Performance of Wireless DS-CDMA System with Fading

A Thesis Submitted by

Nigar Sultana   **200616026**

Himika Rahman   **200616032**

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Department of Electrical, Electronics and Communication Engineering

Military Institute of Science and Technology

Dhaka – 1216, Bangladesh

DECLARATION OF THE CANDIDATE

This is to certify that the work presented in this particular report is an outcome of the project work carried out by Nigar Sultana, student number 200616026 and Himika Rahman, student number 200616032, of department of Electrical, Electronics and Communication Engineering under the supervision of Dr. Satya Prasad Majumder, Professor of department of Electrical and Electronic Engineering, BUET.

This report was not submitted anywhere for the award of any degree or diploma or publication.

Signature of Supervisor

_____

Dr. Satya Prasad Majumder

Professor

Department of Electrical and Electronic Engineering

BUET, Dhaka.

Signature of the Authors

_____

Nigar Sultana   Student No. 200616026

_____

Himika Rahman   Student No. 200616032

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GLOSSARY AND ACRONYMS

AM	Amplitude Modulation
ASK	Amplitude Shift Keying
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CDM	Code Division Multiplexing
CDMA	Code Division Multiple-Access
DS-CDMA	Direct Spread Code Division Multiple-Access
DSSS	Direct Signal Spread-Spectrum
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple-Access
FM	Frequency Modulation
FSK	Frequency Shift Keying
GSM	Global System for Mobile Communication
ISI	Inter-Symbol Interference
MAI	Multiple Access Interference
MATLAB	Matrix Laboratory
MC-CDMA	Multi-Carrier Code Division Multiple-Access

M-PSK	Modulation Phase Shift Keying
MUI	Multi-User Interference
PM	Phase Modulation
PN	Pseudorandom Noise
PSD	Power Spectral Density
PSK	Phase Shift Keying
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RA	Random Access
RMS	Root Mean Square
SINR	Signal to Interference and Noise Ratio
SNR	Signal-to-Noise Ratio
TDM	Time Division Multiplexing
TDMA	Time Division Multiple-Access
TMA/FMA	Time/Frequency Multiple-Access
W-CDMA	Wireless Code Division Multiple Access
WDM	Wavelength Division Multiplexing

NOMENCLATURE

f_c	Frequency of Carrier Signal
f_m	Frequency of Information Signal
A_c	Amplitude of Carrier
A	Root Mean Square (RMS) Amplitude
$V_b \ or \ d_k(t)$	Baseband Signal
V_{am}	Amplitude modulated Transmitted Signal
V_{fm}	Frequency modulated Transmitted Signal
F_d	Doppler Shift
T_b	Bit Interval
T_c	Bit Interval
$\Pi(t/T_b)$	Rectangular Pulse
$a_k(t)$	Spreading Signal
$P_{Tc}(t)$	Chip Pulse Waveform
$x_k(t)$	Band Pass Signal
$\emptyset$	PSD
E_c	Chip Energy
E_b	Bit Energy
I(t)	Inter-cell Interference
w(t)	Background White Gaussian Noise with Zero Mean
n(t)	Baseband Gaussian Noise
a(t)	De-spreading Signal

y(t)	Demodulator Output
d(t)	Original Baseband Signal
P	Average Power
f_b	Transmission Bit Rate
N_0	Noise Spectral Density
C	Carrier Power
T	Ambient Temperature
k	Boltzmann's Constant
F	Noise Factor
P_d	Desired Signal Power
bn(t)	Bernoulli Distributed
Z_0	Gaussian Random Variable
I_0	Deterministic or two-sided PSD
P	Probability
M	Modulation Order or User Number
r (t)	Received Signal
α	Factor That Controls Path Loss
K	Rice factor

ABSTRACT

This paper develops and models a DS-CDMA wireless network by simulation. It present an over view of CDMA transmission systems as compared to other multiple access schemes. The channel parameters and channel conditions are varied and the performance studied. The investigation of spreading, modulation and coding is carried out. BPSK modulation techniques are used to see the performance of the system when each is used. The BER is used as a tool to monitor the system output as SNR is varied. The AWGN channel is used in the simulation. The simulation starts with a single user and later the number of users is increased and the results evaluated. The final results are compared to the theoretically calculated results and finally concluded.

Chapter: One

Introduction to Communication System

1.1 Introduction

A communication system is the combination of circuits and devices put together to accomplish the transmission of information from one point to another. There are many different types of information sources and there are different forms for messages. In general, messages may be classified as analog or digital. Analog messages (such as speech, music, temperature...etc) are represented by continuous-time variables while discrete messages (such as text or numeric data) are represented by discrete symbols. Often the message produced by an information source is not suitable for transmission and therefore an input transducer must be used. For example, a microphone converts speech (i.e. the message signal) from a pressure wave to an electrical voltage and the message is represented by an analog waveform. In other examples, the analog signal voltage is proportional to temperature, pressure or light intensity. In a digital signal, discrete values of voltage represent various states of the message source. For example, a computer keyboard can generate more than 100 discrete symbols.

For any communication system to be useful, three main parts are essential. These parts are shown in Figure 1.

Information in (Source) → TX → Transmission Channel → RX → Information out (Destination)

Noise Interference Distortion
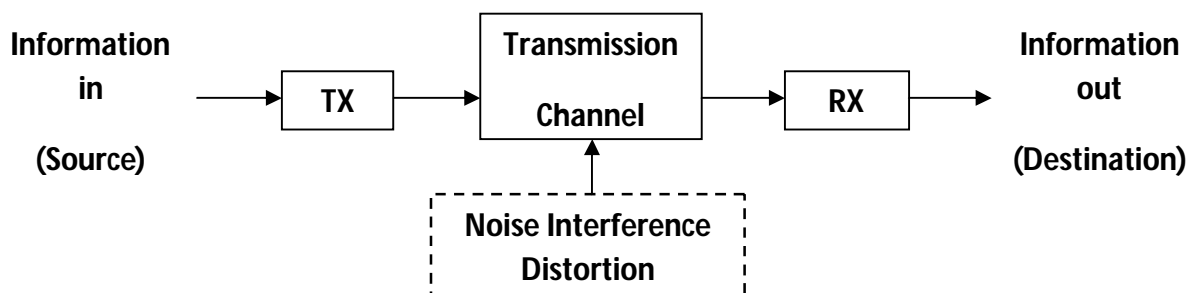
Figure 1: Basic Parts of a Communication System

A transmitter is used to couple the message signal to the transmission medium (i.e. the channel). The transmitter may simply filter, amplify and couple the signal to the medium or it may impose the message signal on a higher frequency carrier wave. The message signal is used to modulate the carrier wave. Use of the higher frequency carrier facilitates wireless radio transmission.

The channel includes the transmission medium and it may introduce noise and distortion. Example channels are coaxial cable, twisted wire, optical fiber or the free space between transmitting and receiving radio antennas.

The receiver extracts the message signal from the received signal and then converts it to a form suitable for the output transducer. The extraction process usually includes amplification, filtering and demodulation.

The output transducer completes the communication system by converting the electric signal to the form desired by the user. Examples of output transducers are loudspeakers, meters, television screens and computer display screens.

1.2 Basic Block Diagram of a Communication System
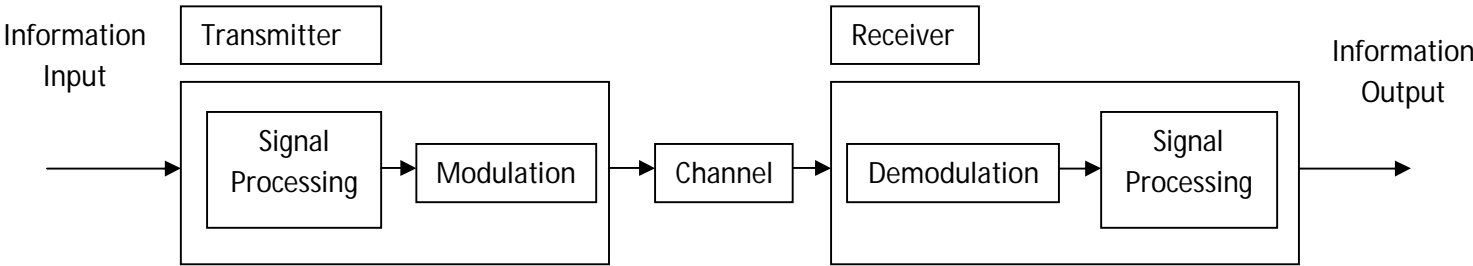
Figure 2: Basic Block Diagram of a Communication System
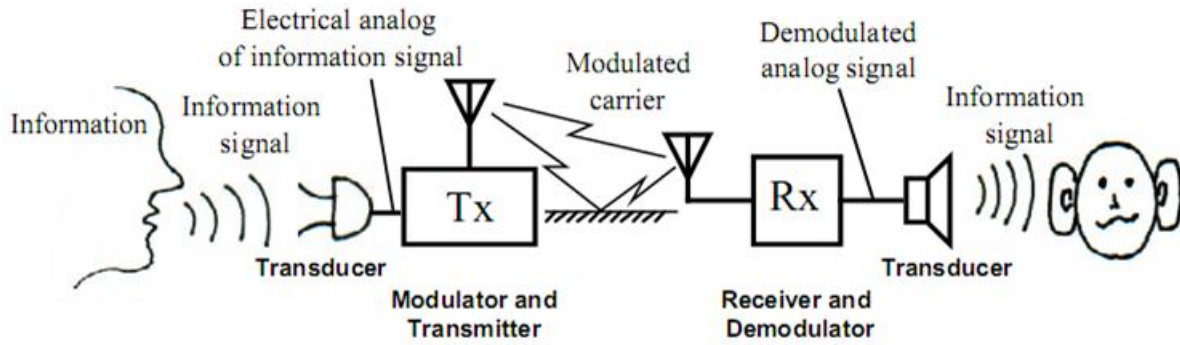
Figure 3: Block diagram of a Analog Communication System
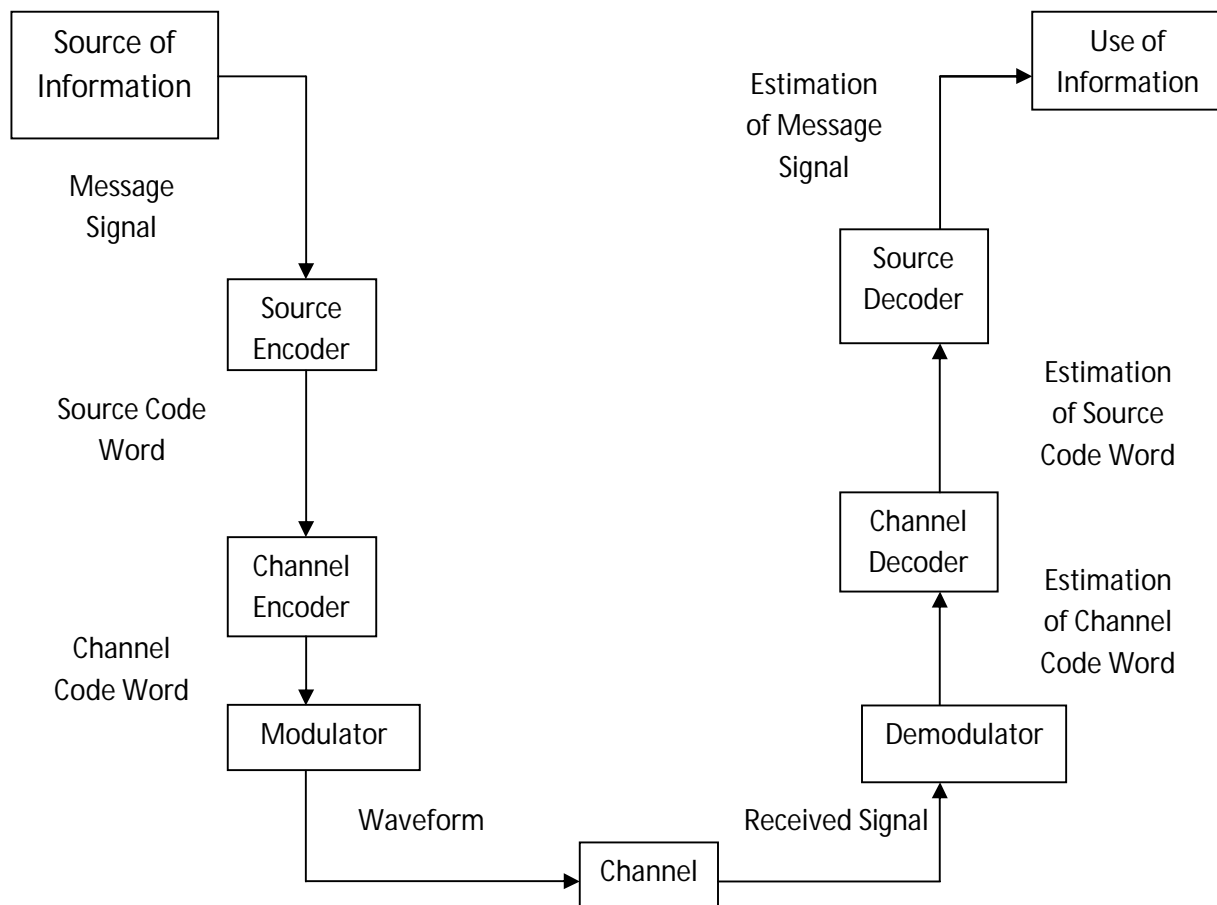
Figure 4: Block diagram of a Digital Communication System

