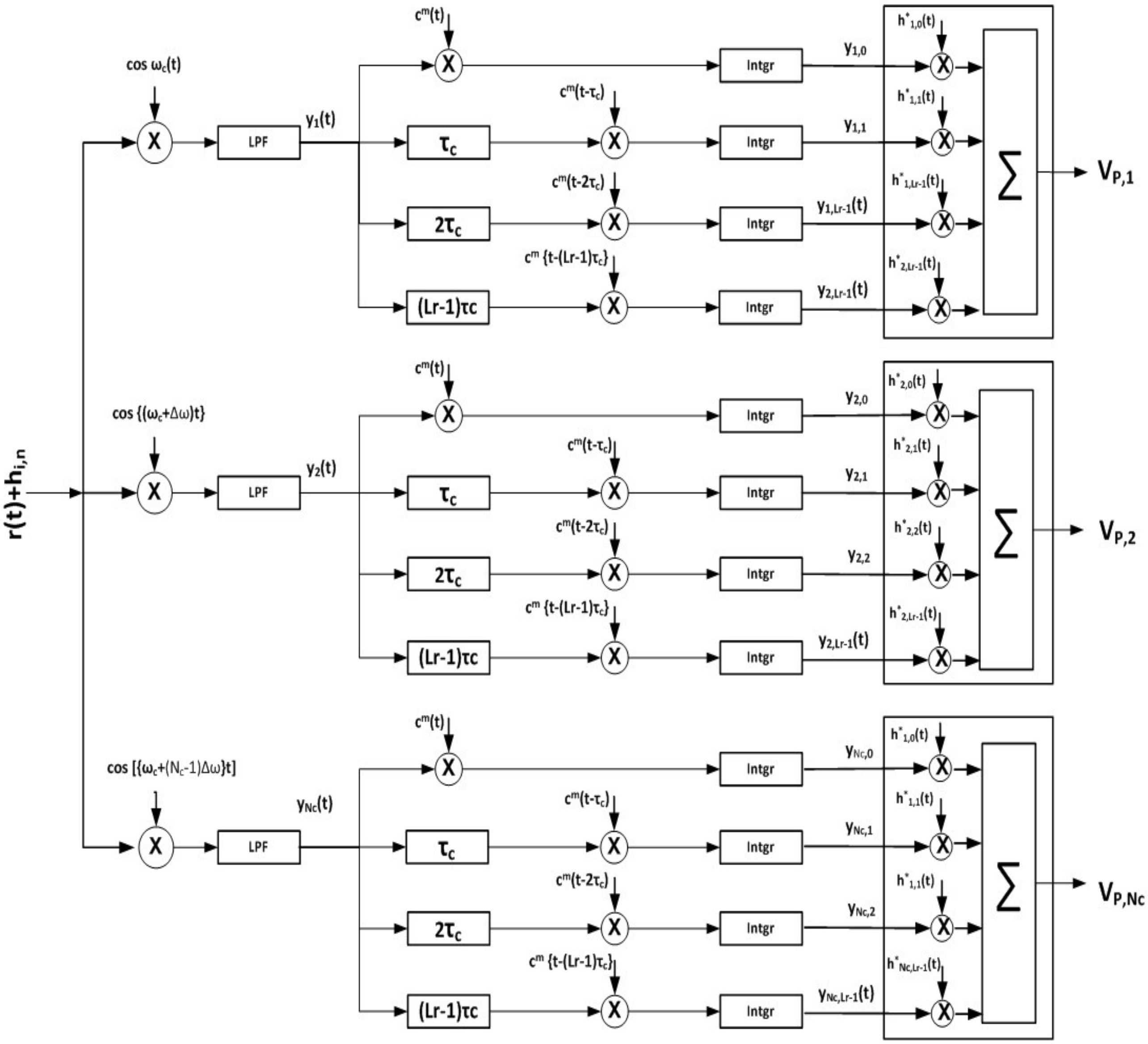

Fig. 2.2 Block diagram of a Rake Receiver for MC-DS-CDMA with OFDM subcarriers

2.4 Receiver Model with Receive Diversity and Rake Receiver

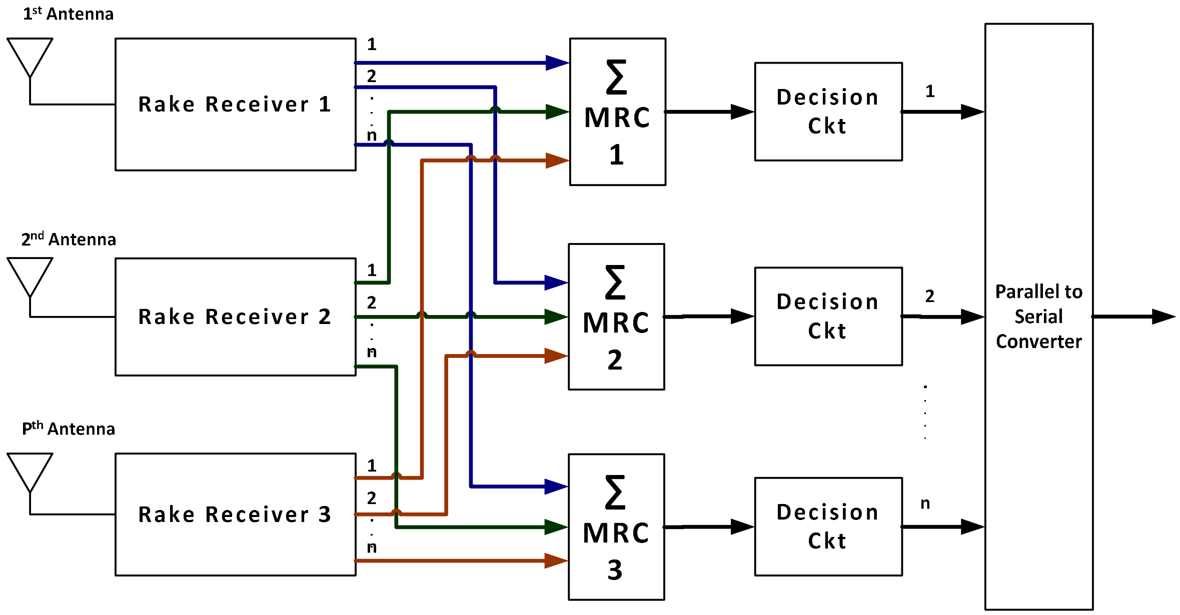

Fig.2.3 Block Diagram of a Receiver Model with Receive Diversity

Fig.2.3 shows the block diagram of a Receiver Model with receive diversity with P number of receiving antennas. Multiple antennas are used to achieve receive diversity. Each of the antennas is so placed that the receive signal undergoes through independent fading. All the antennas are equipped with Rake structure resulting an improvement in BER performance. Rake receiver using several sub-receivers/fingers which are assigned to different multipath component are designed to counter the effects of multipath fading.

2.5 Analysis of Multicarrier CDMA with RAKE Receiver

The general expressions of the transmitted signal of the j-th user with code $c^j(t)$ is,

$$s^j(t) = \int_{n=1}^{N_c} \sqrt{2P_T} \ . \ b_n^j(t) \ . \ c^j(t) \ . \ \cos[\{\omega_c + (n-1)\Delta\omega\}t + \varphi_n(t)] \tag{2.1}$$

Where,

$$c^j(t) = \sum_{l=0}^{L-1} c_l^j \, p(t - lT_c) \tag{2.2}$$

Here, P_T is the transmitted power per symbol, T_c is the chip period, b_n^j is the transmitted symbol of j-th user in n-th sub channel which is being modulated by the n-th sub-carrier of frequency ω_c+(n-1)Δω, $c^j(t)$ is the PN sequence code for the j-th user and $c^j(t)$ represents the l-th chip of the j-th code word, N is the code length, ω_c is the carrier frequency of the reference channel, $\Delta\omega$ is the frequency spacing between two successive channels, $\varphi_n(t)$ is the instantaneous /random phase angle of each sub-carrier, assumed to be uniformly distributed over [0,2π].

Now the expression of the received signal corresponding to the i-th path when there are j active users, is

$$r_{in}(t) = \int_{j=1}^{k} \sqrt{2P_r} \ . \ b_n^j(t - i\tau_c) \ . \ c^j(t - i\tau_c) \ . h_{in}(t) \ . \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c) + \varphi_n(t)] + n(t) \tag{2.3}$$

Where, P_r is the received signal power, K is the number of user , τ_c is the chip delay and n(t) is additive white Gaussian noise (AWGN) with two sided power spectral density $\frac{N_0}{2}$. Here $h_{i,n}$ is the fading parameter.

Now the composite signal received for the whole sequence is,

$$r(t) = \sum_{i=0}^{L_r-1} r_{i,n}(t) \tag{2.4}$$

Now, signal at the output of the n-th coherent demodulator is,

$$y_n(t) = LPF\ .\ \sum_{i=0}^{L_r-1} r_{i,n}(t) \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)] \tag{2.5}$$

$$y_n(t) = LPF \sum_{i=0}^{L_r-1} \sum_{j=1}^{k} \sqrt{2P_r} b_n^j(t - i\tau_c)\ .\ c^j(t - i\tau_c)\ .h_{in}(t)\ .\ \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)] + n(t)\ .\ \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)] \tag{2.6}$$

$$y_n(t) = LPF \sum_{i=0}^{L_r-1} \sum_{j=1}^{k} \sqrt{2P_r} b_n^j(t - i\tau_c)\ .\ c^j(t - i\tau_c)\ .h_{in}(t)\ .\ \frac{1}{2}[\cos\theta_i(t) + \cos\varphi_n(t)] + n(t) \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c) \tag{2.7}$$

Where, $\theta_i(t) = 2\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c) + \varphi_n(t)$

$$y_n(t) = \sum_{i=0}^{L_r-1} \sum_{j=1}^{k} \sqrt{\frac{P_r}{2}} b_n^j(t - i\tau_c)\ .\ c^j(t - i\tau_c)\ .h_{in}(t)\ .\ \cos\{\varphi_n(t)\} + n(t) \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c) \tag{2.8}$$

To determine the signals of the i-th branch of the Rake receiver and N_c-th sub –carrier,$y_n(t)$is multiplied with $c^m(t - i\tau_c)$ where i =0 to $(L_r - 1)$, So the output of the i-th corelator corresponding to the m-th user is

$$y_{n,i}(t) = \frac{1}{T_b} \int_0^{T_b} y_n(t)\ .\ c^m(t - i\tau_c)dt\ \ ; \qquad i = 0{:}\, L_r - 1 \tag{2.9}$$

$$y_{n,i}(t) = \frac{1}{T_b} \int_0^{T_b} [\sum_{i=1}^{L_r^-1} \sum_{j=1}^{k} \sqrt{\frac{p_r}{2}} b_n^j(t - i\tau_c)\ .\ c^j(t - i\tau_c)\ .\ h_{in}(t)\ .\cos\{\varphi_n(t)\}\ .\ c^m(t - i\tau_c)dt + \frac{1}{T_b} \int_0^{T_b} n(t)\ .\ \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)\quad c^m(t - i\tau_c)dt \tag{2.10}$$

$$y_{n,i}(t) = \sum_{i=1}^{L_r^-1} \sum_{j=1}^{k} \sqrt{\frac{p_r}{2}} b_n^j(t - i\tau_c)\ .\ h_{in}(t)\ .\ \cos\{\varphi_n(t)\}\ .\ \frac{1}{T_b} \int_0^{T_b} c^j(t - i\tau_c)\ .\ c^m(t - i\tau_c)dt + \frac{1}{T_b} \int_0^{T_b} n(t)\ .\ \cos[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)\quad c^m(t - i\tau_c)dt \tag{2.11}$$

$$v_{p,n} = \sum_{i=1}^{L_r-1} y_{n,i}(t)\ .\ h_{in}^*(t) \tag{2.12}$$

$$v_{p,n} = \sum_{i=0}^{L_r-1} \sum_{j=1}^{k} \sqrt{\frac{p_r}{2}} b_n^j (t - i\tau_c) \ . \cos\{\varphi_n(t)\} \ . \ [h_{in}(t) \ . \ h_{in}^*(t)] \ . \frac{1}{T_b} \int_0^{T_b} c^j (t - i\tau_c) \ . \ c^m(t - i\tau_c) dt \ + \frac{1}{T_b} \int_0^{T_b} n(t) \ . \ \cos\,[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c) \quad c^m(t - i\tau_c) dt \quad (2.13)$$

2.6 Determination of signal power

Here, j=m gives signal component and is given by the expression,

$$v_{n,sig} = \sum_{i=0}^{L_r-1} \frac{p_r}{2} b_n^m (t - i\tau_c) \ . \ \cos\{\varphi_n(t)\} \ . \ [h_{in}(t) \ . \ h_{in}^*(t)] \ . \frac{1}{T_b} \int_0^{T_b} c^m (t - i\tau_c)^2 \, dt \quad (2.14)$$

$$v_{n,sig} = \sum_{i=0}^{L_r-1} \sqrt{\frac{p_r}{2}} \ . \ [h_{in}(t) \ . \ h_{in}^*(t)] \ . \ b_n^m (t - i\tau_c) \ . C_{o,m} \quad (2.15)$$

Where, $C_{o,m} = \frac{1}{T_b} \int_0^{T_b} c^m (t - i\tau_c)^2 \, dt$

$C_{o,m} = LT_C$

$C_{o,m} = G_P T_C$

$P_r = MS\{v_{n,sig}\}$

$$P_r = \sum_{i=0}^{L_r-1} \frac{p_r}{2} \ . \ [h_{in}(t) \ . \ h_{in}^*(t)]^2 \ . \ \left|C_{o,m}\right|^2 \quad (2.16)$$

Now the Mean Square Signal Power of n-th subcarrier is,

$$P_r = L_r \times \frac{p_r}{2} \times |h_{in}(t) \ . \ h_{in}^*(t)|^2 \quad (2.17)$$

Where,$[h_{in}(t) \ . \ h_{in}^*(t)]^2 = |h|^4$ and $\left|C_{o,m}\right|^2$=1

2.7 Determination of MAI power

Again, the condition j≠m gives Multi Access Interference (MAI) and the expression is,

$$v_{n,MAI} = \sum_{i=0}^{L_r-1} \sum_{j=0}^{k} \sqrt{\frac{p_r}{2}} \ . \ [h_{in}(t) \ . \ h_{in}^*(t)] \ . \ b_n^j (t - i\tau_c) \ . \ \cos\{\varphi_n(t)\} \ . \frac{1}{T_b} \int_0^{T_b} c^j (t - i\tau_c) \ . c^m (t - i\tau_c) \, dt \quad (2.18)$$

Where,

$$r_{j,m} = \frac{1}{T_b}\int_0^{T_b} c^j(t - i\tau_c)\,.\,c^m(t - i\tau_c)\,dt$$

$$r_{j,m} = \frac{1}{G_P}\sum_{l=1}^{G_P} C_{j,l}\,.\,C_{m,l}$$

$$P_{MAI,n} = MS\{v_{n,MAI}\}$$

$$P_{MAI,n} = (k-1)\,.\;L_r\,.\frac{p_r}{2}\;.\;[h_{in}(t)\,.\;h_{in}^*(t)]^2\;.\;MS(r_{j,m}) \tag{2.19}$$

Now the MAI power for the n-th subcarrier,

$$P_{MAI,n} = (k-1)\,.\;L_r\,.\frac{p_r}{2}\;.\;[h_{in}(t)\,.\;h_{in}^*(t)]^2\;.\;\frac{1}{G_P} \tag{2.20}$$

2.8 Determination of Noise Power

Now the noise component of the n[th] coherent demodulator is -

$$\frac{1}{T_b}\int_0^{T_b} n(t)\,.\;\cos\,[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)\quad c^m(t - i\tau_c)dt \tag{2.21}$$

Which is a Gaussian random variable with zero mean and variance,

$$E\left[\frac{1}{T_b^2}\int_{s=0}^{T_b}\int_{t=0}^{T_b} n(t)\,n(s)\,c^m(t - i\tau_c)\,c^m(s - i\tau_c)\;\cos\,[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)]\;\cos\,[\{\omega_c + (n-1)\Delta\omega\}(s - i\tau_c)]\,dt\,ds\right] \tag{2.22}$$

$$= \frac{1}{T_b^2}\int_{s=0}^{T_b}\int_{t=0}^{T_b} E\,[n(t)\,n(s)]\,E[c^m(t - i\tau_c)\,c^m(s - i\tau_c)]\;\cos\,[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)]\;\cos\,[\{\omega_c + (n-1)\Delta\omega\}(s - i\tau_c)]\,dt\,ds$$

$$= \frac{1}{T_b^2}\int_{t=0}^{T_b}\frac{N_0}{2}\delta(t-s)\,E\,[c^m(t - i\tau_c)]^2\cos^2\,[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)]\;dt$$

$$= \frac{N_0}{2}\frac{1}{T_b^2}\frac{1}{2}\int_{t=0}^{T_b} 2\cos^2\,[\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)]\;dt$$

$$= \frac{N_0}{4T_b^2} \int_{t=0}^{T_b} 1 + cos\ [2\{\omega_c + (n-1)\Delta\omega\}(t - i\tau_c)]\ dt$$

$$\approx \frac{N_0}{4T_b}$$

So the variance of noise power, $\sigma_n^2 = \frac{N_0}{4T_b}$ (2.23)

2.9 Signal to interference plus noise ratio (SINR) analysis:

Now Signal to Interference plus Noise Ratio (SINR) can be expressed as:

$$SINR = \frac{p_r}{\sigma_{MAI}^2 + \sigma_n^2} \tag{2.24}$$

$$\text{SINR}=\gamma_P(n,h) = \frac{L_r \cdot \frac{P_r}{2} \cdot [h_{in}(t) \times h_{in}^*(t)]^2}{(K-1) \cdot L_r \cdot \frac{P_r}{2} \cdot [h_{in} \times h_{in}^*(t)]^2 \cdot \frac{1}{G_p} + \sigma_n^2} \tag{2.25}$$

$$\gamma_P(n,h) = \frac{L_r \cdot \frac{P_r}{2} \cdot [h_{in}(t) \times h_{in}^*(t)]^2}{(K-1) \cdot L_r \cdot \frac{P_r}{2} \cdot [h_{in} \times h_{in}^*(t)]^2 \cdot \frac{1}{G_p} + \frac{N_0}{4T_b}} \tag{2.26}$$

$$P_r T_b = E_b \tag{2.27}$$

$$\gamma(n,h) = \frac{L_r \cdot \frac{P_r}{2} \cdot [h_{in}(t) \times h_{in}^*(t)]^2 \times \frac{4T_b}{N_0}}{(K-1) \cdot L_r \cdot \frac{P_r}{2} \cdot \frac{4T_b}{N_0} [h_{in} \times h_{in}^*(t)]^2 \cdot \frac{1}{G_p} + 1} \tag{2.28}$$

$$\gamma(n,h) = \frac{2\left(\frac{E_b}{N_0}\right) \cdot L_r \cdot |h|^4}{2\left(\frac{E_b}{N_0}\right) \cdot (k-1) \cdot L_r \cdot |h|^4 \cdot \frac{1}{G_P} + 1} \tag{2.29}$$

So the resultant SINR with receive diversity, $\gamma_p(n,h) = \sum_{P=1}^{P} \gamma(n,h)$ (2.30)

$$\gamma_p(n,h) = \text{P x } \frac{2\left(\frac{E_b}{N_0}\right) \cdot L_r \cdot |h|^4}{2\left(\frac{E_b}{N_0}\right) \cdot (k-1) \cdot L_r \cdot |h|^4 \cdot \frac{1}{G_P} + 1} \tag{2.31}$$

where, P is the number of receiving antennas.

2.10 Bit error rate analysis (BER):

Now, The Conditional BER for BPSK modulated signal is given by,

$$BER(n,h) = \frac{1}{2} erfc[\sqrt{\frac{\gamma(n,h)}{2}}] \tag{2.32}$$

For Nakagami–m fading distribution, the probability density function (pdf) of the Nakagami–m distributed random variable $h_{l,k}$ is given by [22], [46],

$$p(h_{l,k}) = 2\ .\ (\frac{m}{\Omega_{l,k}})^m . \frac{{h_{l,k}}^{2m-1}}{\Gamma(m)}\ .\ e^{-(m.\frac{{h_{l,k}}^2}{\Omega_{l,k}})} \tag{2.33}$$

Where,

$\Gamma(m)$ represents the Gamma function

$\Omega_{l,k}$ is the average path gain and

m is the Nakagami-m fading parameter and parameter m of amplitude distribution characterizes the severity of fading over the l-th resolvable path [38].For instance, m=1/2 and m=1 correspond to the one-sided Gaussian fading and the well-known Rayleigh fading respectively. In the limit, as m → ∞, the Nakagami-m fading channel converges to a non-fading additive white Gaussian noise (AWGN) channel. Furthermore, the Ricean and lognormal distributions can also be closely approximated by the Nakagami distributions for m>1 [22].

Hence unconditional BER can be derived as below –

$$BER(n) = \int_0^\infty BER(n,h)\ .\ p(h)\ .\ dh \tag{2.34}$$

or, by substituting equation (2.32) and (2.33) into equation (2.34) we get,

$$BER(n) = \int_0^\infty \frac{1}{2} erfc\left[\sqrt{\frac{\gamma(n,h)}{2}}\right].\ 2\ .\ (\frac{m}{\Omega_{l,k}})^m . \frac{{h_{l,k}}^{2m-1}}{\Gamma(m)}\ .\ e^{-(m.\frac{{h_{l,k}}^2}{\Omega_{l,k}})} dh \tag{2.35}$$

Average BER is then obtained as,

$$BER = \frac{1}{N} \sum_n BER(n) \tag{2.36}$$

CHAPTER 3
RESULTS AND DISCUSSION

3.1 Results and Discussion

In this chapter, the performance results of a MC DS CDMA system are evaluated numerically through matlab simulation based on the theoretical analysis described in chapter-2. Performance results are evaluated in terms of BER without and with Rake receiver considering Nakagami-m fading channel. BER performance curves are evaluated by considering various system parameters such as number of users, processing gain, order of Nakagami fading, number of rake fingers etc. The parameters used for numerical computations are shown in the following table:

Parameters	Values
Number of users K	1-25
Processing Gain, G_p	64, 128, 256, 512
Order of Nakagami fading, m	4
Number of Rake fingers, L_r	1-6
Number of receiving antenna	1-6

3.2 Performance Results over Nakagami-m Fading Environment with and without Rake Receiver without Receive Diversity

Following the theoretical analysis shown in section 3, we evaluate the bit error rate performance of a MC-DS-CDMA wireless communication system without rake receiver under Nakagami-m fading channel. The results are evaluated without receive diversity (P=1). The plots of BER versus number of users for a MC-DS-CDMA system with Nakagami fading of order, m=4 is shown in Fig 3.1 for different values of processing gain and number of users without rake receiver.

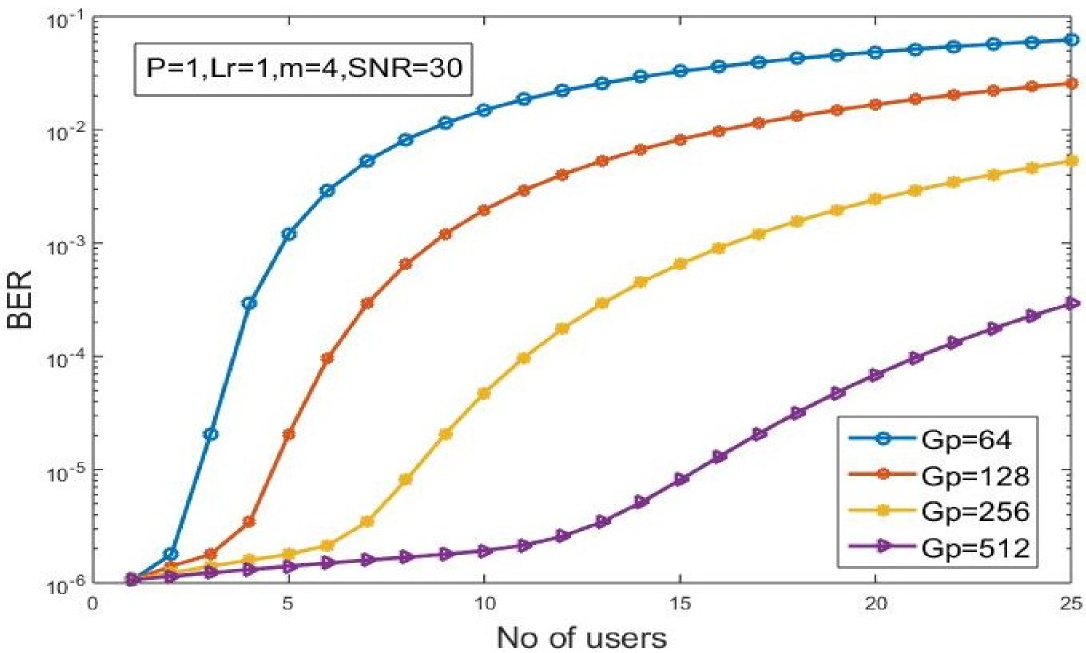

Fig.3.1 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different processing gain, G_p=64,128,256,512 for a MC-DS-CDMA wireless communication system without receive diversity (P=1) with Nakagami order m=4 at number of Rake finger L_r=1

It is evident from the curve that as the number of users increases BER increases. But for the higher order of processing gain BER did not show increasing trend. For example, a processing gain of G_p=64, the BER increases from 10^{-3} to $6.21 x 10^{-2}$ when the number of user increases from 5 to 25. In contrast when G_p=512, the BER increases slightly from $1.4 x 10^{-6}$ to $2.91 x 10^{-4}$for the same increment of users. Also it is clear from the curve that as the processing gain increases BER decreases. For example for no. of users, K=25 and G_P=64 the BER is to $6.21 x 10^{-2}$ whereas it reduces to $2.91 x 10^{-4}$ keeping other parameters constant. Bit error rate increases with increase in the number of users due to effect of MAI. The level of the BER floor depends on the value of processing gain, G_p and number of users, K. BER reduces for higher values of processing gain for a given number of users and vice versa.