1.3 Different Types of Communication System

Communication systems are mainly two types. These are:

⊕ Digital Communication System

⊕ Analog Communication System

Now these are discussed briefly:

⊕ Digital Communication System:

The transmission of digital data through a digital platform that has the ability to combine text, audio, graphics, video and data. Digital communication enables data to be transmitted in an efficient manner through the use of digitally encoded information sent through data signals. These data signals are easily compressed and, as such, can be transmitted with accuracy and speed.

Unlike in an analog communications where the continuity of a varying signal cannot be broken, in a digital communication a digital transmission can be broken down into packets as discrete messages. Transmitting data in discrete messages not only facilitates the error detection and correction but also enables a greater signal processing capability. Digital communication has, in large part, replaced analog communication as the ideal form of transmitting information through computer and mobile technologies.

⊕ Analog Communication System:

Analog Communication is a data transmitting technique in a format that utilizes continuous signals to transmit data including voice, image, video, electrons etc. An analog signal is a

variable signal continuous in both time and amplitude which is generally carried by use of modulation.

Analog circuits do not involve quantization of information unlike the digital circuits and consequently have a primary disadvantage of random variation and signal degradation, particularly resulting in adding noise to the audio or video quality over a distance.

Data is represented by physical quantities that are added or removed to alter data. Analog transmission is inexpensive and enables information to be transmitted from point-to-point or from one point to many. Once the data has arrived at the receiving end, it is converted back into digital form so that it can be processed by the receiving computer.

1.4 Different Types of Modulation

A Process by which characteristics of base band Signal is changed to suit the media is known as Modulation.

Types of Modulation:

- Analog Modulation
- Digital Modulation

Analog Modulation Techniques:

- Amplitude Modulation
- Frequency Modulation
- Phase Modulation

Digital Modulation Techniques:

- ASK(Amplitude shift Keying)
- FSK (Frequency shift Keying)
- PSK (Phase shift Keying)

Ξ Amplitude Modulation (AM):

In Amplitude modulation (AM), the information signal is mixed with the carrier signal in such a way as to cause the amplitude of the carrier to vary at the frequency of the information signal.

$$V_{am}(t) = A_c[1 + V_b(t)] \cos 2\pi f_c t$$

It is the most common form of modulation because of the ease with which the baseband signal can be recovered from the transmitted signal.
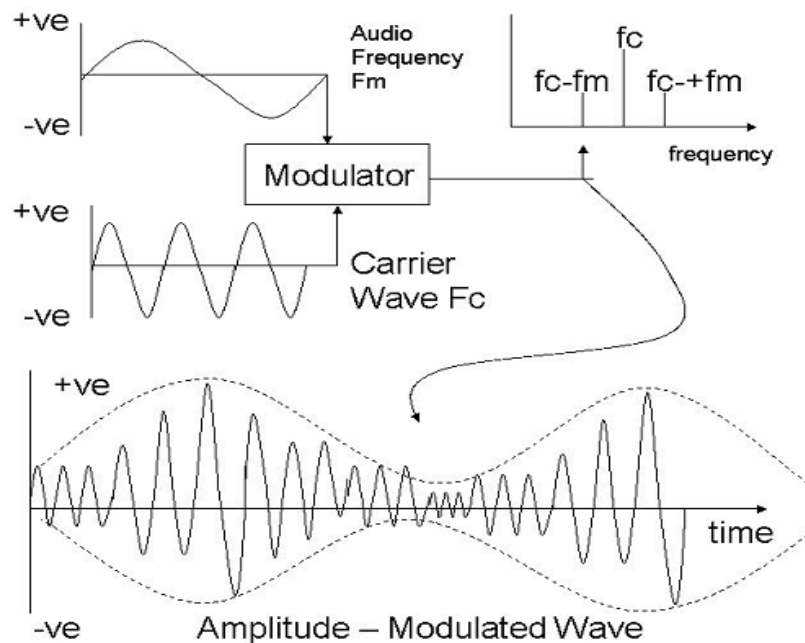
Figure 5: Amplitude Modulation

Ξ Frequency Modulation (FM):

A modulation technique in which the frequency of the carrier is varied in accordance with some characteristic of the baseband signal.

$$V_{fm}(t) = A_c \cos\left[\omega_c t + k \int_{-\infty}^{t} v_b(t)dt\right]$$

With frequency modulation, the modulating signal and the carrier are combined in such a way that causes the carrier frequency (f_c) to vary above and below its normal (idling) frequency.

Throughout this process the amplitude of the carrier is not affected. The carrier frequency change above and below that of the un-modulated condition is proportional to sign and amplitude of the modulating signal. The amplitude of the carrier remains constant as shown in figure below.
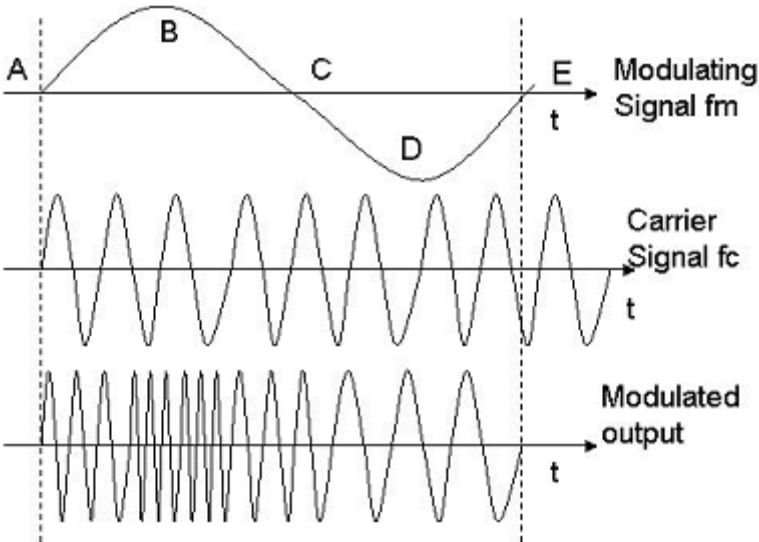
Figure 6: Frequency Modulation

Ξ Phase Modulation (PM):

Phase modulation is a type of frequency modulation. Here, the amount of the carrier frequency shift is proportional to both the amplitude and frequency of the modulating signal.

The phase of the carrier is changed by the change in amplitude of the modulating signal as shown in Figure below.
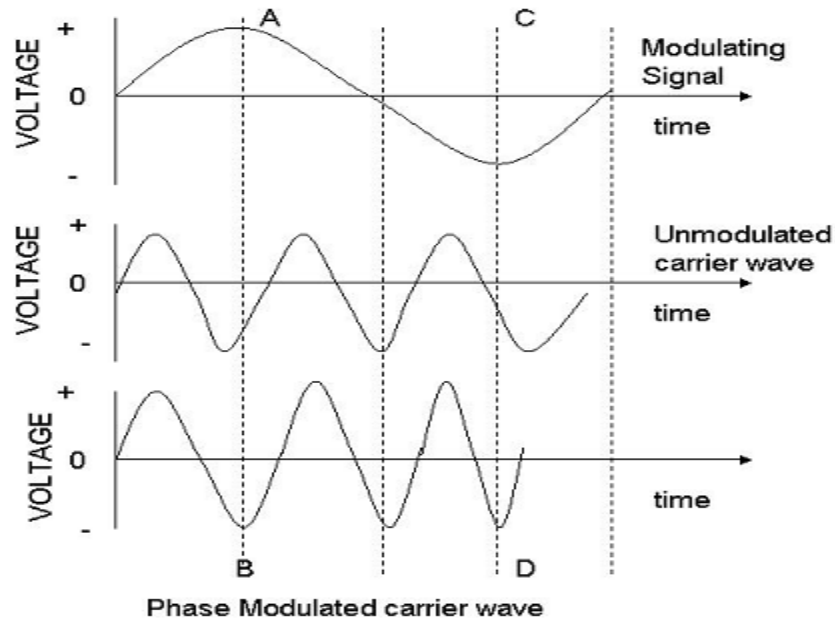
Figure 7: Phase Modulation

The modulated carrier wave is lagging the carrier wave when the modulating frequency is positive. This can be clearly seen if we concentrate on the peak amplitude along line AB (previous slide). When the modulating frequency is negative, the modulated carrier wave is leading the carrier wave. This can be seen clearly by looking at the peak amplitude along line CD.