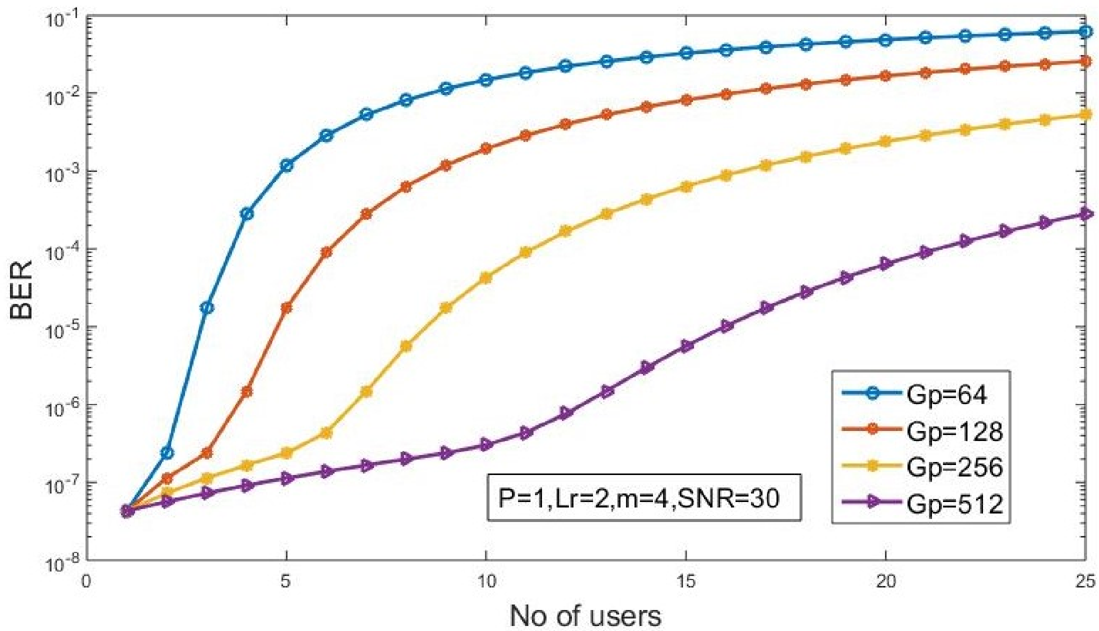

Fig.3.2 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different processing gain, G_p=64,128,256,512 for a MC-DS-CDMA wireless communication system without receive diversity (P=1) with Nakagami order m=4 at number of Rake finger L_r=2.

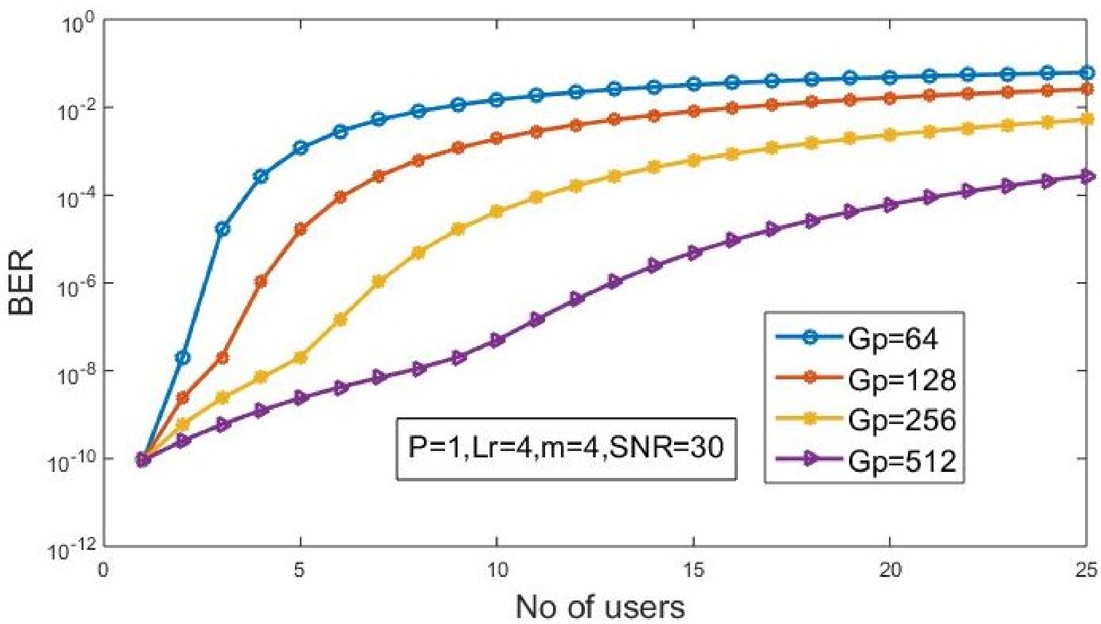

Fig.3.3 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different processing gain, G_p=64,128,256,512 for a MC-DS-CDMA wireless communication system without receive diversity (P=1) with Nakagami order m=4 at number of Rake finger L_r=4.

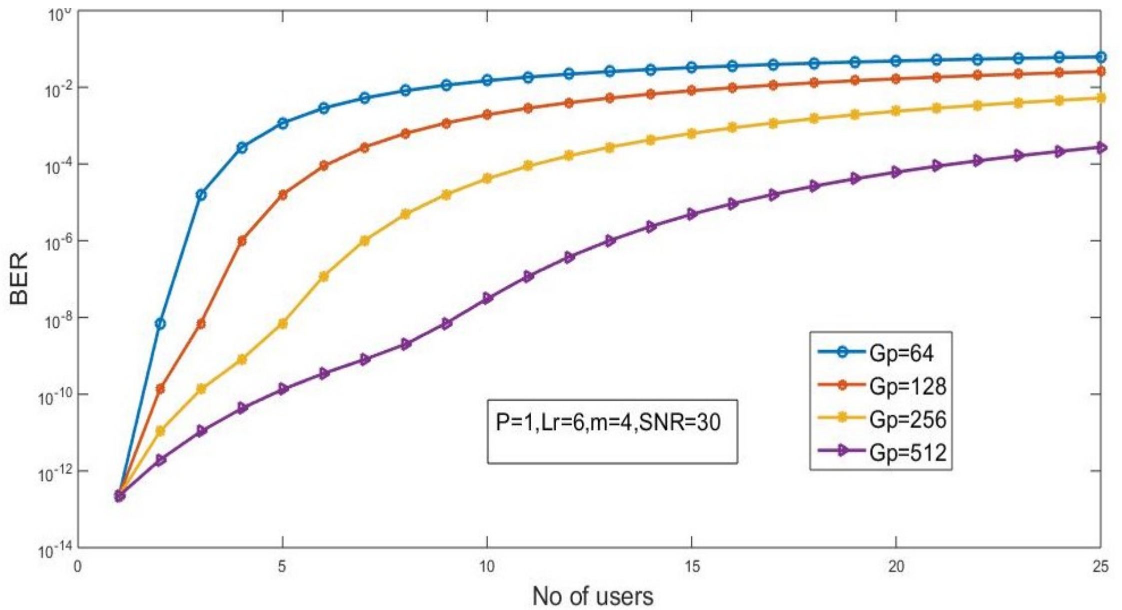

Fig.3.4 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different processing gain, G_p=64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P=1) with Nakagami order m=4 at number of Rake finger L_r=6.

In Fig.3.2 to 3.4, the BER is plotted for different combinations of rake finger, L_r. SNR=30, m=4 and L_r = 2, 4 and 6 are used to plot the curve 3.2, 3.4 and 3.6 respectively. Each figure is plotted with various processing gain, G_P=64,128, 256 and 512.It is noticed that as the number of rake fingers increases, the BER decreases for lower values of users. For example with L_r=2 and no. of user in between 0 to 5, BER level found at below 10^{-7} whereas with L_r=6, BER level found at below 10^{-12} for the same number of users. Again for the higher values of users, BER increases in smaller values of processing gain. It is evident from the graph that for higher values of rake fingers and processing gain BER level reduces for higher values of users. For example, in Fig.3.4, the BER level occurs at 6.9×10^{-2} for L_r =6 and G_P=64 with no. of users, K=25. In contrast the BER level occurs at 2.71×10^{-4} for L_r =6 and G_P=512 with equal no. of users, K=25. It is also noticed that in Fig.3.4 the BER level increases as the number of user increases from 5 to 25 with G_p=512 and L_r=6. For K = 5, BER=1.26×10^{-10} and for K=25, BER=2.71×10^{-4} keeping other parameter constant.

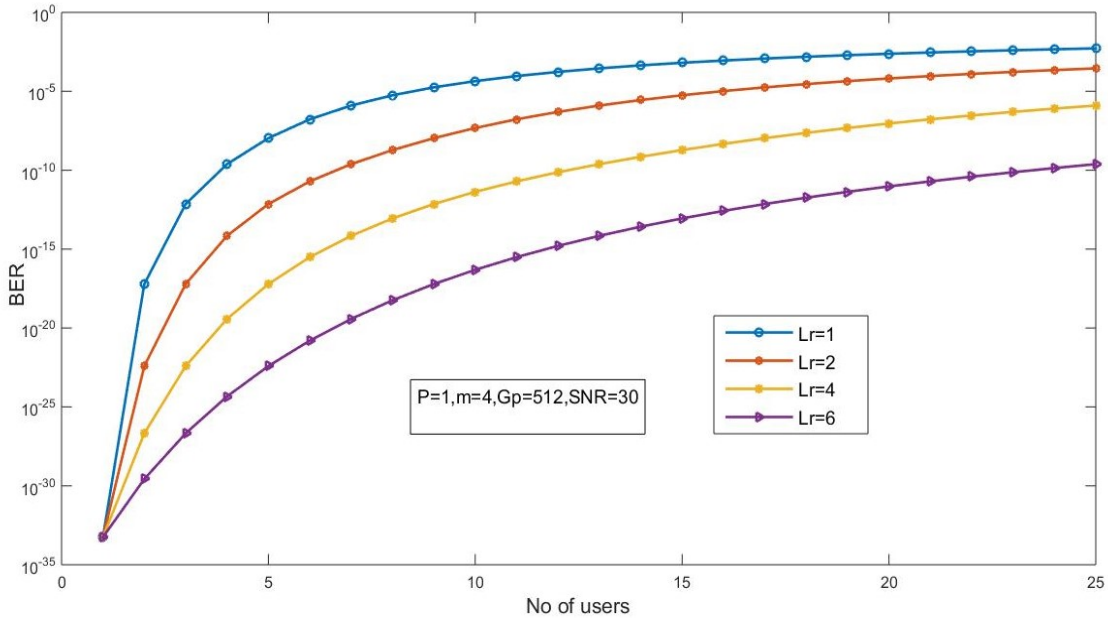

Fig.3.5 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different number of rake fingers, L_r = 1,2,4 and 6 with P = 1

In Fig.3.5 the BER with number of simultaneous users is plotted at a fixed processing gain of G_p = 512, P = 1, SNR = 30dB, m = 4. From the figure it is evident that as the number of rake fingers increases BER decreases for a fixed processing gain. For example, with number of users K = 25, the BER level found at $5.22\text{x}10^{-3}$ for L_r = 1 and BER = $2.397\text{x}10^{-10}$ for L_r = 6 at a fixed processing gain of G_p = 512. Thus from the figure it is evident that BER reduces by an order of magnitudes as L_r increases from 1 to 6.

3.3 Performance Results over Nakagami-m Fading Environment with Rake Receiver and with Receive Diversity

In this section we evaluate the bit error rate performance of a MC-CDMA wireless communication system with and without rake receiver under Nakagami-m fading channel. The results are evaluated with receive diversity (P=2).

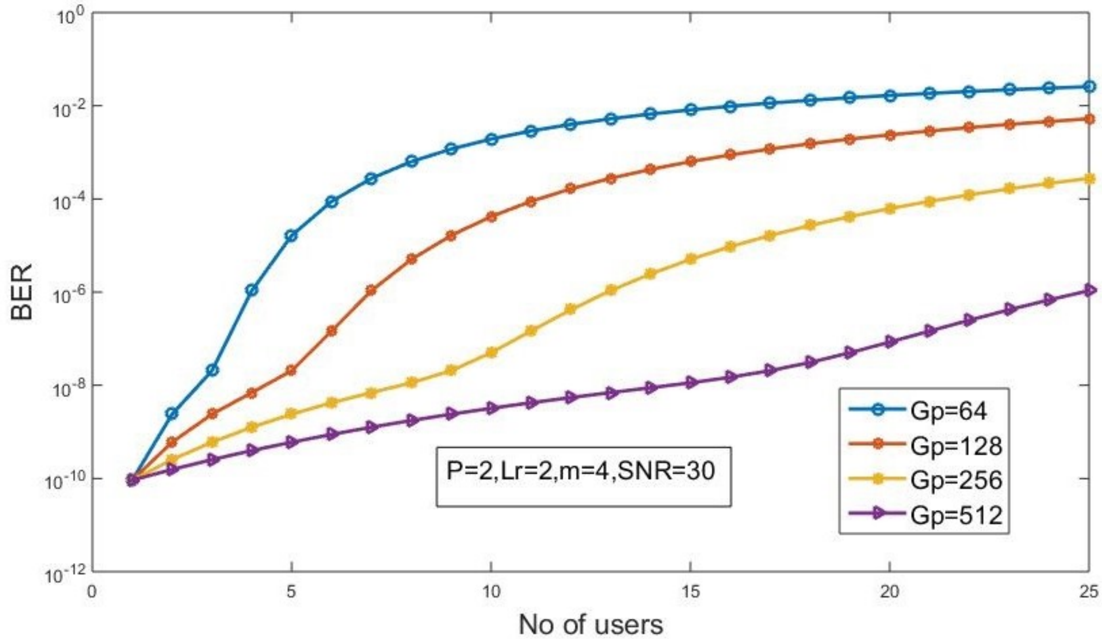

Fig.3.6 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different processing gain, G_p = 64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P = 2) with Nakagami order m = 4 at number of Rake finger L_r = 2.

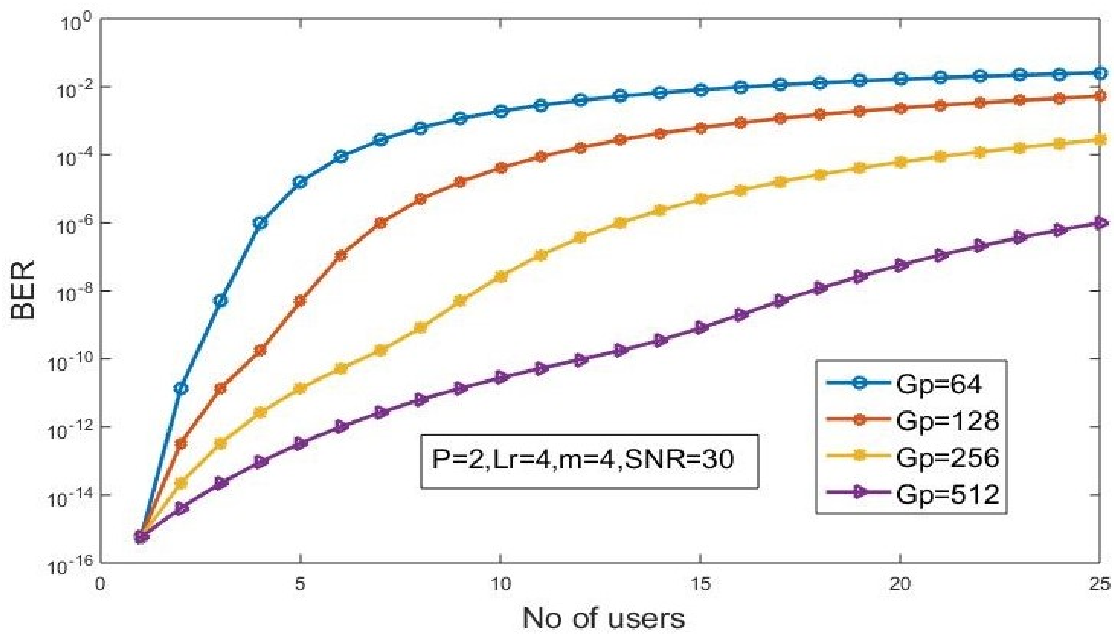

Fig.3.7 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different processing gain, G_p = 64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P = 2) with Nakagami order m = 4 at number of Rake finger L_r = 4.

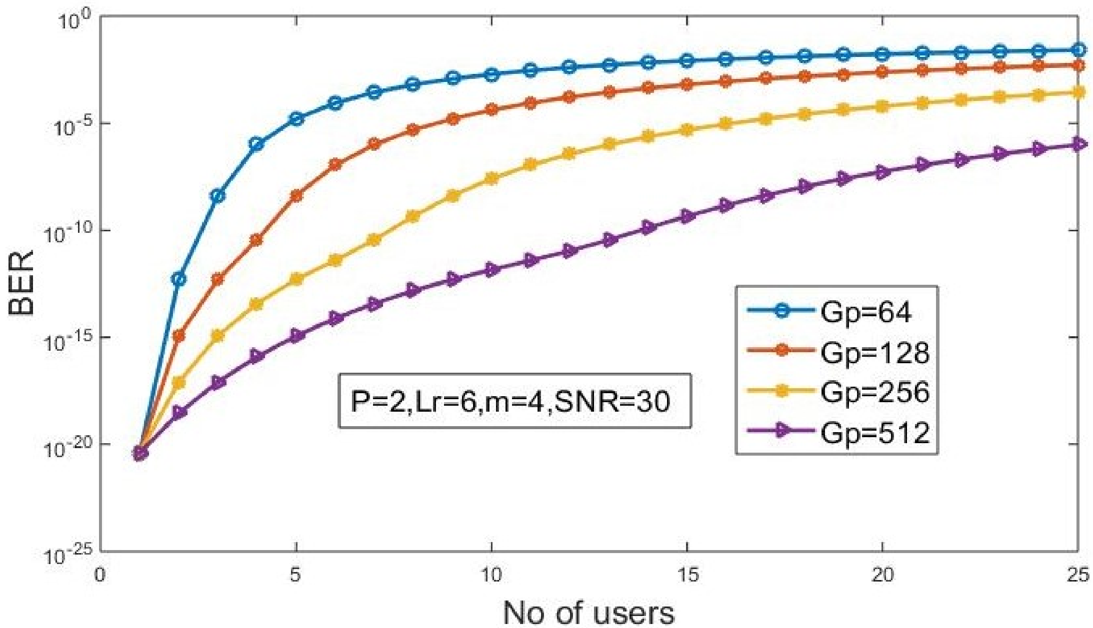

Fig.3.8 Plots of BER versus number of simultaneous users in Nakagami fading channel with MRC equalization for different processing gain, G_p = 64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P = 2) with Nakagami order m = 4 at number of Rake finger L_r = 6.

In Fig.3.6 to Fig.3.8, the BER is plotted for different combinations of rake finger, L_r. SNR=30, m=4 and L_r = 2,4 and 6 are used to plot the curve 3.6, 3.7 and 3.8 respectively. Each figure is plotted with various processing gain, G_P=64,128, 256 and 512. In comparison with Fig. 3.2 to Fig.3.4 without receive diversity, it is noticed that the BER decreases for lower values of users as the number of rake fingers increases. For example with L_r=2 and no. of user in between 0 to 5, BER level found at below 10^{-10} whereas with L_r=6, BER level found at below 10^{-20} for the same number of users. Again for the higher values of users, BER increases in smaller values of processing gain. It is evident from the graph that for higher values of rake fingers and processing gain BER level reduces for higher values of users. For example, in Fig.3.4, the BER level occurs at 2.56×10^{-2} for L_r =6 and G_P=64 with no. of users, K=25. In contrast the BER level occurs at 9.8×10^{-7} for L_r =6 and G_P=512 with equal no. of users K=25. In comparison with Fig.3.4, it was evident from Fig.3.8 that the level of BER floor decreases by order of magnitudes with receive diversity (P=2).

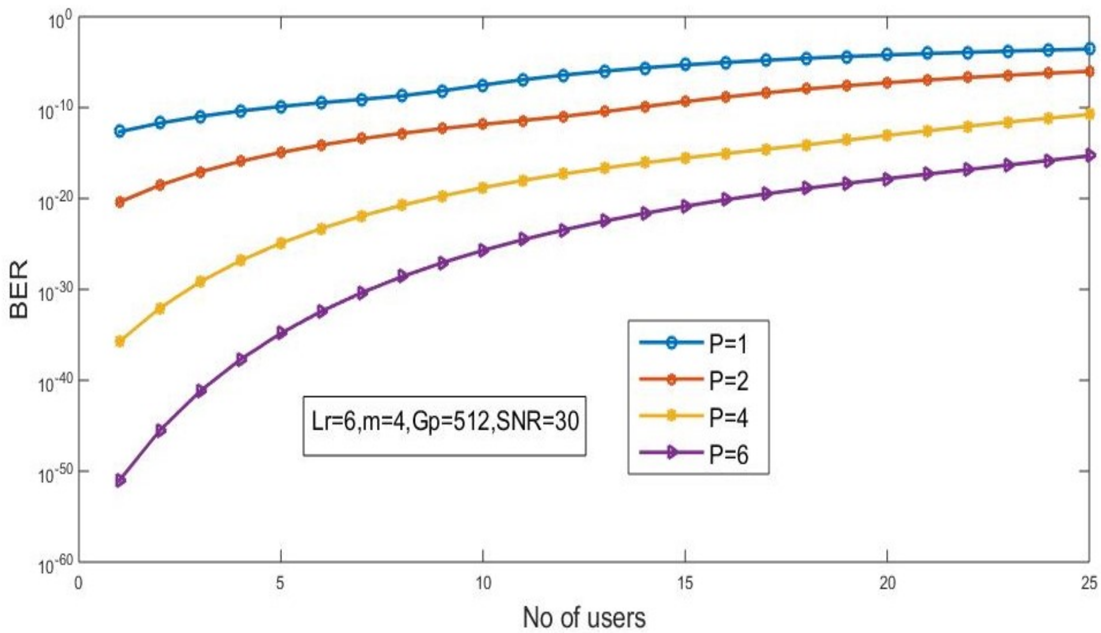

Fig.3.9 Plots of BER versus number of users for different receiving antennas, P = 1,2,4 and 6 for a MC-DS-CDMA wireless communication system with number of Rake finger, L_r = 6.

The variation of BER with the number of user is shown in Fig.3.9. The curve is plotted with a fixed processing gain of G_p = 512 with various receiving antennas, P = 1, 2, 4 and 6. m = 4, L_r = 6, SNR = 30 dB are used to plot the curve. It is noticed that as the number of receiving antenna increases, the BER decreases. For example with P = 1 and no. of user in between 0 to 5, BER level found at below 10^{-10} whereas with P = 6,BER level found at below 1.61x 10^{-35} for the same number of users. Also it is evident from the graph that for P = 1, BER = 2.75×10^{-4} with number of users, K = 25 whereas it reduces to 4.925×10^{-16} for equal number of users keeping other parameters constant. Therefore the decrease in BER level indicates the improvement in system performance.

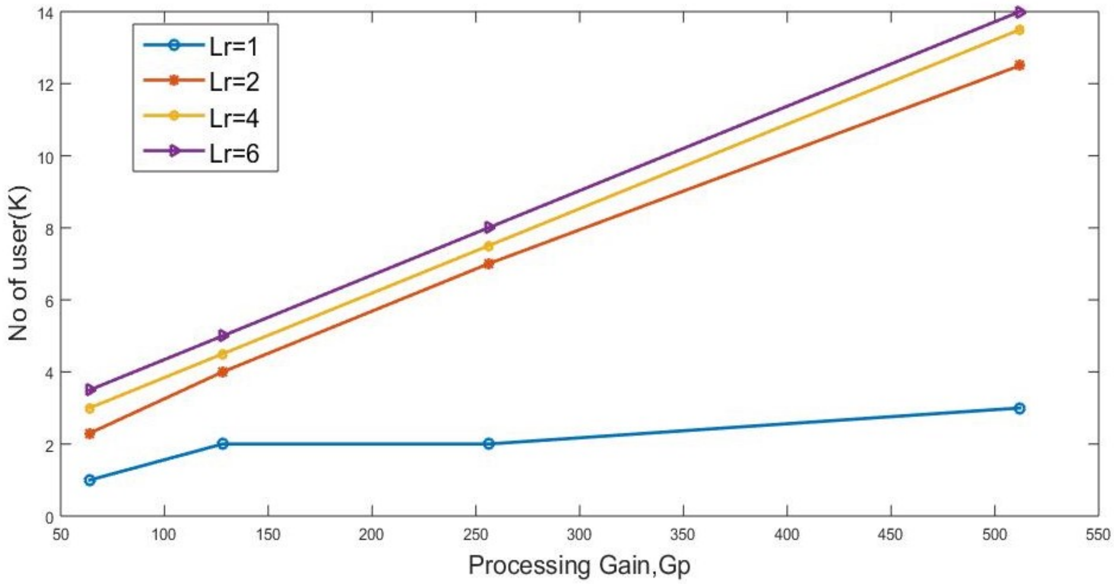

Fig.3.10 Plots of number of users versus different number of processing gain in Nakagami fading channel with MRC equalization with $L_r = 1$, $L_r = 2$, $L_r = 4$ and $L_r = 6$ at P = 2.

The plots of number of user versus processing gain with Nakagami fading of order m = 4 at a fixed BER = 10^{-6} are shown in Fig 3.10 for different values of rake fingers. The results are evaluated at number of rake fingers, $L_r = 1$, $L_r = 2$, $L_r = 4$ and $L_r = 6$ and it is observed that number of user increases with increased number of rake fingers along with increased processing gain.

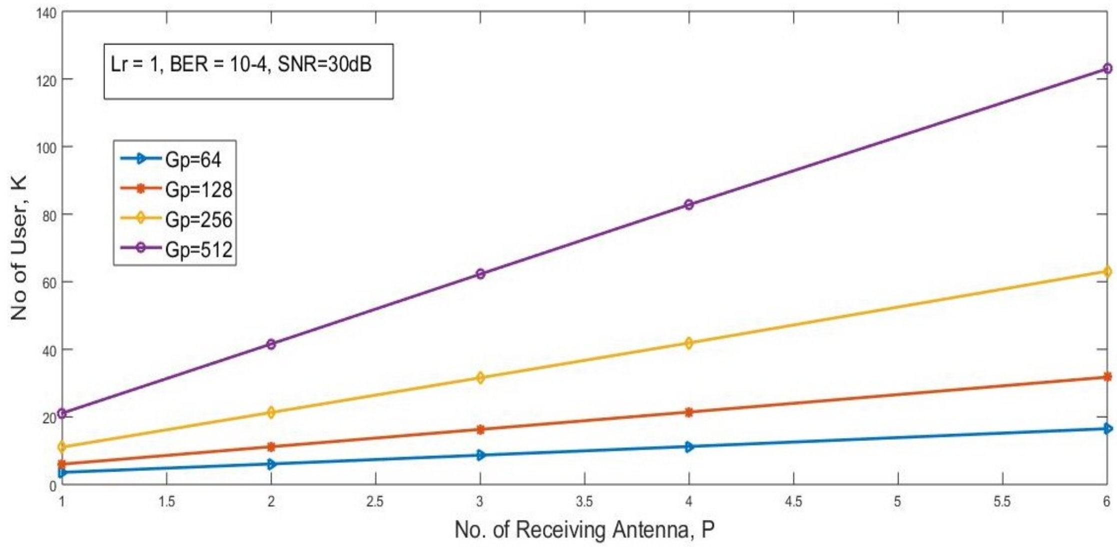

Fig.3.11 Plots of number of users versus different number of receiving antenna for different processing gain, G_p=64,128,256,512for a MC-DS-CDMA wireless communication system with number of Rake finger, Lr=1.