Ξ Amplitude Shift Key (ASK):

In this method the amplitude of the carrier assumes one of the two amplitudes dependent on the logic states of the input bit stream. A typical output waveform of an ASK modulator is shown in Fig.
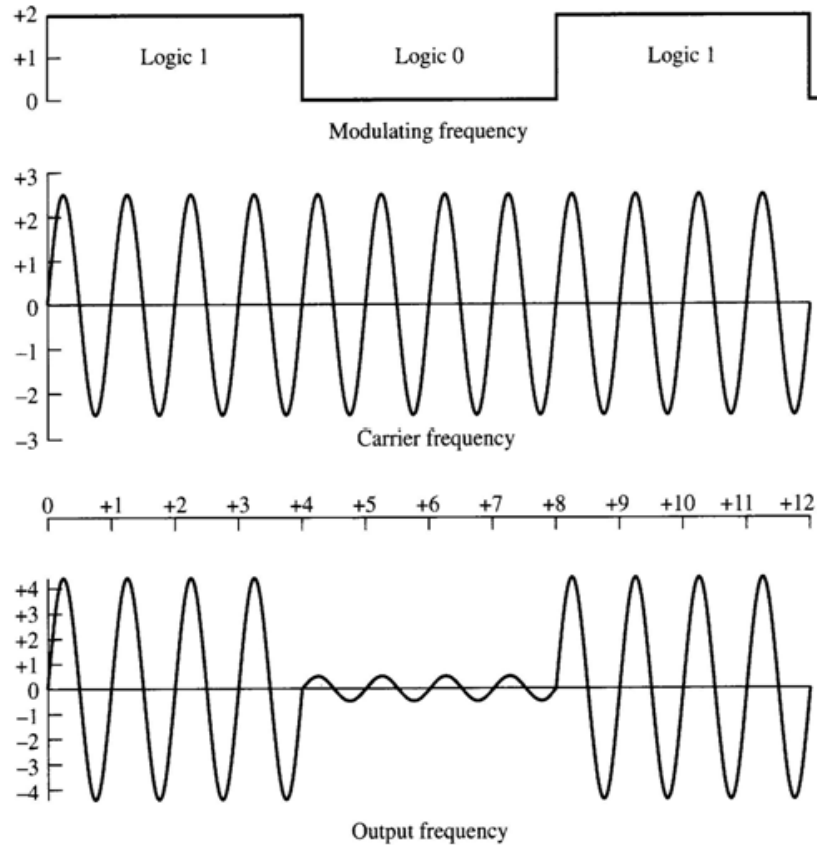
Figure 8: Amplitude Shift Key (ASK)

Ξ Frequency Shift Keying (FSK):

This modulation technique is the digital equivalent of linear FM where only two different frequencies are utilized. A single bit can be represented by a single cycle of the carrier, but if the data rate is not critical, then multiple cycles can be used Demodulation can be achieved by detecting the outputs of a pair of filters centered at the two modulation frequencies.
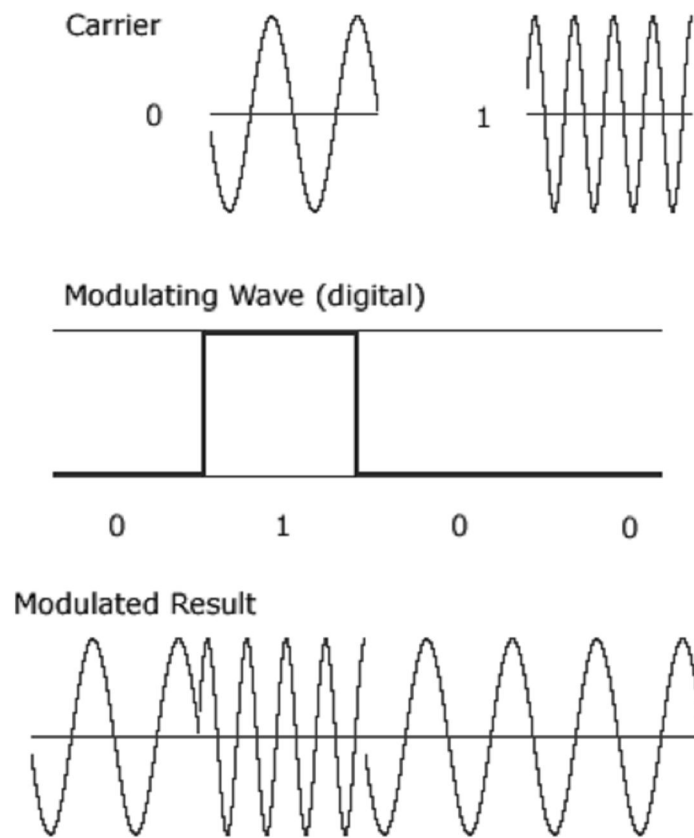
Figure 9: Frequency Shift Key (FSK)

Ξ Phase Shift Keying (PSK):

Usually in binary phase coding, the carrier is switched between +/-180°according to a digital baseband sequence. This modulation technique can be implemented quite easily using a balanced mixer shown, or with a dedicated BPSK modulator. Demodulation is achieved by multiplying the modulated signal by a coherent carrier (a carrier that is identical in frequency and phase to the carrier that originally modulated the BPSK signal).

This produces the original BPSK signal plus a signal at twice the carrier which can be filtered out.
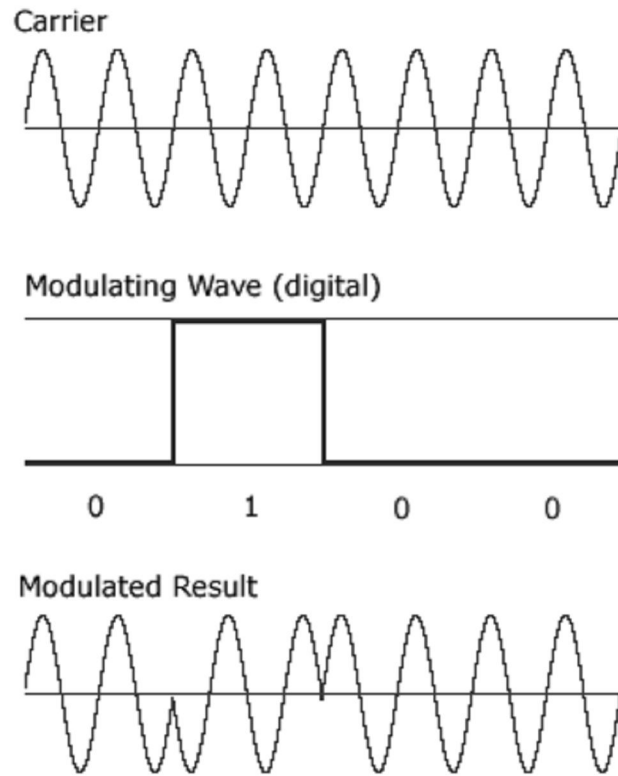
Figure 10: Phase Shift Keying (PSK)

1.5 Limitations of a Communication System

The concept of bandwidth applies to both signal and systems as a measure of speed. Now all electrical system contains energy-storage elements and stored energy cannot be changed instantaneously. Therefore, every communication system has a finite bandwidth B that limits the rate of signal variation. Insufficient channel bandwidth causes severe distortion.

Noise:

There are different types of noise which limits performance off communication system.

They are:

- **Internal Noise**

  - Thermal Noise
  - Shot Noise

External Noise

- Atmospheric Noise - due to lightning discharges (affects signals below 20 MHz)
- Galactic Noise - sun, interstellar radiation (affects signals within 15 MHz - 500 MHz)
- Man-made Noise - motors, neon signs, power lines

1.6 Different Types of Multiplexing Scheme

In telecommunications and computer networks, **multiplexing** (also known as **muxing**) is a process where multiple analog message signals or digital data streams are combined into one signal over a shared medium. The aim is to share an expensive resource.

- Frequency Division Multiplexing **(FDM)**
- Time Division Multiplexing **(TDM)**
- Wavelength Division Multiplexing **(WDM)**
- Code Division Multiplexing **(CDM)**

1.7 Multiple Accesses

- Frequency Division Multiple-Access **(FDMA)**
- Time Division Multiple-Access **(TDMA)**
- Time/Frequency Multiple-Access **(TMA/FMA)**

- Random Access **(RA)**
- Code Division Multiple-Access **(CDMA)**
    - ⊕ Frequency-Hop CDMA
    - ⊕ Direct-Sequence CDMA
    - ⊕ Multi-Carrier CDMA **(FH or DS)**

FDMA:

In FDMA, the bandwidth of the available spectrum is divided into separate channels, each individual channel frequency being allocated to a different active remote station for transmission. In order to reduce interference between users allocated adjacent channel bands, guard bands are used to act as buffer zones. The guard bands are necessary because of the impossibility of achieving ideal filtering for separating different users.
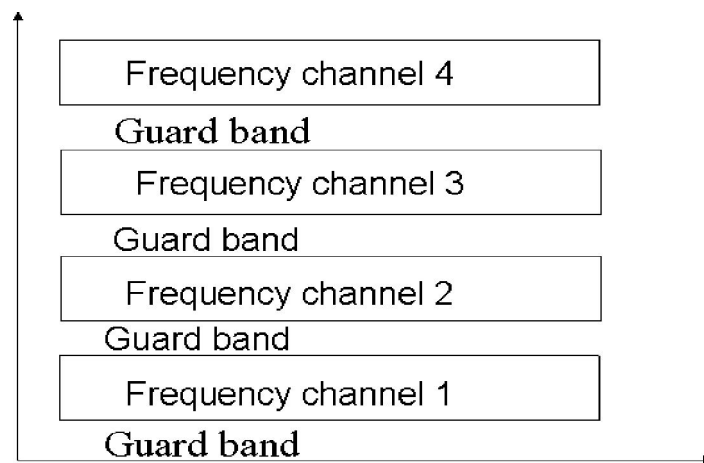
Figure 11: FDMA

TDMA:

In TDMA the same spectrum channel frequency is shared by all the active remote stations, but each is only permitted to transmit in short bursts of time (slots), thus sharing the channel between all the remote stations by dividing it over time (hence time division). Buffer zones in

the form of guard times are inserted between the assigned time slots to reduce interference between users by allowing for time uncertainty that arises due to system imperfections.
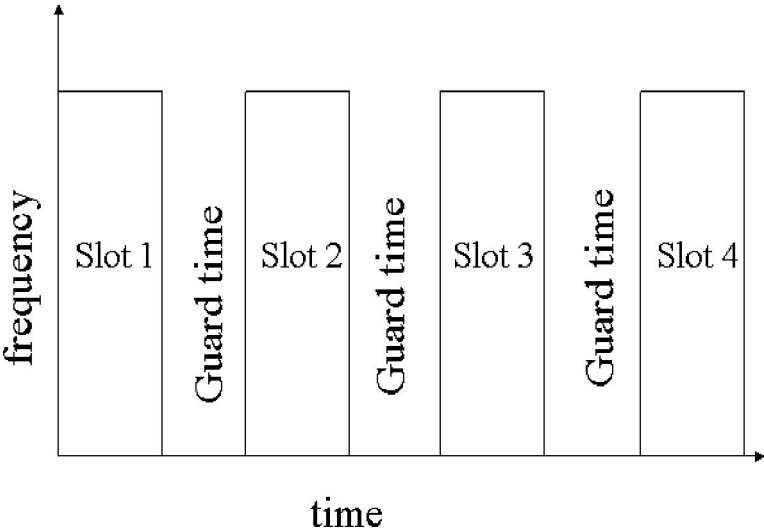
Figure 12: TDMA

CDMA:

In a CDMA system all users occupy the same frequency, and there are separated from each by means of a special code. Each user is assigned a code applied as a secondary modulation, which is used to transform user's signal into spread-spectrum-coded version of the user's data stream. The receiver then uses the same spreading code to transform the spread-spectrum signal back into the original user's data stream.
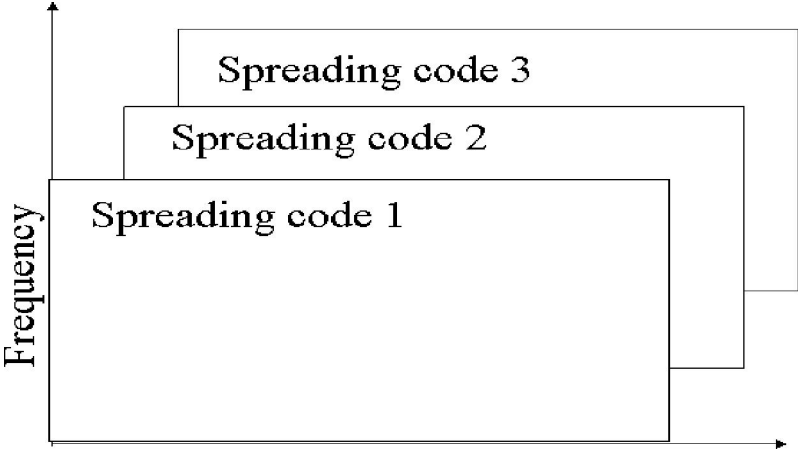
Figure 13: CDMA

1.8 Basic Form of a Wireless Communication System

Wireless communication is the transfer of information over a distance without the use of electrical conductors or wires. The distances involved may be short (a few meters as in television remote control) or long (thousands or millions of kilometers for radio communications). When the context is clear, the term is often shortened to "wireless". Wireless communication is generally considered to be a branch of telecommunications.

It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. There is a radio transmitter or receiver which is capable of being moved, regardless of whether it actually moves or not. Due to stochastic nature of mobile radio channel, its characterization mandates the use of practical measurements and statistical analysis. The aim of such an evolution is to quantify two factors of primary concern.

- ⊕ Median signal strength, which enables us to predict the minimum power needed to radiate from the transmitter so as to provide an acceptable quality of coverage over a predetermined service area.
- ⊕ Signal variability, which characterizes the fading nature of the channel.

Let us consider with cellular radio that has the inherent capability of building mobility into the telephone network. With such a capability, a user can move freely within a service area and simultaneously communicate with any telephone subscriber in the world. An idealized model of the cellular radio system consists of an array of hexagonal cells with a base station located at the centre of each call; a typical cell has a radius of 1-12 miles. The function of the base stations is to act as an interface between mobile subscribers and the cellular radio system. The base stations are themselves connected to a switching centre by dedicated wire lines.

The mobile switching center has two important roles. First, it acts as the interface between the cellular radio system and the public switched telephone network. Second, it performs overall

supervision and control of the mobile communications. It performs the latter function by monitoring the signal-to-noise ratio of a call in progress, as measured at the base station in communication with the mobile subscriber involved in the call. When the SNR falls below a prescribed threshold, which happens when the mobile subscriber leaves its cell or when the radio channel fades, it is switched to another base station. This switching process, called a handover or hand off, is designed to move a mobile subscriber from one base station to another during a call in transparent fashion, that is, without interruption of service.

The cellular concept relies on two essential features.

⊕ **Frequency Reuse:** The term frequency reuse refers to the use of radio channels on the same carrier frequency to cover different areas, which are physically separated from each other sufficiently to ensure that co-channel interference is not objectionable. Thus instead of covering an entire local area from a single transmitter with high power at a high evolution, frequency reuse makes it possible to achieve two commonsense objectives: ke4ep the transmitter power from each base station to a minimum, and position the antennas of the base station just high enough to provide for the area coverage of the respective cells.

⊕ **Cell Splitting:** When the demand for service exceeds the number of channel allocated to a particular cell, cell splitting is used to handle the additional growth in traffic within that particular cell. Specifically, cell splitting involved a revision of cell boundaries, so that the local area formerly regarded as a single cell can now contain a number of smaller cells and use the channel complements to these new cells. The new cells, which have a smaller radius than the original cells, are called microcells. The transmitter power and the antenna height of the new base stations are correspondingly reduced, and the same set of frequencies are reduced in accordance with a new plan.

1.9 Limitations of a Wireless Communication System

One of the major problems that present it is the already limited spectrum available for communications. The remaining free spectrum has to be used to its maximum potential, spread

spectrum technology presenting itself as a suitable means of increasing performance. Splitting up of the environment into a number of small cells also increases the overall accessible bandwidth of the communication system, but also increases the cost as more cell sites are required. Techniques such as diversity combining can also be used to increase the available bandwidth through improved reception capabilities.

Wireless communication are not that much reliable as wire communication. Also it is considered to be slower than the wired one. Sometimes it is very difficult to configure securely. Another important thing is it has a range depending on the protocol. A terrestrial wireless communication is less secure and it is not reliable for long distance links because of the shortage of spectrum space. Spectrum plays vital role in communication. Only limited spectrums are available for wireless transformation. Sometimes collision occurs in but it takes lot of time to transfer.

Encryption and decryption are the two most important factors of wireless communication but most of the times it creates a big problem for the users. Sometimes users cannot able to open some of data transferred using the encryption method. They need some secret code to open. It creates a big problem. To overcome the entire problem one may have to use satellite communication, but the cost factor is very high. It may be useful for long distance communication but it is more expensive for purely local use. Another important disadvantage of wireless communication is interception of signals simultaneous communication. So that's why most of them prefer one to one transformation but it takes lot of time to transfer.

The unconstrained nature of the communication medium of radio requires the issue of network security to be addressed. Verification of communication entities must also be performed to ensure that only registered devices may communicate using the network, and that only registered devices may receive the data. Some form of encryption may be required for communications to avoid interception of data transmitted over the network by devices not taking part in the communications.

In addition to security considerations from external devices accessing the network, interfering signals can be generated by other devices in the office environment, for example printers and other electromechanical devices. These devices can temporarily disrupt a communication link through the noise that they generate.

1.10 Fading

The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse. As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the source to the receiver. This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver. Strong destructive interference is frequently referred to as a "**deep fade"** and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio.

In wireless communications, fading is deviation or the attenuation that a carrier-modulated telecommunication signal experiences over certain propagation media. The fading may vary with time, geographical position and/or radio frequency, and is often modeled as a random process. A fading channel is a communication channel that experiences fading. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.

The terms slow and fast fading refer to the rate at which the magnitude and phase change imposed by the channel on the signal changes. The coherence time is a measure of the minimum time required for the magnitude change of the channel to become uncorrelated from its previous value.

⊕ **Slow Fading** arises when the coherence time of the channel is large relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. The amplitude change caused by shadowing is often modeled using a log-normal distribution with a standard deviation according to the log-distance path loss model.

⊕ **Fast Fading** occurs when the coherence time of the channel is small relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel varies considerably over the period of use.

⊕ **Rayleigh Fading** is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices.

Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.

Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. If there is a dominant line of sight, Rician fading may be more applicable.

• **Rician Fading** is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by two different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths,

typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.

Rayleigh fading is the specialized model for stochastic fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalized concept of Rician fading. In Rayleigh fading, the amplitude gain is characterized by a Rayleigh distribution

As the carrier frequency of a signal is varied, the magnitude of the change in amplitude will vary. The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading.

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

⊕ In **frequency-selective fading**, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience de-correlated fading.

1.11 Doppler Spread

Doppler spread and Coherence Time take into account the relative motion between mobile and base station, or by movements of objects in the channel. They describe the time varying nature of the channel in a small scale region.

When a signal of frequency f_c is transmitted, the received signal spectrum, called the Doppler spectrum, will have components $f_c - f_d$ to $f_c + f_d$, where f_d is the Doppler shift.

That is the difference in frequencies between different channel paths. It reduces the useful energy in each subcarrier and introduces Inter Carrier Interference ICI [3]. Nevertheless, the time variation of the channel introduces time selectivity during transmission. It offers higher degree of diversity which can be exploited by the channel decoder to improve system performance. In the literature, the effect was introduced for OFDM and MC-CDMA systems. However, assumes an infinite number of sub-carriers to derive an analytical expression of the local-mean Bit Error Rate BER deduced from a local- mean Signal to Interference and Noise Ratio SINR expression. The instantaneous SINR is not accounted for.

1.12 Interference

Interference is the addition (superposition) of two or more waves that result in a new wave pattern. Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency.

Two non-monochromatic waves are only fully coherent with each other if they both have exactly the same range of wavelengths and the same phase differences at each of the constituent wavelengths.

The total phase difference is derived from the sum of both the path difference and the initial phase difference (if the waves are generated from two or more different sources). It can then be concluded whether the waves reaching a point are in phase (constructive interference) or out of phase (destructive interference).

For two coherent sources, the spatial separation between sources is half the wavelength times the number of nodal lines.