It is observed that bit error rate increases with increase in the number of users due to effect of MAI. The level of the BER floor depends on the value of processing gain, G_p and number of users, K. BER reduces for higher values of processing gain for a given number of users and vice versa.

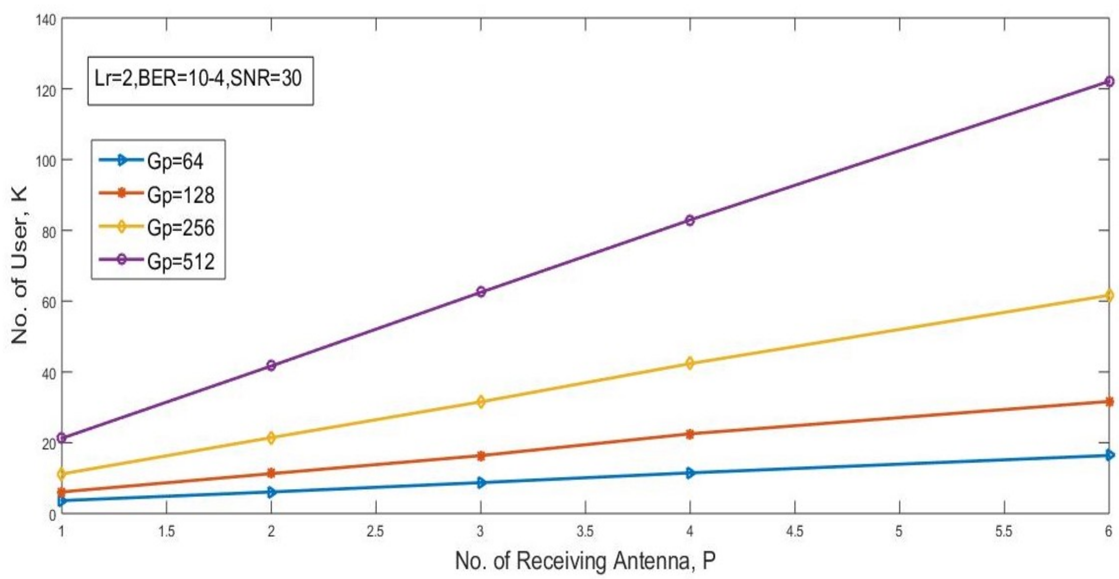

Fig.3.12 Plots of number of users versus number of receiving antenna for different processing gain, G_p=64,128,256,512for a MC-DS-CDMA wireless communication system with number of Rake finger, Lr=2.

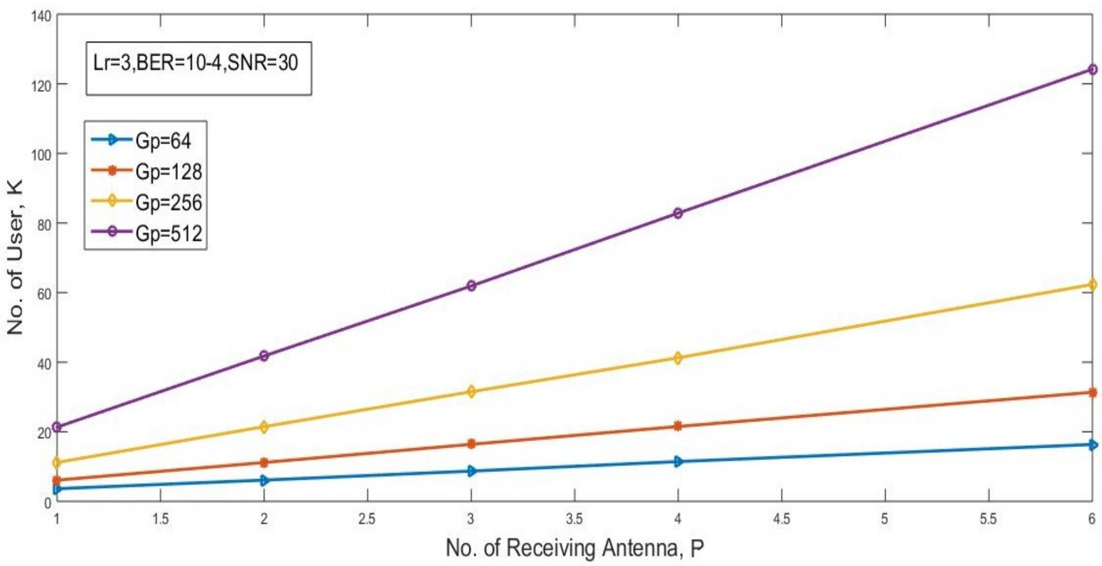

Fig.3.13 Plots of number of users versus number of receiving antenna for different processing gain, G_p=64,128,256,512for a MC-DS-CDMA wireless communication system with number of Rake finger, Lr=3

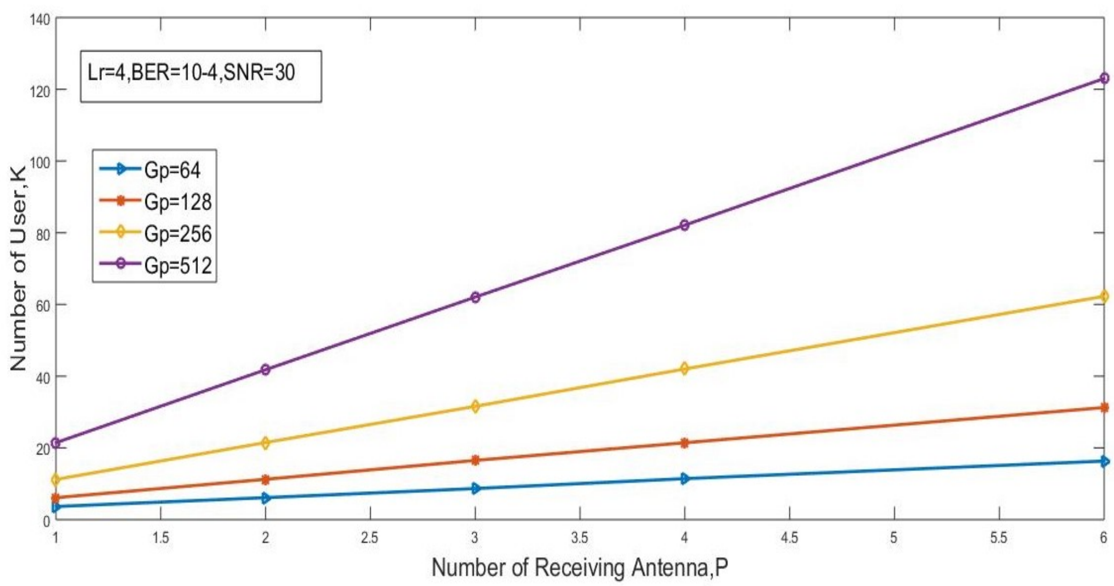

Fig.3.14 Plots of number of users versus number of receiving antenna for different processing gain, Gp=64,128,256,512for a MC-DS-CDMA wireless communication system with number of Rake finger, Lr=4.

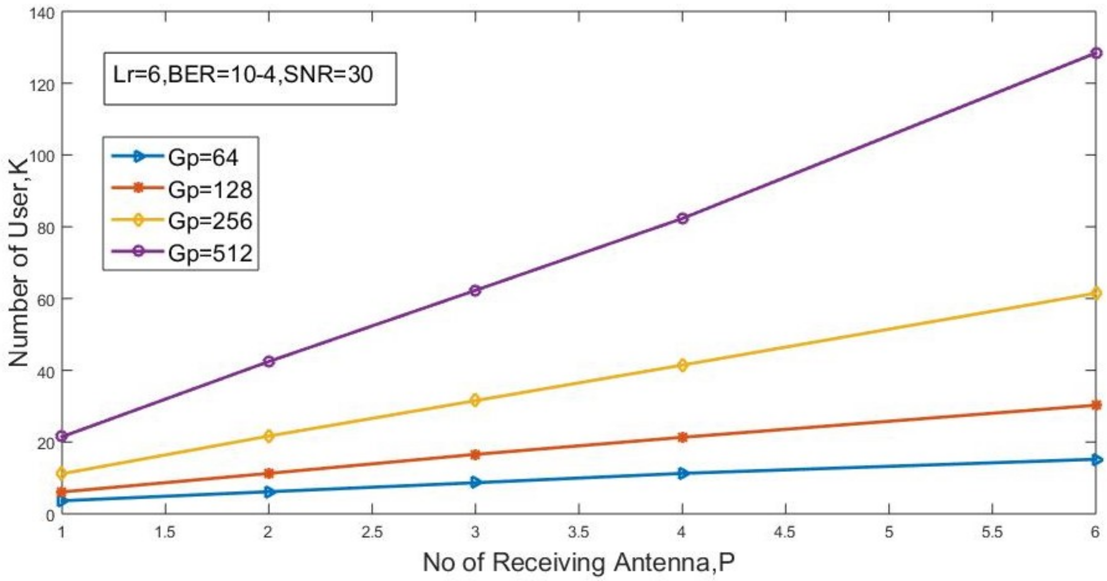

Fig.3.15 Plots of number of users versus number of receiving antenna for different processing gain, G_p=64,128,256,512for a MC-DS-CDMA wireless communication system with number of Rake finger, L_r=6.

The plots of number of users vs. number of receiving antenna over Nakagami-m fading channel at a fixed BER = 10^{-4} and SNR = 30 dB are shown in Fig 3.11 to Fig.3.15 for different values of processing gain .The results are evaluated at number of Rake finger L_r = 1, L_r = 2, L_r = 3, L_r = 4 and L_r = 6 respectively. It is observed that there is a significant increase in the number of users with increase in the number of receiving antenna at a given number of rake fingers due to receive diversity. For example, the users corresponds to P = 1, L_r = 1 at a processing gain, G_p = 512 is 21 whereas it increases to 123 when P = 6, keeping other parameters fixed.

Again from Fig. 3.15, it is also noticed that at L_r = 6, P = 6 the number of users are 15, 30, 61 and 128 corresponding to processing gain G_p = 64, G_p = 128, G_p = 256 and G_p = 512 respectively. It is observed that there is a significant improvement in the value of number of users for higher order of processing gain.

3.4 Performance Evaluation of a MC-DS-CDMA Wireless Communication System with Rake Receiver Employing EGC under Nakagami-m Fading Environment

Performance parameter of BER in case of Nakagami-m fading environment employing EGC has been plotted in Fig.3.16 .Here the figure is plotted without receive diversity (P = 1).BER versus number of simultaneous users is plotted with Nakagami order, m = 4, SNR = 30dB, L_r = 1. The processing gain of G_P = 64,128,256 and 512 is used to plot this curve.

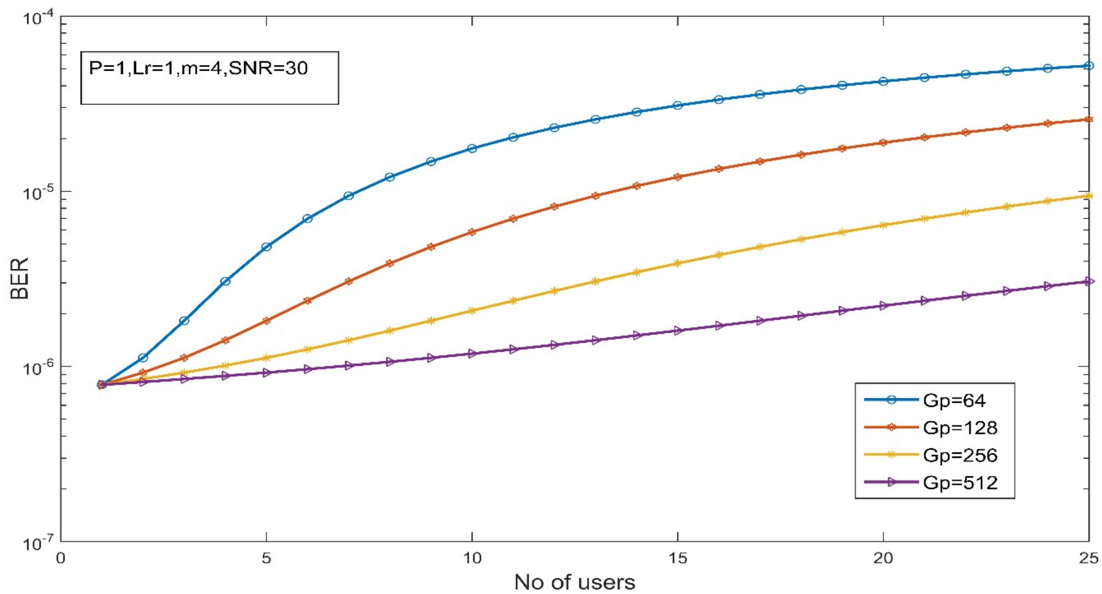

Fig.3.16 Plots of BER versus number of simultaneous users in Nakagami fading channel with ECG equalization for different processing gain, G_p = 64,128,256,512 for a MC-DS-CDMA wireless communication system without receive diversity (P = 1) with Nakagami order m = 4 at number of Rake finger L_r = 1

It is evident from the curve that as the number of users increases BER increases. But for the higher order of processing gain BER did not show increasing trend. For example, a processing gain of G_p = 64, the BER increases from 4.75×10^{-6} to 5.20×10^{-5} when the number of user increases from 5 to 25.In contrast when G_p = 512, the BER increases slightly from 9.25×10^{-7} to 3.058×10^{-6} for the same increment of users. Also it is clear from the curve that as the processing gain increases BER decreases. For example for no. of users, K = 25 and G_P = 64 the BER is 5.20×10^{-5}whereas it reduces to 3.058×10^{-6} keeping other parameters constant.