Light from any source can be used to obtain interference patterns, for example, Newton's rings can be produced with sunlight. However, in general white light is less suited for producing clear interference patterns, as it is a mix of a full spectrum of colors, that each have different

spacing of the interference fringes. Sodium light is close to monochromatic and is thus more suitable for producing interference patterns. The most suitable is laser light because it is almost perfectly monochromatic.

Constructive and destructive interference:

Consider two waves that are in phase, with amplitudes A_1 and A_2. Their troughs and peaks line up and the resultant wave will have amplitude $A = A_1 + A_2$. This is known as constructive interference.

If the two waves are π radians, or 180°, out of phase, then one wave's crests will coincide with another wave's troughs and so will tend to cancel out. The resultant amplitude is $A = |A_1 - A_2|$. If $A_1 = A_2$, the resultant amplitude will be zero. This is known as destructive interference.

When two sinusoidal waves superimpose, the resulting waveform depends on the frequency (or wavelength) amplitude and relative phase of the two waves. If the two waves have the same amplitude A and wavelength the resultant waveform will have amplitude between 0 and 2A depending on whether the two waves are in phase or out of phase.
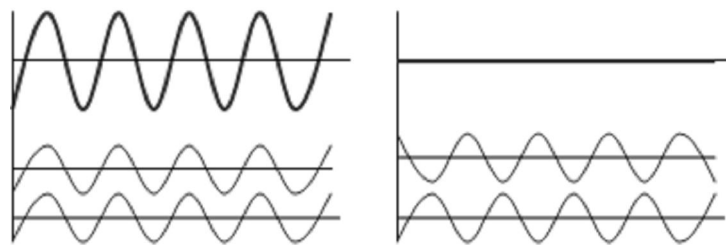
Figure 14: Constructive and Destructive Interference

For two waves of same frequency with intensity I1 and I2 then for constructive interference there will be superposition in such a way that the resultant intensity is not equal to the sum of individual intensities of the two waves; similarly, in destructive interference the resultant intensity is not equal to the difference of the individual intensities of the two waves.

1.13 Carrier Interference and ISI

In telecommunication, inter-symbol interference (ISI) is a form of distortion of a signal in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon as the previous symbols have similar effect as noise, thus making the communication less reliable. ISI is usually caused by multipath propagation or the inherent non-linear frequency response of a channel causing successive symbols to "blur" together. The presence of ISI in the system introduces errors in the decision device at the receiver output. Therefore, in the design of the transmitting and receiving filters, the objective is to minimize the effects of ISI, and thereby deliver the digital data to its destination with the smallest error rate possible. Ways to fight inter-symbol interference include adaptive equalization and error correcting codes.

Causes: (a) Multipath Propagation and (b) Band-Limited Channels
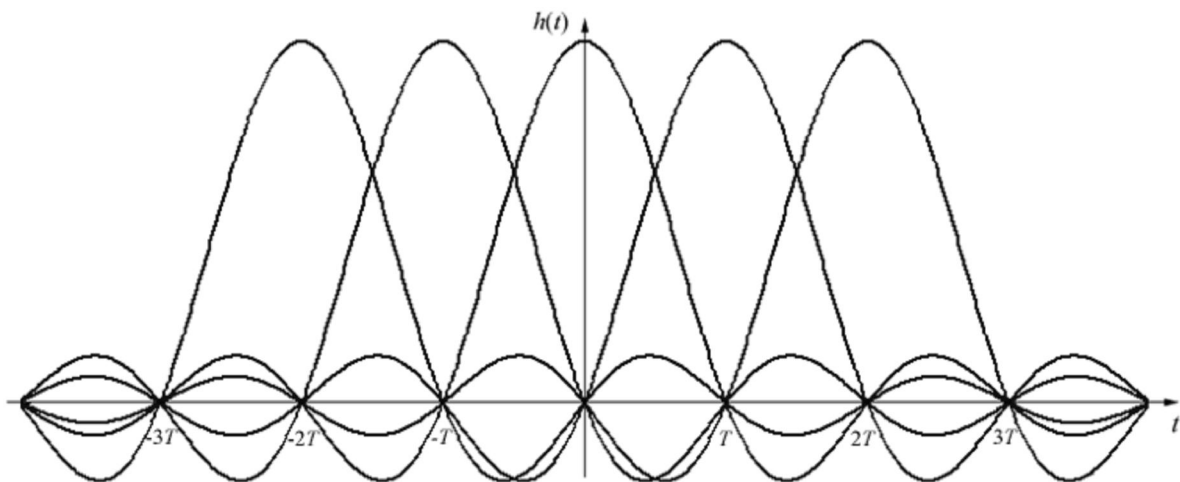
Figure 15: Demonstrating Zero ISI

Countering ISI:

There are several techniques in telecommunication and data storage that try to work around the problem of inter-symbol interference.

- ❖ Design systems such that the impulse response is short enough that very little energy from one symbol smears into the next symbol.

- ❖ Accept the fact that the overall impulse response oscillates up and down for several symbol times. Design the system so that at the precise point where the receiver samples the current symbol, the impulse response of all previous symbols is exactly crossing zero at that point -- in other words, use a filter satisfying the Nyquist ISI criterion, so it has the zero-ISI property at the sample points. See Nyquist ISI criterion for details.

- ❖ Deliberately spread out the impulse response of a single symbol so that it is non-zero over several sampling times. Even though it's impossible to tell the difference between a "1" bit and a "0" bit if the receiver only looks at one sample, the receiver can take a series of samples and figure out which binary sequence, when spread out by the (well-characterized) impulse response, most closely matches the observed series of samples (partial response maximum likelihood PRML). With an appropriate convolutional code (trellis modulation) on the transmitter and the Viterbi algorithm at the receiver, this can correct for impulse noise that destroys any one sample, because the effect of one bit will be evident in several samples.

- ❖ In the Gaussian minimum-shift keying, ISI is introduced before sending by using a Gaussian filter: this way it is possible to recover lost symbols using the surrounding ones by the Viterbi algorithm.

- ❖ Other techniques design symbols that are more robust against inter-symbol interference. Decreasing the symbol rate (the "baud rate"), and keeping the data bit rate constant (by coding more bits per symbol), reduces inter-symbol interference.

- ❖ Other techniques try to compensate for inter-symbol interference. For example, hard drive manufacturers found they could pack much more data on a disk platter when they switched from Modified Frequency Modulation MFM to Partial Response Maximum Likelihood (PRML). Even though it's impossible to tell the difference between a "1" bit and a "0" bit if you only look at the signal during that bit, you can still tell them apart by looking at a cluster of bits at once and figuring out which binary sequence, when smeared out by the

(well-characterized on a particular hard drive) inter-symbol interference, most closely matches the observed signal. Trellis modulation is a closely related technique.

❖ Equalization is also frequently used to reduce the impact of inter-symbol interference. See, for example, IEEE 802.3's 10GBASE-LRM Task Force, where equalization is being used to extend 10 Gigabit Ethernet's distance on 50 μm multi-mode optical fiber.

1.14 Limitations of a Wireless CDMA System

Here are some technology comparisons between FDMA/TDMA and CDMA fading resistance. Because CDMA systems use a higher bandwidth compared to systems that use FDMA the systems are less vulnerable to frequency-selective fading. On the other hand, the near-far effect means that fast power control is needed in CDMA systems to ensure that interference is not too large flexibility. A FDMA/TDMA system is limited by its choice of channel bandwidth and time slot structure, which typically cannot be changed after standardization. In a CDMA system, on the other hand, there source sharing is accomplished by control the amount of power transmitted for each user, which can be changed in real time. Frequency planning systems based on FDMA require frequency planning, which is difficult and time consuming. This is not necessary with CDMA systems. Mobile stations based on TDMA transmit in short pulses, causing strong power peaks and potentially interfering with other devices. CDMA based mobile stations, on the other hand, transmit continuously, and only changing the power steps according to varying radio conditions and desires bit rates. Complexity in the high bandwidth and chip rates of CDMA makes the transmitters and receivers more complex to design and manufactures compared to FDMA and TDMA based devices.

1.15 Objective of the Thesis Work

1.15.1 Objectives

This thesis aims at describing DS-CDMA technology background and fundamentals. It also involves investigation and implementation of the spreading, modulation and coding in CDMA wireless systems with and without fading. AWGN channel is used to simulate the channel. The simulation will evaluate the design options the designer have to take into consideration in the design of the wireless communication system and how they affect the network. This is achieved by investigation of the BER performance of DS-CDMA.

1.15.2 Limitations and Scope of Investigation

Wireless communication systems are more prone to interference hence perfect power control is essential. Because power control is a very broad topic, we will therefore assume perfect power control was achieved in our design.

Fading channel is one of the important factors that affect the propagating signal, however in this thesis we will only model AWGN channels and Rayleigh fading due to the complexity in modeling fading channels.

The scope of this report is to investigate and implement the spreading, modulation and coding in DS-CDMA wireless communications network. This will be modeled in an AWGN channel using Matlab.

1.15.3 Procedure Used to Gather Information

Previous researches were used to gather the background of CDMA and other multiple access methods. The internet and library text books were used to gather all the literature information required. For building the system, Matlab and help files were used. The results were obtained from the simulation.

1.15.4 Plan of Development

The thesis is divided into 4 chapters. Chapter 1 introduces the content of the report by elaborating the basic of wireless communication system, background to investigation, objectives, limitations and scope to investigation. The procedures used to gather information are also included as well as plan of development. Chapter 2 shows the basic of DS-CDMA system methodology which will be used to investigate the system performance. It also shows which parameters we will be concentrate on to investigate and implement the system performance. This chapter reviews the literature so as to establish the background theory. The expected results of the system are discussed in chapter 3. This is where we present the implementation of our simulation program and the actual performance of the system is analyzed viewing the simulation results. Finally chapter 4 makes concluding and recommendation remarks about the implementation of the system.

Chapter: Two

Performance Analysis of a Wireless DS-CDMA System

2.1 CDMA Basics

The gradual increasing demand in cell phones users has given attention for research on how to maximize the capacity of the channels. It has been researched that multiple access schemes achieves this goal by allowing multiple users in the same channel at the same time. CDMA is a spread-spectrum multiple-access technique which has recently received considerable interest in various applications including cellular mobile communications.

Multiplexing allows a large number of users to share access to a single communication channel by assigning frequency slot, time slot or a special code. CDMA is a spread spectrum technique that encodes data with a special code for each channel. We have seen great use of this multiple access scheme in the application of cellular systems. It offers better advantages than other spread spectrum techniques which are TDMA and FDMA as stated earlier. In CDMA, all users can transmit at the same time. CDMA has been shown to provide up to six times the capacity of TDMA or FDMA based networks.