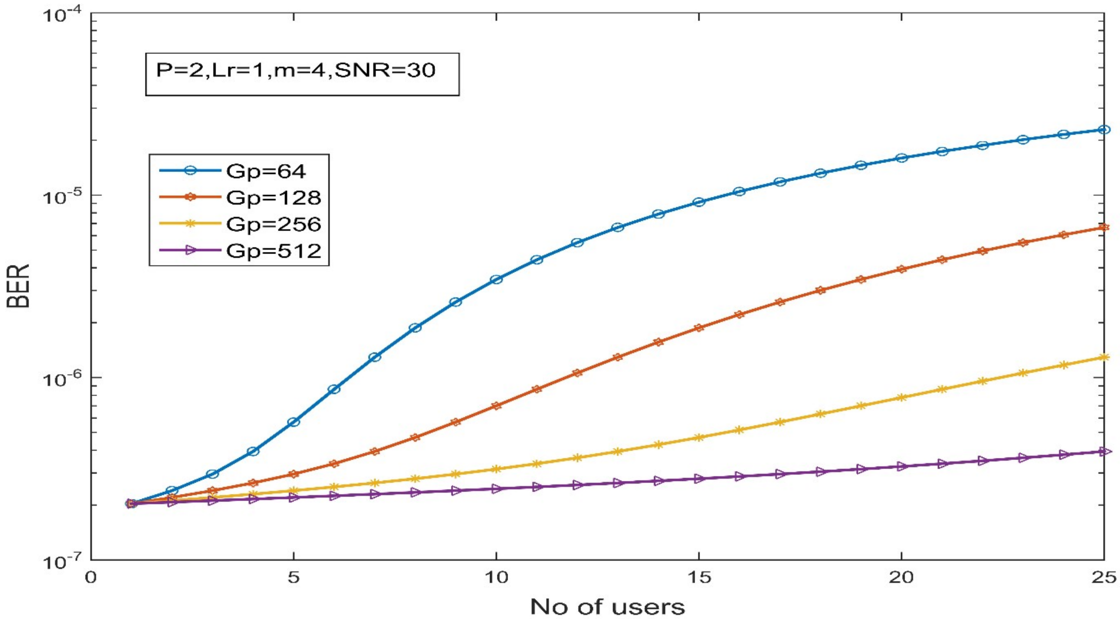

Fig.3.17 Plots of BER versus number of simultaneous users in Nakagami fading channel with ECG equalization for different processing gain, G_p=64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P = 2) with Nakagami order m =4 at number of Rake finger L_r = 1.

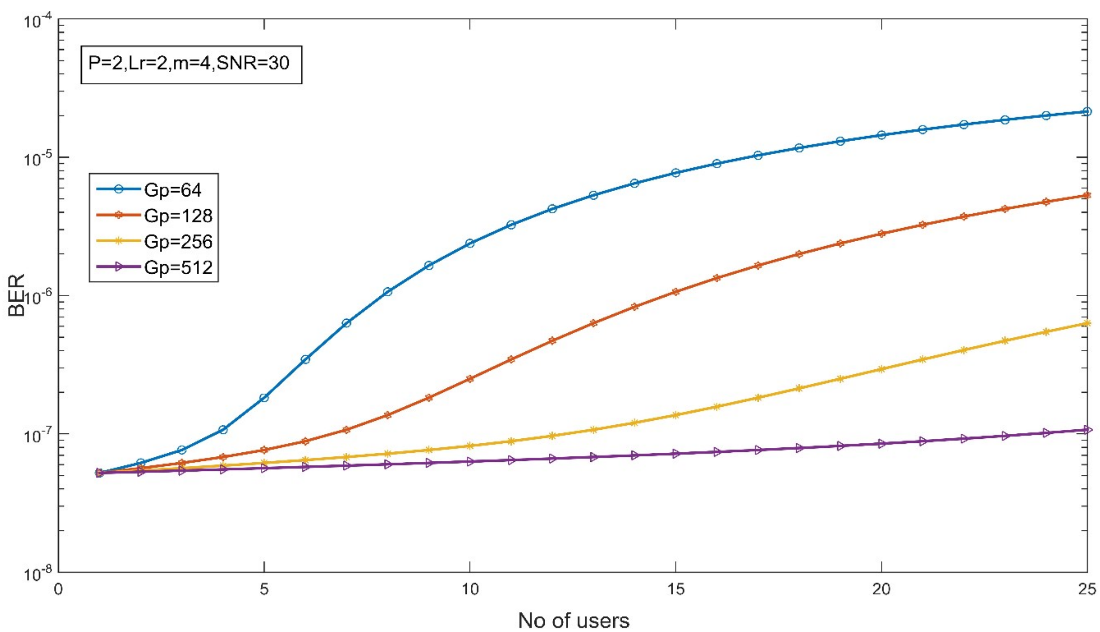

Fig.3.18 Plots of BER versus number of simultaneous users in Nakagami fading channel with ECG equalization for different processing gain, G_p=64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P=2) with Nakagami order m = 4 at number of Rake finger L_r = 2.

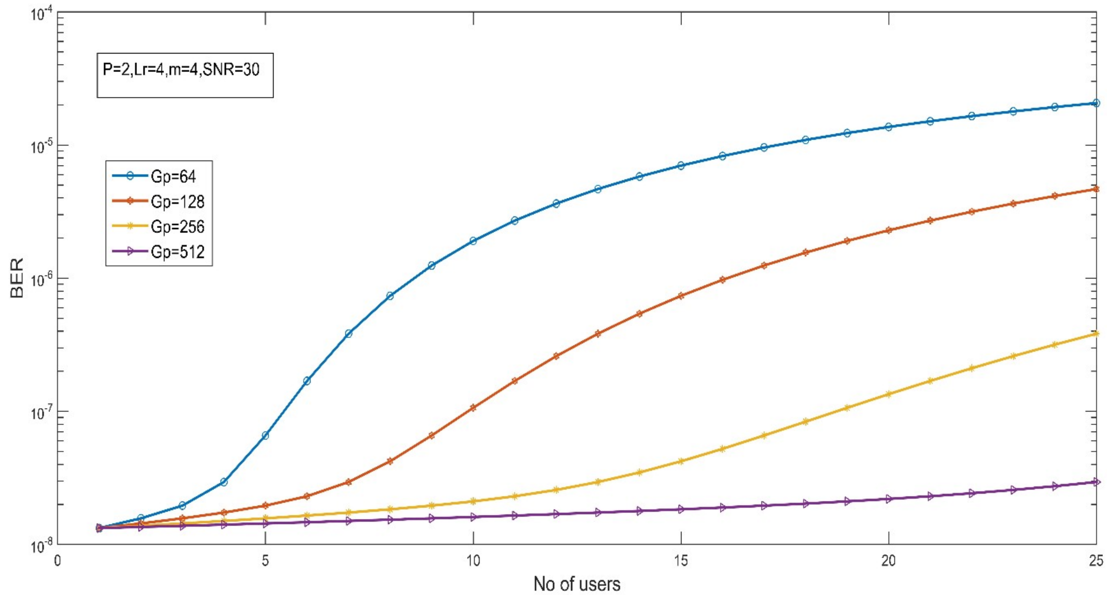

Fig.3.19 Plots of BER versus number of simultaneous users in Nakagami fading channel with ECG equalization for different processing gain, G_p=64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P=2) with Nakagami order m=4 at number of Rake finger L_r =4.

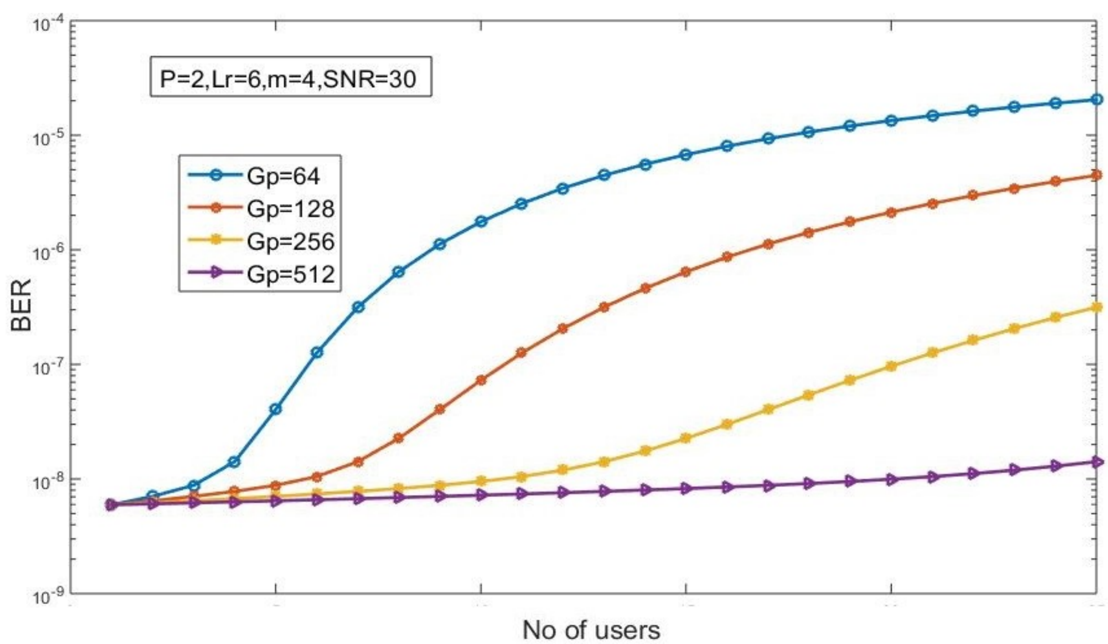

Fig.3.20 Plots of BER versus number of simultaneous users in Nakagami fading channel with ECG equalization for different processing gain, G_p= 64,128,256,512 for a MC-DS-CDMA wireless communication system with receive diversity (P =2) with Nakagami order m = 4 at number of Rake finger L_r =6.

In Fig.3.16 to Fig.3.20, the BER is plotted for different combinations of rake finger L_r. SNR = 30, m = 4 and L_r= 1, 2, 4 and 6 are used to plot the curve of Fig. 3.17, Fig3.18, Fig.3.19 and Fig.3.20 respectively. Each figure is plotted with various processing gain, G_P = 64, 128,256 and 512.It is noticed that as the number of rake fingers increases, the BER decreases for lower values of users. For example with L_r = 1 and number of user in between 0 to 5, BER level found at below 10^{-6} whereas with L_r=6, BER level found at below 10^{-8} for the same number of users. Again for the higher values of users, BER increases in smaller values of processing gain. It is evident from the graph that for higher values of rake fingers and processing gain BER level reduces for higher values of users. For example, in Fig.3.17, the BER level occurs at $2.28x10^{-5}$ for L_r= 1 and G_P =64 with no. of users, K =25. In contrast in Fig.3.20 the BER level occurs at $1.41x10^{-8}$ for L_r = 6 and G_P = 512 with equal number of users K =25. It is also noticed that in Fig. 3.20 the BER level remained almost constant as the number of user increases from 5 to 25 with G_p=512. For K =5, BER = $6.457x10^{-9}$ and for K = 25, BER = $1.409x10^{-8}$ keeping other parameter constant. This shows a very slight increase in BER indicating the improvement in system performance for higher values of processing gain and rake fingers.

3.5 Effects of Varying Nakagami-m Fading Order for a MC-DS-CDMA Wireless Communication System with Rake Receiver and Receive Diversity

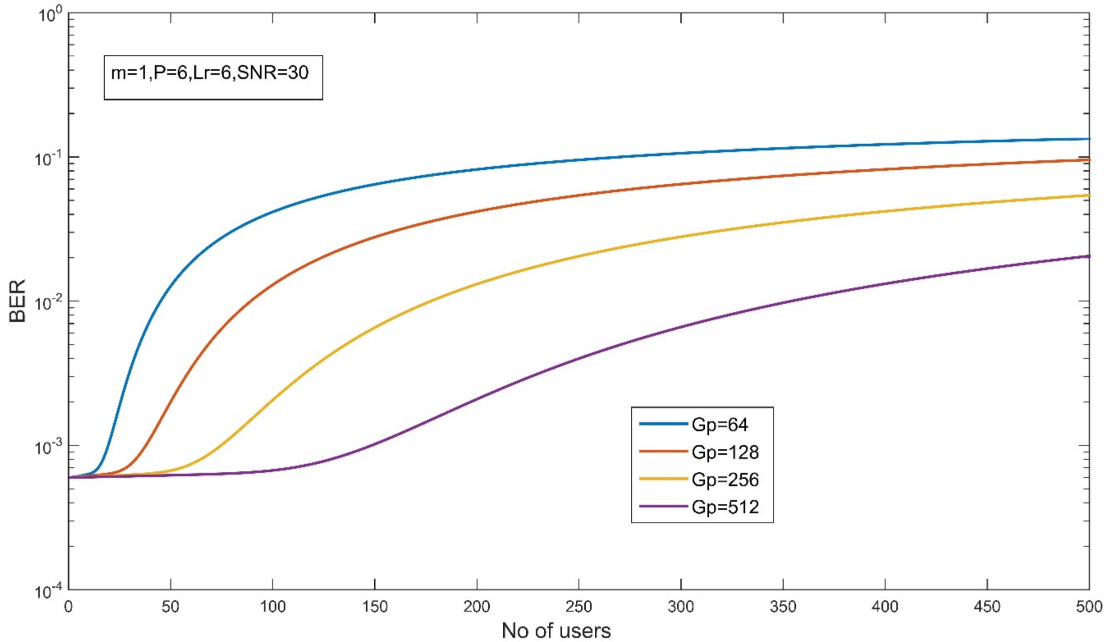

Fig.3.21 Plots of BER versus number of simultaneous users a Nakagami fading channel with MRC equalization at m = 1.

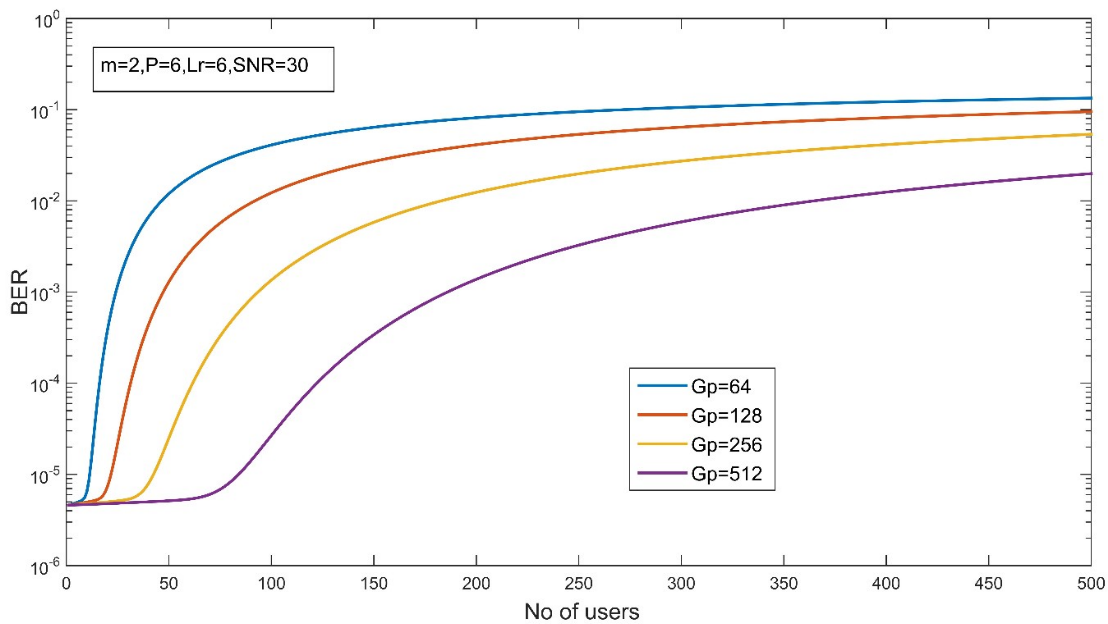

Fig.3.22 Plots of BER versus number of simultaneous users in a Nakagami fading channel with MRC equalization at m = 2.

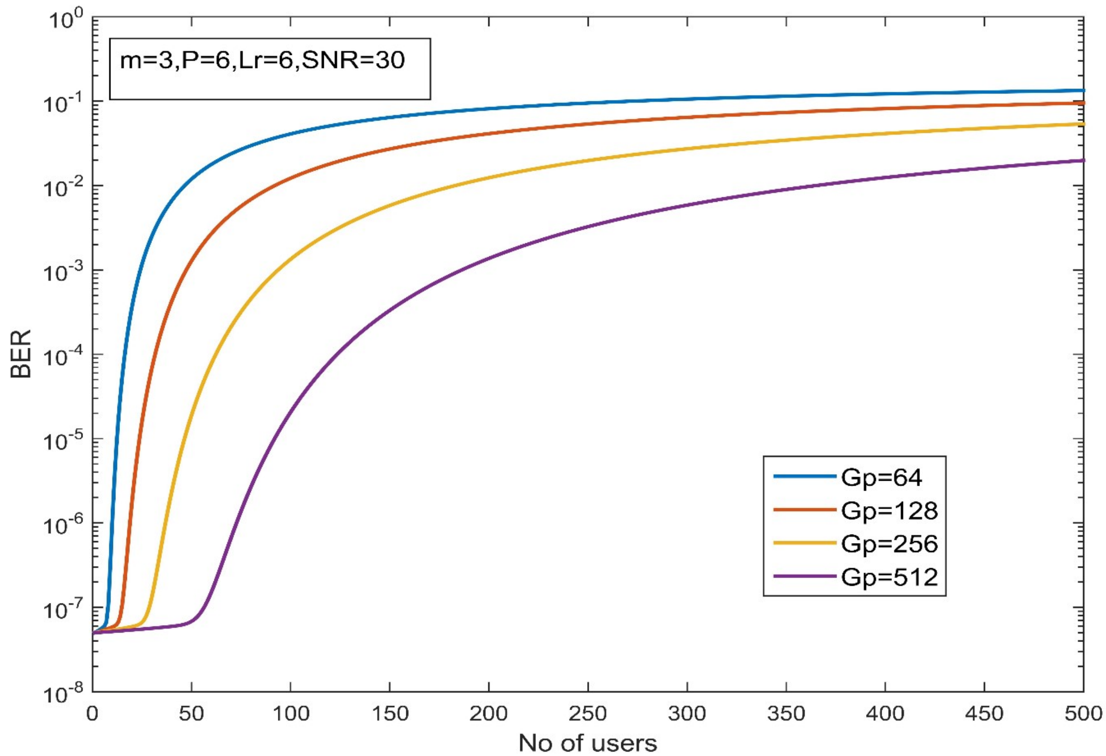

Fig.3.23 Plots of BER versus number of simultaneous users in a Nakagami fading channel with MRC equalization at m = 3

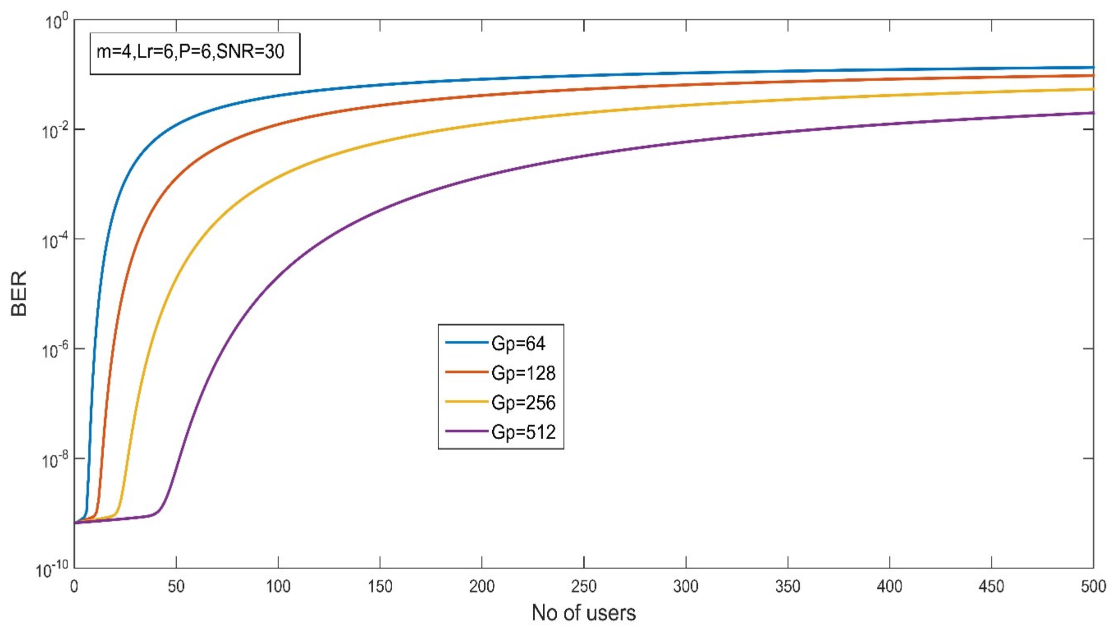

Fig.3.24 Plots of BER versus number of simultaneous users in a Nakagami fading channel with MRC equalization at m = 4

In Fig 3.21 to Fig. 3.24, the variation of BER with the number of simultaneous users are plotted using P= 6, Lr = 6,SNR = 30 with different processing gain G_p = 64, 128, 256 and 512.Here, the value of fading parameter, m = 1, 2, 3 and 4 are used to plot Fig.3.21, Fig. 3.22, Fig. 3.23 and Fig. 3.24 respectively. From all these curves it is evident that as the number of simultaneously active user increases BER of the system increases indicating the degradation of the system performance. As the MAI increases with the increase of simultaneously active user, BER increases consequently. It is also observed that BER decreases with the increase of fading parameter, m. The value of m indicates the severity of the fading of the channel. Higher values of m indicates less severe fading. Thus BER decreases with the increase of the value of m. From the graph of Fig.3.21, it is evident that BER>10^{-4} is achievable with m = 1, P = 6, Lr = 6, SNR = 30 whereas BER >10^{-10} is achieved with m = 4 keeping other parameters constant. So it is noticed that for higher values of m BER decreases which indicates the improvement in system performance.

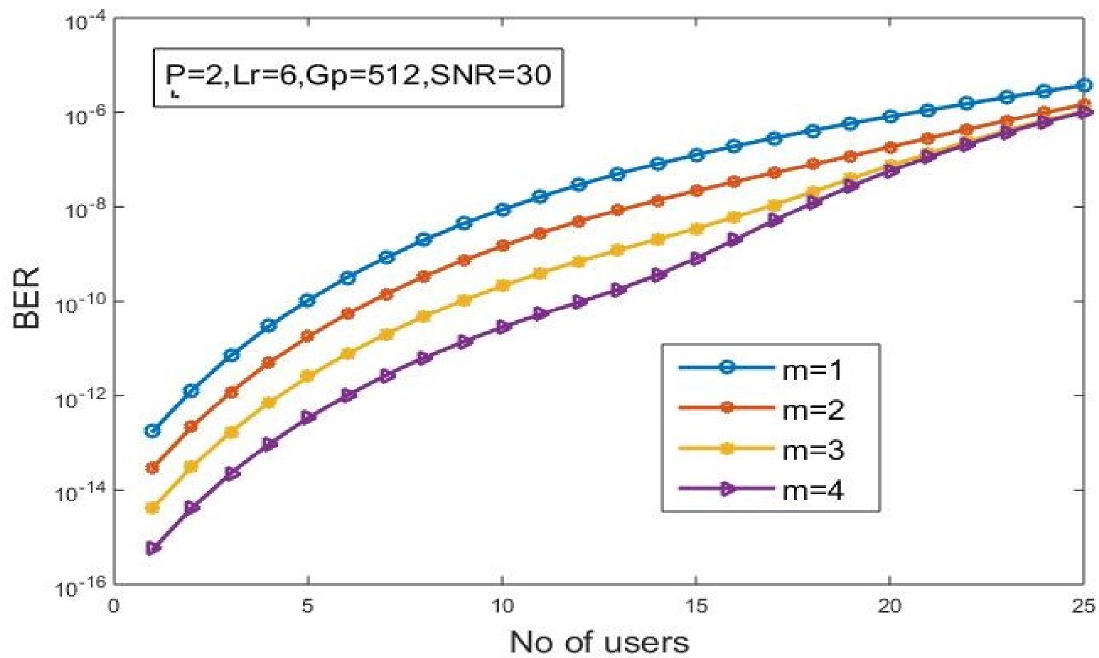

Fig.3.25 Plots of BER versus number of simultaneous users in Nakagami fading channel with m =1, 2, 3 and 4 with a fixed processing gain, G_p= 512

The variation of BER with the number of user is shown in Fig.3.25. The curve is plotted with a fixed processing gain of G_p=512 with various Nakagami-m fading order of m=1, 2, 3 and 4 P=2, L_r=6, SNR=30 dB are used to plot the curve .It is noticed that as the Nakagami-m fading order, m increases, the BER decreases. For example with m=1and no. of user in between 0 to 5, BER level found at below 10^{-12} whereas with m = 4, BER level found at below 10^{-14} for the same number of users. Also it is evident from the graph that for m=1, BER = 3.68×10^{-6} with number of users, K=25 whereas it reduces to 9.987×10^{-7} for equal number of users keeping other parameters constant. Therefore the decrease in BER level indicates the improvement in system performance.

The BER curves of m=3 and m=4 lie with each other in an imbricated manner for higher values of users resulting in no significant difference in BER levels. For example, for m=3 and m=4, the BER level found at $9.987 \times 10^{-7}$for equal number of users, K=25.