However CDMA is interference limited, therefore error correction coding is very important to the systems. In particular, wireless channel is more prone to interference which gives rise to the near far problem. This effect is present when an interfering transmitter is much closer to the receiver than the intended transmitter. The result is that proper data detection is not possible hence the power control is required. Power control in DS-CDMA helps reduce excessive interference throughout the system. The other disadvantage of CDMA is that bandwidths of an

information bearing signal after spreading are much wider. However looking at its advantages it is still considered the best in comparison with FDMA and TDMA.

DS-CDMA uses pseudorandom (PN) noise to spread normally narrowband information signals over a wide band of frequency. Each user is assigned a distinct code waveform c(t) which is then multiplied with the user's data and transmitted simultaneously.

The spreading code or chip sequence c(t) is made up of a sequence of +1 and -1. This requires a bandwidth considerably larger than the frequency content of the original information. The spreading codes are used for spectrum spreading, and to allow multiple access to the channel. Figure below shows a simple sequence spreading. These codes have to be orthogonal to avoid interference between channels, however this is not easy to achieve in real life. They are also used to improve the privacy of the communicators by giving the signal to authorized receiver only.
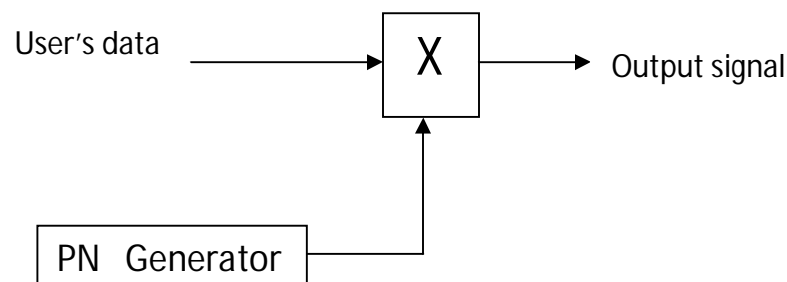
Figure 16: Simple Direct Sequence Spreading Technique.

The spreading sequence is illustrated in figure below with the chip period of 4.
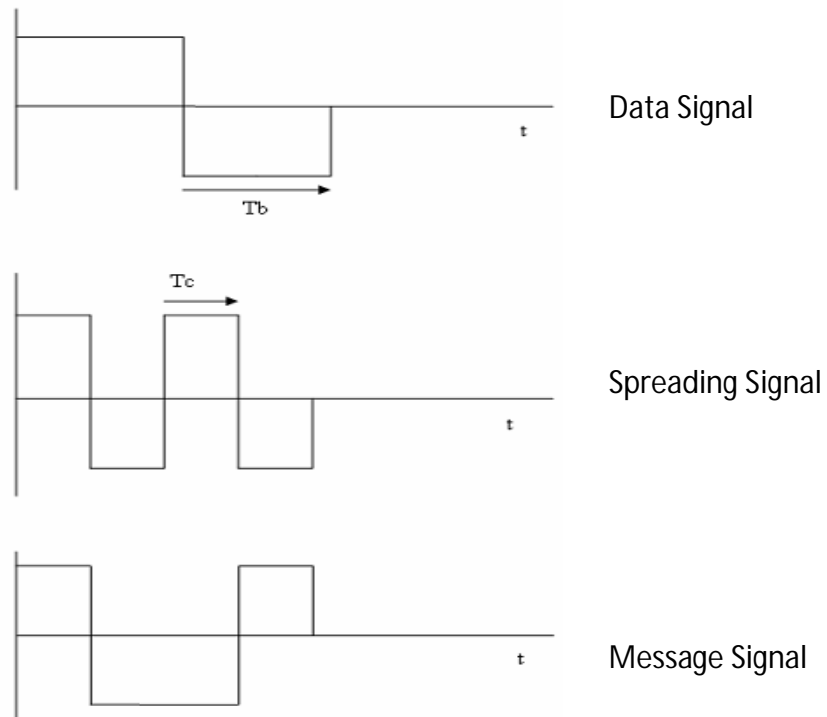
Figure 17: Spreading Sequence with the Chip Period of 4.

The major contributor to the degradation of Signal to Noise and Interference Ratio (SNIR) is multi-user interference which is caused by users in the channel interfering with each other. Multiple Access Interference (MAI) limits the capacity of DS-CDMA systems.

This interference is due to time offsets between signals. This is because each user has different time and phase delays after his transmission, thus the bit errors are dependent. To minimize multi-user interference, each transmission should be nearly orthogonal to each other. In an ideal situation, all signals would be completely orthogonal but this is difficult to achieve in practical wireless communication systems.

2.2 Properties of DS-CDMA

Based on the analysis of the DS-CDMA system, we can summarize some properties of DS-CDMA as follows:

Universal Frequency Reuse: As CDMA achieves the orthogonality among the transmitted signals from the mobile users by using the orthogonal, or approximately orthogonal, PN - sequences in spreading the signals, the total frequency bandwidth allocated to the system can be reused from cell to cell. As a result, we achieve the minimum cell cluster size (N=1) and maximum frequency reuse. This significantly reduces the complexity of frequency planning in cellular system design.

Soft Handoff: Because of the universal frequency reuse, a mobile user can simultaneously communicate with several nearby base stations using the same frequency band and the same spreading signal in each link. When the mobile user is at the cell boundary, it can establish a connection with the new base station before terminating the connection with the old base station. This will improve handoff performance.

High Transmission Accuracy - With spread spectrum, we can. use Rake receivers to mitigate the fading dispersive channel impairments and. therefore, improve transmission accuracy, especially during soft handoff.

Soft Capacity - The PN sequences are not truly orthogonal, MAI will degrade the transmission BER performance. The maximum number of users that can be supported in each cell depends on the required quality of service (QoS) and is limited by MAI. To be discussed in Subsection 6.4.3. As a result, unlike TDMA and FDMA, there is no hard limit on the number of users in each cell. During peak traffic hours, if the users' car tolerates a lower QoS to a certain degree, the system can accommodate more users to satisfy the high service demands in that period.

Flexibility- as CDMA is interference limited, if a user does not transmit, it does not transmit any interference with other active users and therefore does not use the system resources. This feature translates to increase resource utilization; with CDMA it is easier to implement the statistical multiplexing. In addition, CDMA has more flexibility than TDMA in supporting multimedia services (with various time-varying traffic rates).

2.3 Direct Sequence Spread Spectrum (DSSS)

Consider a radio cell with a population of K users. Each of the mobile users is assigned a unique spreading sequence. Each symbol in the PN sequence is called a chip. Figure below shows the functional block diagram of the transmitter and receiver for the k-th user, k=1, 2,....K. For simplicity, we are considering real-valued binary spreading waveforms. The information carrying baseband signal $d_k(t)$ is

$$d_k(t) = \Sigma s_{k,i} \Pi \left(\frac{t - iT_b}{T_b}\right)$$

Where, $s_{k,i} \in \{-1,+1\}$ is the i-th binary information bit, T_b is the information bit interval, and $\Pi(t/T_b)$ is the rectangular pulse

$$\Pi\left(\frac{t}{T_b}\right) = \begin{cases} 1, & 0 \leq t \leq T_b \\ 0, & \text{otherwise} \end{cases}$$

The spreading signal of the k-th user is $a_k(t)$ and can be represented as

$$a_k(t) = \Sigma a_{k,l} P_{Tc}(t - lTc)$$

where $a_{k,l} \in \{-1,+1\}$ is the l-th chip of binary PN sequence assigned to user k, $P_{Tc}(t)$ is the chip pulse waveform depending on baseband pulse shaping and T_c is the chip interval, corresponding to a chip rate of $1/T_c$. The spreading process is to modulate $a_k(t)$ onto $d_k(t)$, which gives the spread signal $a_k(t)d_k(t)$. The spreading function $a_k(t)$ is often phase shift keyed

onto the baseband signal $d_k(t)$. The spreading signal $a_k(t)d_k(t)$ is then modulated with carrier frequency f_c ($>>1/T_c$) resulting in the band pass signal $x_k(t)$ with amplitude A_c and bit interval T_b.
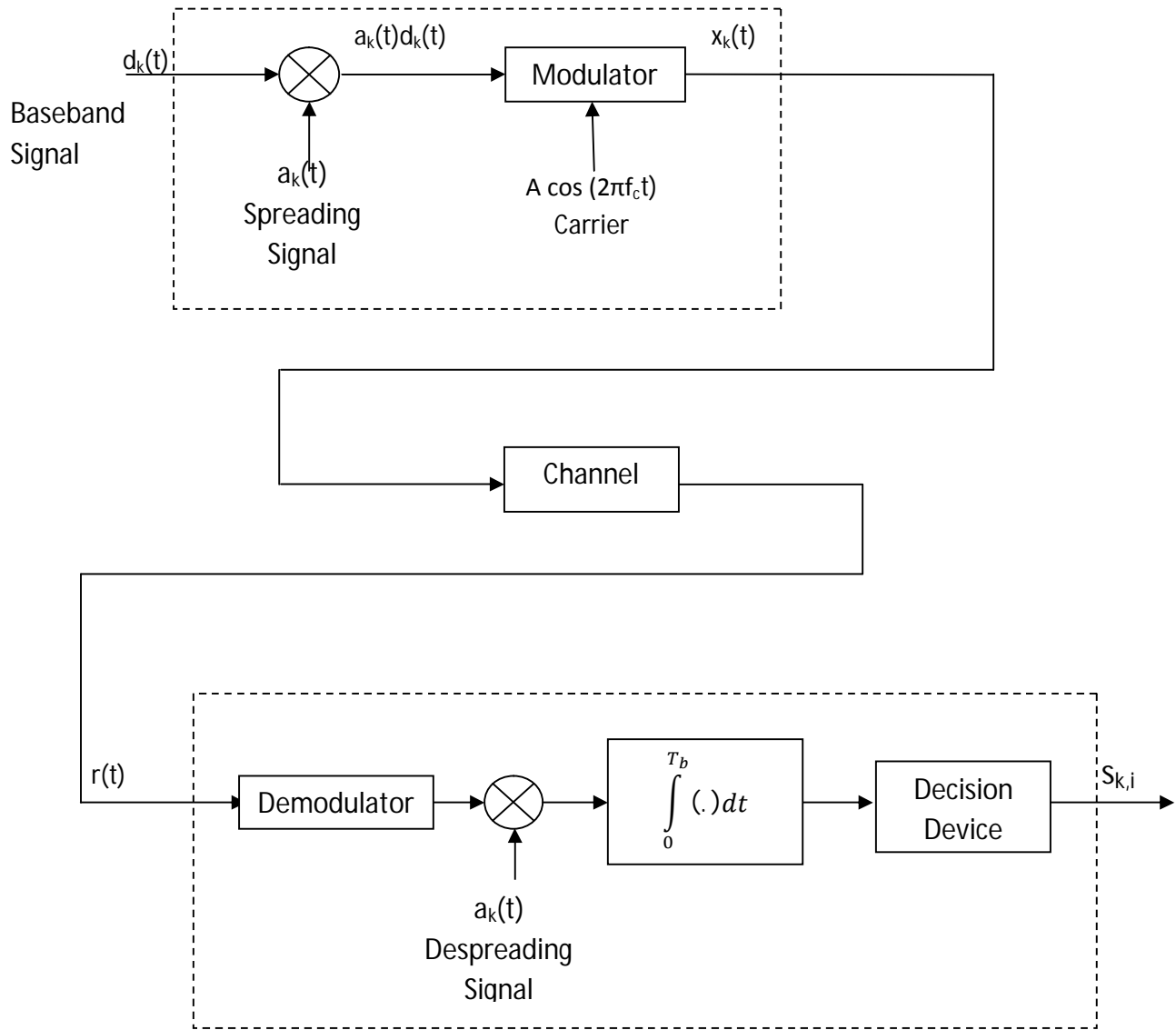
Figure 18: Functional Block Diagram of User k Transmitter and Receiver in a DS-CDMA System.

Normally, $T_b = LT_c$, where L is an integer. The principal of signal spreading is that L>>1. Since the spreading signal has a chip rate much larger than the transmitted information symbol rate, the

bandwidth of the spread signal is much larger than the bandwidth of the baseband information signal; hence, the name spread pass-band modulation with coherent demodulation. If the PN sequence is periodic, with period L, then the transmitted signal is

$$x_k(t) = A_c\left[\sum_i s_{k,i} \sum_{l=1}^{L} a_{k,l} \Pi\left(\frac{t - iT_c - lT_c}{T_b}\right)\right] \cos(2\pi f_c t)$$

Normally, the information bits and the PN sequence chips are completely independent. The psd of the transmitted signal is

$$\Phi_1(f) = \frac{E_c}{2}\{\text{sinc}^2[(f - f_c)T_c] + \text{sinc}^2[(f + f_c)T_c]\}$$

Where $E_c = \int_0^T [x_k(t)]^2 dt = \frac{1}{2} A_c^2 T_c$ is the chip energy. For comparison, without spread spectrum, the transmitted signal would be $A_c d_k(t)\cos(2\pi f_c t)$ and the corresponding psd would be

$$\Phi_2(f) = \frac{E_b}{2}\{\text{sinc}^2[(f - f_c)T_c] + \text{sinc}^2[(f + f_c)T_c]\}$$

Where, $E_b = \int_0^T [A_c d_k(t)\cos^2(2\pi fct)]dt = \frac{1}{2} A_c^2 T_b = LE_c$ is the bit energy.
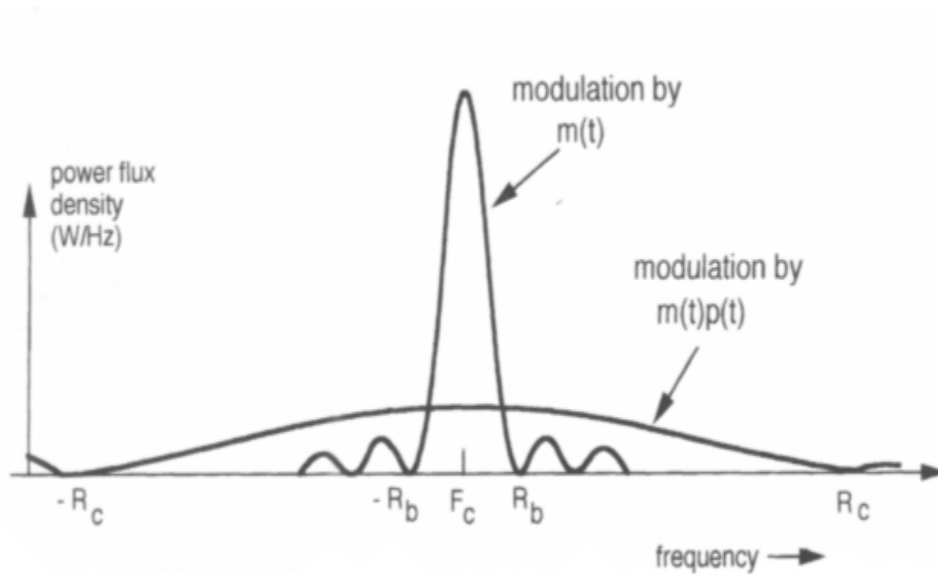
Figure 19: Power spectral density without and with spreading.

The output emerging from the channel, which is also the input to the receiver, is a superposition of the spread signals from all users in the same radio cell, plus background noise and interference from neighboring cells. Let r(t) denote the received signal. Under the assumption all the K users in the cell are synchronized in time and have the same received signal power $A_c^2/2$, r(t) is given by

$$r(t) = \sum_{k=1}^{K} x_k(t) + I(t) + w(t)$$

Where I(t) represents inter-cell interference and w(t) represents background white Gaussian noise with zero mean and two sided psd $N_0/2$. Both intra-cell interference and inter-cell interference are due to multiple accesses and, therefore, are called multiple access interference (MAI). If the desired signal is the signal transmitted by user 1 and the transmitted signals from all other users are interference, then for the purpose of detecting user 1's signal at the receiver, it can be expressed as

$$r(t) = A_c a_1(t)d_1(t) \cos(2\pi f_c t) + \sum_{k=2}^{K} A_c a_k(t)d_k(t) \cos(2\pi f_c t) + I(t) + w(t)$$

The first block in the receiver is the demodulator, which translates the received signal centered at frequency fc to baseband centered at frequency zero. This is done by a correlator or matched filter in coherent demodulation. The output of the demodulator at the end of the lth chip interval is

$$\frac{1}{T_c} \int_{lT_c}^{(l+1)T_c} r(t) \cos(2\pi f_c t)dt$$

Over each chip interval $a_k(t)d_k(t)$ (k=1,2,.....,K) is a constant. The demodulation output as a function of time, y(t), can be written as

$$y(t) = \frac{A_c}{2} a_1(t)d_1(t) + \sum_{k=2}^{K} \frac{A_c}{2} a_k(t)d_k(t) + n(t)$$

Where

$$n(t) = \frac{1}{T_c} \sum_l \left\{ \int_{lT_c}^{(l+1)T_c} [I(t) + w(t)] \cos(2\pi f_c t)dt \right\} \Pi\left(\frac{t-lT_c}{T_c}\right)$$

is due to the inter-cell interference and additive background noise. In general, the integral can be approximated by a zero-mean Gaussian random variable and is independent from chip to chip. As a result n(t) is baseband Gaussian noise with bandwidth approximately equal to $1/T_c$. To extract user 1's transmitted signal from the demodulator output is the receiver .$a_1(t)$ should be used as the de-spreading signal. De-spreading is achieved by firth multiplying the demodulator output, y(t),with $a_1(t)$ and then integrating the product over each symbol interval. Since $a_1^2(t)=1$ at any t, we have,

$$a_1(t)y(t) = \frac{A_c}{2} d_1(t) + \sum_{k=2}^{K} \frac{A_c}{2} a_1(t)a_k(t)d_k(t) + a_1(t)n(t)$$

Where, the first term represents the desired signal component and is a constant over each symbol interval. It is clearly observed that the de-spreading process indeed recover the original baseband signal $d_1(t)$ from the spread signal $d_1(t)a_1(t)$ can be viewed as a new spreading signal with the same chip rate. With a very high chip rate, the power of the interference is approximately uniformly distributed over the frequency band $[0,1/T_c]$. For the inter-cell interference plus noise term, since (a)$a_{1,l}$ takes on the values of -1 and +1 with the equal likelihood ,(b) n(t) in each chip interval is a zero -mean Gaussian random variable and (c) $a_1(t)$ and n(t)is the same as that of n(t).therefore the power of the inter-cell interference and noise is approximately uniformly distributed over the frequency band $[0,1/T_c]$.

To suppress the interference and noise, the next step in the receiver is to integrate the de-spread signal over each information symbol interval over which the desired signal component is a constant. The output of the integrator at the end of the i-th symbol is

$$\frac{1}{T_b} \int_{iT_b}^{(i+1)T_b} a_1(t)y(t) \, dt = \frac{A_c T_b}{2}\alpha_1 d_{1,i} + \frac{A_c T_b}{2} a_k d_{k,l} + n_i$$

Where, $$\alpha_1 = \frac{1}{T_b} \int_{iT_b}^{(i+1)T_b} [a_1(t)^2] \, dt = 1$$

is the autocorrelation of the spreading signal $a_1(t)$over the symbol interval and

$$\alpha_k = \frac{1}{T_b} \int_{iT_b}^{(i+1)T_b} a_1(t) \, a_k(t)dt$$

Where, k=2, 3.......K

is the cross correlation between the spreading signals $a_1(t)$ and $a_k(t)$ over the symbol interval. If all the spreading signals $a_k(t)$,k=1,2,......,K are orthogonal in the symbol interval, then there is no inter-cell interference in the recovered baseband signal. The effect of the inter-cell interference and background noise on the signal detection is given by the last term n_i, which is

$$n_i = \frac{1}{T_b} \int_{iT_b}^{(i+1)T_b} a_1(t)n(t) \, dt$$

In the frequency domain, the integrator is a low-pass filter with bandwidth approximately equal to $1/T_b$. The LPF lets the desired signal component $A_c/2d_1(t)$go through without distortion and greatly reduces interference and noise power. The de-spreading process significantly improves the signal-to-interference plus noise ratio (SNR).

The spread spectrum system performance is measured by the processing gain, G_p,is defined as the SNR improvement achieved by de-spreading. That is,

$$G_p = \frac{\text{SINR after despreading}}{\text{SINR beforedespreading}}$$

2.3.1 Signal-to-Noise Ratio (SNR)

Signal-to-noise ratio is a term for the power ratio between a signal and the background noise:

$$SNR = \frac{P_{signal}}{P_{noise}}$$

Where, P is average power. Either signal and noise power must be measured at the same or equivalent points in a system, and within the same system bandwidth. If the signal and the noise are measured across the same impedance, then the SNR can be obtained by calculating the square of the amplitude ratio:

$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} = \left(\frac{A_{\text{signal}}}{A_{\text{noise}}}\right)^2$$

Where, A is root mean square (RMS) amplitude (for example, typically, RMS voltage). Because many signals have a very wide dynamic range, SNRs are usually expressed in terms of the logarithmic decibel scale. In decibels, the SNR is, by definition, 10 times the logarithm of the power ratio:

$$\text{SNR (dB)} = 10\log_{10}\left(\frac{P_{\text{signal}}}{P_{\text{noise}}}\right) = 20\log_{10}\left(\frac{A_{\text{signal}}}{A_{\text{noise}}}\right) = P_{\text{signal,dB}} - P_{\text{noise,dB}}$$

2.3.2 Bit Error Rate (BER)

Bit error rate (BER) is used in digital telecommunication as a figure of merit for how effectively the receiver is able to decode transmitted data. It is the percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power.