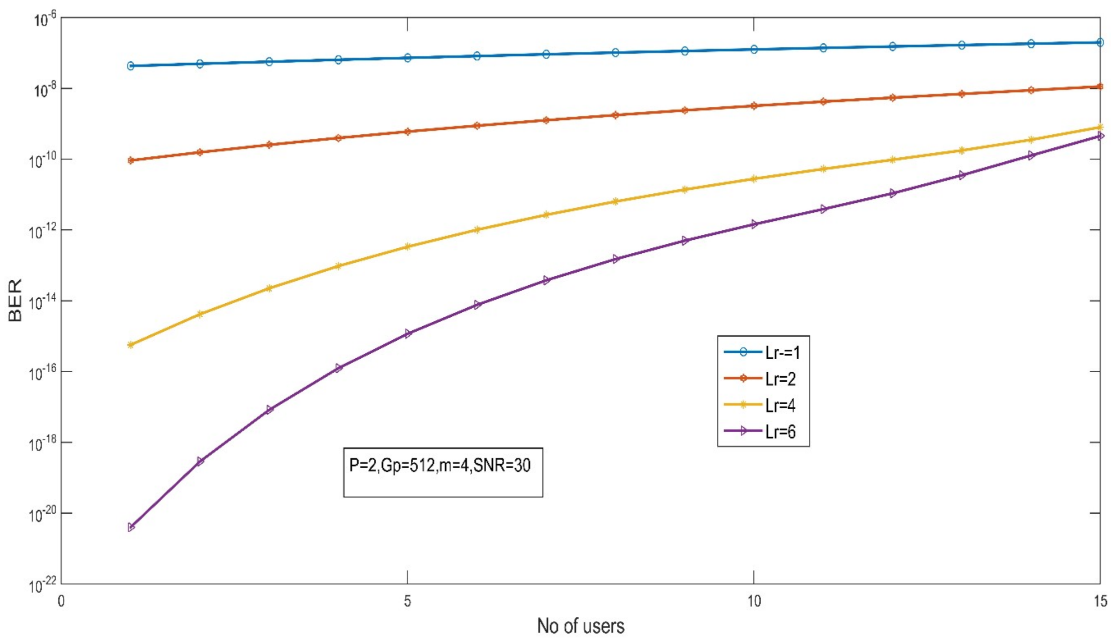

Fig.3.26 Plots of BER versus number of simultaneous users in Nakagami fading channel with L_r =1, 2, 3 and 4

BER in case of MC-DS-CDMA system has been plotted in Fig.3.22 with the number of users. The curve is plotted with a fixed processing gain of G_p=512 with different number of rake fingers, L_r = 1, 2, 4 and 6.The curve is plotted with the parameter of P = 2, L_r = 6, SNR = 30 dB and m = 4. It is evident from the curve that that as the number of rake fingers increases, the BER decreases. For example a MC-DS-CDMA system without rake receiver that is with L_r=1 BER level found at 1.99 $\times 10^{-7}$ for number of user, K= 15. In contrast BER level found at 4.52×10^{-10} with Lr=6 for equal number of users. Thus the reduction in BER level indicates the improvement in system performance with increase in rake fingers at a fixed processing gain.

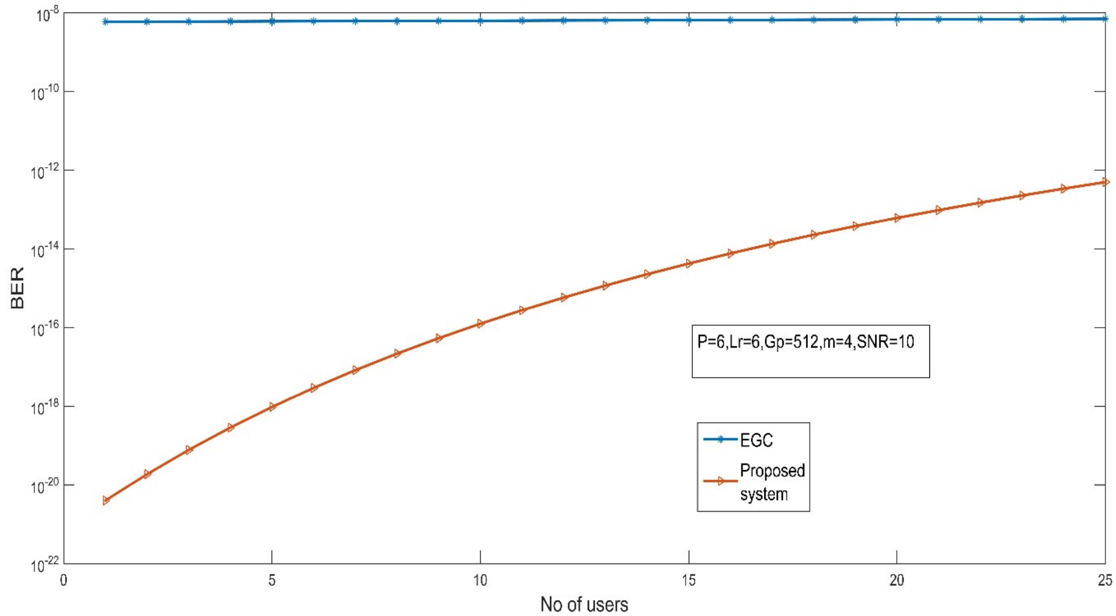

Fig.3.27 Plots of BER versus number of simultaneous users in Nakagami fading channel with EGC and proposed system.

In Fig.3.27 the BER is shown as a number of active users in a Nakagami-m fading channel for EGC and our proposed system based on MRC. The figure is plotted at a fixed processing gain of G_p=512 for different values of fading parameter such as h =1 and h=170 respectively. Two important observations is evident from the figure. From the figure, it is evident that BER estimation for EGC remains constant for specified number of users. On the other hand, in our proposed system using MRC the BER level found at below 10^{-12} whereas for EGC the level found at 10^{-8} for a specified number of users, K=25.Also in our proposed system the BER level decreases significantly for lower number of users. For example, for K=5 the BER level found at 10^{-18} whereas for K=25 the BER level found at 4.989×10^{-13}. Thus our proposed system using MRC outperforms EGC in a Nakagami-m fading channel for a MC-DS-CDMA wireless communication system.

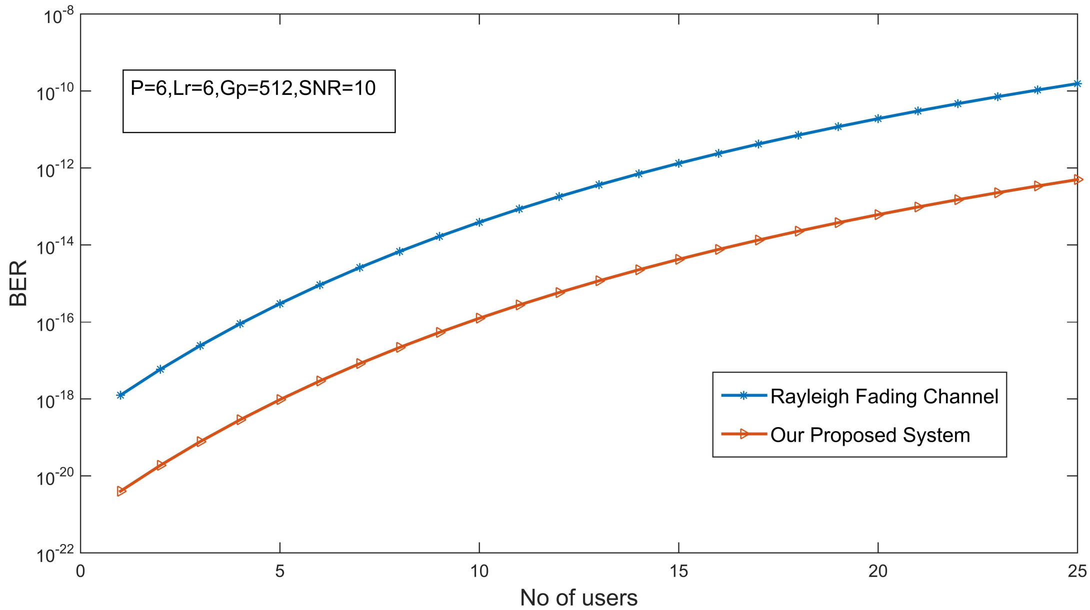

Fig.3.28 Plots of BER versus number of simultaneous users in Rayleigh fading channel with proposed system

In Fig.3.28 the BER is shown with a number of active users for a MC-DS-CDMA wireless communication system using OFDM in a Rayleigh fading channel and our proposed system in Nakagami-m fading channel. The figure is plotted at a fixed processing gain of G_p=512, P = 6, L_r = 6, SNR = 10 dB. In this figure the BER versus number of simultaneous users is plotted in a Rayleigh fading channel using, m=1 and Nakagami-m fading channel using m=4 respectively. It is evident from the figure that the BER level reduces by an order of magnitudes in Nakagami-m fading channel instead of Rayleigh fading channel. In Rayleigh fading channel the BER level found at 1.55×10^{-10} for number of users, K=25 whereas it reduces to 4.98×10^{-13} for equal number of users. Thus it is evident that BER estimation in Nakagami-m fading channel is much lower than that of Rayleigh fading channel specified number of users. Therefore our proposed system using Nakagami-m fading channel exhibits better performance than that of Rayleigh fading channel.

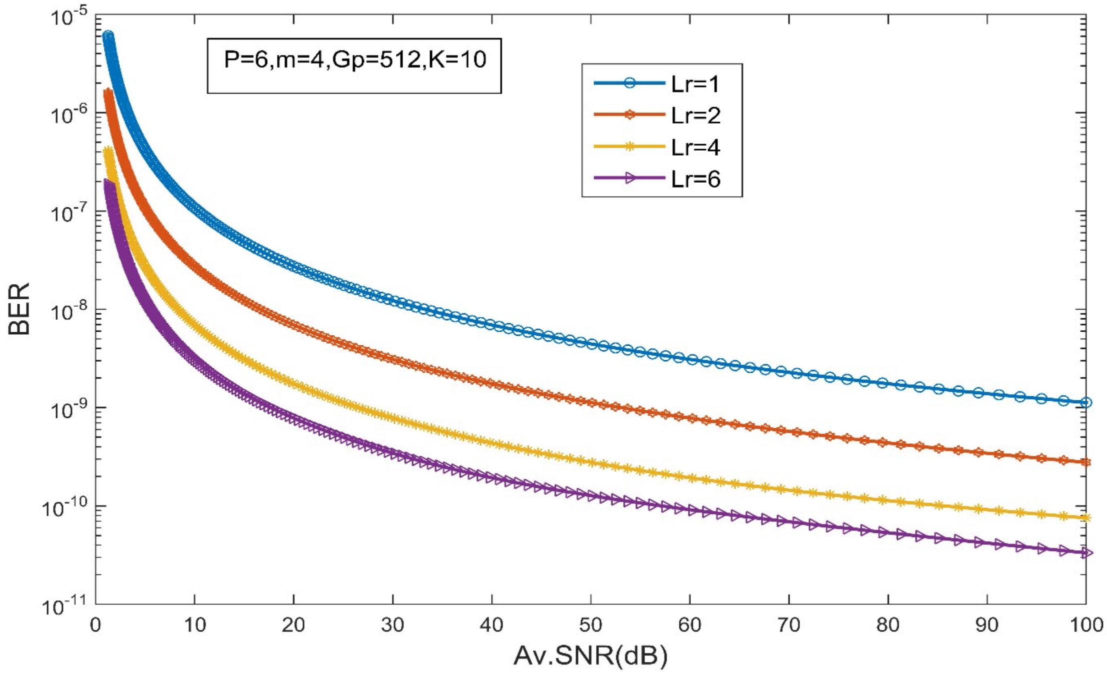

Fig.3.29. Plots of BER versus Av.SNR (dB) in Nakagami fading channel with P = 6 and $G_{p=}$ 512 with different number of Rake fingers, L_r = 1, 2, 4, 6

Fig.3.29 illustrates the variation of BER with Av. SNR (dB). The curve is plotted with different number of rake fingers, $L_{r=}$ 1, 2, 4 and 6.The curve is plotted with the parameter of P = 6, K = 10, G_p = 512 and m = 4. It is evident from the curve that as the number of rake fingers increases, the BER decreases. For example, for L_r = 1, the BER level found at $1.126x0^{-9}$ for Av. SNR (dB) = 10^2. In contrast BER level found at 3.25 x 10^{-11} with L_r = 6, for the same value of Av. SNR (dB). BER reduces significantly as the number of rake fingers increases from 1 to 6. Thus the reduction in BER level for increment in rake fingers indicates the improvement in system performance.

CHAPTER 4

CONCLUSION AND SCOPE OF FUTURE WORK

4.1 Conclusion

In this thesis, the BER performance of a multicarrier direct sequence CDMA (MC-DS-CDMA) wireless communication system is analyzed over Nakagami-m fading environment employing Rake receiver with and without receive diversity. Analysis is presented for a MC-DS-CDMA wireless communication system with rake receiver for each OFDM sub channels to deduce the expressions of Multi-access interference (MAI), Signal to interference plus noise ratio (SINR) and Average Bit Error Rate (BER) considering Maximal Ratio Combining (MRC) technique. Here the significance of Rake receiver, receive diversity and processing gain on BER performance are observed for Nakagami-m fading channel. Bit error rate is numerically evaluated for each OFDM sub band considering MRC for the rake combiner. Average BER results show that there is a significant improvement in BER performance with increase in Rake fingers.

It is observed that, there is an improvement in the BER performance as the number of rake finger increases. BER reduces by order of magnitudes with increase in the number of rake fingers. We also noticed that BER level reduces with the increase in the number of receiving antenna. For example, the BER level corresponding to P = 1, L_r = 4, k = 13 at the processing gain G_p=512 is 10^{-6} whereas it is reduced to 10^{-10} with P=2 over Nakagami-m fading channel.Again from numerical simulation we also noticed that there is a significant increase in the number of users with increase in the number of rake fingers along with increased processing gain.For example, at a fixed BER $= 10^{-6}$, the user corresponds to G_p = 512, P = 1, L_r = 1 is 3 whereas it increases to 14 when L_r = 6 keeping other parameters fixed.

4.2 Scope of Future Work

Thesis developed the framework for a MC-DS-CDMA system using Maximal Ratio Combining (MRC) technique with receive diversity. In this thesis Binary Phase Shift Keying (BPSK) has been considered as a modulation technique. Future research can be carried out for Quadrature Phase Shift Keying (QPSK) and 8 arrays PSK. Performance of a MC-DS –CDMA system can be improved by employing some forward error correction coding techniques like convolution coding and turbo coding along with space-frequency block code, space-time block code and combination of both. Also the performance of a multiple input multiple output (MIMO), multi-tone CDMA (MT-CDMA) system over Nakagami-m fading channel can be the scope of future works.

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