The BER is an indication of how often a packet or other data unit has to be retransmitted because of an error. If the BER is higher than typically expected for the system, it may indicate that a slower data rate would actually improve overall transmission time for a given amount of transmitted data since the BER might be reduced, lowering the number of packets that had to be resent.

A BERT (bit error rate test or tester) is a procedure or device that measures the BER for a given transmission.

$$\frac{E_b}{N_0}\,(\text{dB}) = C - N_0 - 10\log_{10}(f_b)$$

when added noise level approaches noise floor of receiver:

$$\frac{E_b}{N_0}\,(\text{dB}) = C - 10\log_{10}(N) - 10\log_b(f) - 10\log\left(1 + \frac{Fkt}{N_i}\right)$$

where: f_b = transmission bit rate

N_0 = noise spectral density (dBm/Hz)

N_i = injected noise spectral density (mW/Hz)

E_b = energy per bit (dBm/Hz)

C = carrier power (dBm)

T = ambient temperature (K)

k = Boltzmann's constant = 1.380×10^{-23} (J/K)

F = noise factor at injection point of receiver

2.3.3 Additive White Gaussian Noise (AWGN)

The term thermal noise refers to unwanted electrical signals that are always present in electrical systems. The term additive means the noise is superimposed or added to the signal where it will limit the receiver ability to make correct symbol decisions and limit the rate of information. Thus, AWGN is the effect of thermal noise generated by thermal motion of electron in all dissipative electrical components i.e. resistors, wires and so on. Mathematically, thermal noise is described by a zero-mean Gaussian random process where the random signal is a sum of Gaussian noise random variable and a dc signal that is

$$z = a + n$$

Where pdf for Gaussian noise can be represented as follows where $\sigma 2$ is the variance of n.

$$p(z) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left\{ \frac{z-a}{\sigma} \right\}^2 \right]$$

A simple model for thermal noise assumes that its power spectral density Gn(f) is a flat for all frequencies and is denoted as

$$G_n(f) = \frac{N_0}{2}$$

Where the factor of 2 to indicate that Gn(f) is a two-sided power spectral density. When noise power has such a uniform spectral density, it is referred as white noise. The adjective "white" is used in the same sense as it is with white light, which contains equal amounts of all frequencies

within the visible band of electromagnetic (EM) radiation. Since thermal noise is present in all communication systems and is a prominent noise source for most system, the thermal noise characteristics that are additive, white and Gaussian are most often used to model the noise in communication systems.

2.3.4 Fading

I. Rayleigh fading

The mobile antenna, instead of receiving the signal over one line-of-sight path, receives a number of reflected and scattered waves. Because of the varying path lengths, the phases are random, and consequently, the instantaneous received power becomes a random variable. In the case of an un-modulated carrier, the transmitted signal at frequency ωc reaches the receiver via a number of paths, the i-th path having an amplitude ai, and a phase ϕi. If we assume that there is no direct path or line-of sight (LOS) component, the received signal s(t) can be expressed as

$$s(t) = \sum_{i=1}^{N} a_i \cos(\omega_c t + \phi_i)$$

where N is the number of paths. The phase ϕi depends on the varying path lengths, changing by 2π when the path length changes by a wavelength. Therefore, the phases are uniformly distributed over $[0,2\pi]$. When there is relative motion between the transmitter and the receiver, above eqn must be modified to include the effects of motion induced frequency and phase shifts. Let the ith reflected wave with amplitude ai and phase ϕi arrive at the receiver from an angle ψi relative to the direction of motion of the antenna. The Doppler shift of this wave is given by

$$\omega_{d_i} = \frac{\omega_c v}{c} \cos \Psi_i$$

where v is the velocity of the mobile, c is the speed of light (3x108 m/s), and the Ψ_i's are uniformly distributed over $[0,2\pi]$. The received signal s(t) can now be written as

$$s(t) = \sum_{i=1}^{N} a_i \cos(\omega_c t + \omega_{d_i} t + \phi_i)$$

Expressing the signal in inphase and quadrature form, $s(t)$ can be written as

$$s(t) = I(t) \cos \omega_c t - Q(t) \sin \omega_c t$$

where the inphase and quadrature components are respectively given as

$$I(t) = \sum_{i=1}^{N} a_i \cos(\omega_{d_i} t + \phi_i)$$

$$Q(t) = \sum_{i=1}^{N} a_i \sin(\omega_{d_i} t + \phi_i)$$

The envelope R is given by

$$R = \sqrt{[I(t)]^2 + [Q(t)]^2}$$

When N is large, the inphase and quadrature components will be Gaussian. The probability density function (pdf) of the received signal envelope, f(r), can be shown to be Rayleigh given by

$$f(r) = \frac{r}{\sigma^2} \exp\left\{-\frac{r^2}{2\sigma^2}\right\} \quad r \geq 0$$

II.   Rician Fading

The Rician distribution is observed when, in addition to the multipath components, there exists a direct path between the transmitter and the receiver. In the presence of a direct path or line-of-sight component, the transmitted signal can be written as

$$s(t) = \sum_{i=1}^{N-1} a_i \cos(\omega_c t + \omega_{d_i} t + \phi_i) + k_d \cos(\omega_c t + \omega_d t)$$

where the constant k_d is the strength of the direct component, ω_d is the Doppler shift along the LOS path, and ω_{di} are the Doppler shifts along the indirect paths. The envelope in this case has a Rician density function given by

$$F(r) = 1 - Q\left(\frac{k_d}{\sigma}, \frac{r}{\sigma}\right) \quad r \geq 0$$

Where $Q\left(\frac{k_d}{\sigma}, \frac{r}{\sigma}\right)$ is the Marcum's Q function. The Rician distribution is often described in terms of the Rician factor K, defined as the ratio between the deterministic signal power (from the direct path) and the diffuse signal power (from the indirect paths). K is usually expressed in decibels as

$$K(dB) = 10\log_{10}\left(\frac{k_d^2}{2\sigma^2}\right)$$

if K_d goes to zero (or if $k_d^2/2\sigma2 \ll r^2/2\sigma2$), the direct path is eliminated and the envelope distribution becomes Rayleigh, with K(dB) = -∞.

2.4 BER with and without Interference

In the absence of path loss, the received signal energy per bit is E_b. For transmission in an AWGN channel without MAI (by using truly orthogonal spreading sequences), the BER for the DS-CDMA user in additive white Gaussian noise of zero mean and two-sided psd $No/2$ is the same as that without spread spectrum modulation, due to the fact that (a)for the desired signal, the functions of spreading at the transmitter and despreading at the receiver cancel each other, and (b) the despreading process does not change the statistics of the noise component at the decision device input. If BPSK is used, the BER for the DS-CDMA user with coherent detection is

$$P_b = Q\left[\sqrt{\frac{2E_b}{N_0}}\right]$$

If the spreading sequences are not orthogonal, the MAI from all other mobile users in the system will increase the transmission error fate. When the number of mobile users in the system is large interferences from all other users are independent and have similar stochastic behavior, from the central limit theorem, the MAI can be approximated as a Gaussian process.

Furthermore, with a large spread spectrum bandwidth W, the psd of the interference is approximately uniform over the bandwidth. As a result, the effect of the MAI on the transmission performance can be treated in the same way as the additive white Gaussian noise, and the BER is

$$P_b = Q \left[\sqrt{\frac{2E_b}{I_0 + N_0}} \right]$$

Where I_o is the two-sided psd of the MAI over the spread spectrum bandwidth. Even though spread spectrum does not provide performance gain over an AWGN channel where the interference (noise) is wideband with an infinite power, it does achieve a processing gain over narrowband interference (jamming).

2.5 Multiple Access Interference

Consider the forward link transmission of a single-cell DS-CDMA system using BPSK, where the multiple access interference due to other users in the cell is synchronized with the desired signal both in chip timing and in carrier phase. It is assumed that (a) all the PN code sequences are independent of each other, and chip values "+1" and "-1" in each sequence are equally likely and are independent of each other; (b) rectangular pulses are used for the spreading waveforms. (c) the receiver uses coherent detections, (d) the number of users in the cell is large, and (e) the received signal power levels from all the mobiles are the same at the base station receiver.

Let K denote the number of mobile users in the system. Consider the detection process at mobile user I's receiver. The received signal r(t) is

$$r(t) = \sqrt{2P_d} \left[a1(t)d1(t) + \sum_{k=2}^{K} \cos(2\pi f_c t + \theta_0) \right] + w(t)$$

where P_d is the desired signal power of the kth user and is independent of k, $d_k(t) = \sum_i s_{k,i}$ $\Pi\left(\frac{t-iT_b}{T_b}\right)$, $a_k(t) = \sum_l a_k(t)d_k(t)$ $a_{k,l}\Pi\left(\frac{t-lT_C}{T_c}\right)$, $s_{k,i}$ ($\in\{-1,+1\}$) is the ith information binary digit and $a_{k,l}$ ($\in \{-1,+1\}$) is the lth chip of the PN code sequence for the kth user, k =1,2.....K T_b and T_c are the bit chip intervals respectively, f_c is the carrier frequency, θ_0 is the carrier phase at t = 0, $\omega(t)$ is the additive white Gaussian noise with zero mean and two-sided psd $N_0/2$,which means E [ω (t) ω (s)] =($N_0/2$) δ (t-s).The output of the coherent demodulator is

$$\frac{1}{T_b}\int_0^{T_b} r(t)[a_1(t) \cos(2\pi f_c t + \theta_0)]dt,$$

The output consists of three components:

(1). The desired signal component, $(\sqrt{P_d/2})s_{1.1}$, which is a constant given $s_{1.1}$;

(2). The noise component.

$$E\left[\frac{1}{T_b^2}\int_0^{T_b}\int_0^{T_b} w(t)w(s)a1(t)a1(s) \cos(2\pi f_c t + \theta_0) \cos(2\pi f_c s + \theta_0)dtds\right]$$

$$=\frac{1}{T_b^2}\int_0^{T_b}\int_0^{T_b} E[w(t)w(s)] E[a_1(t) a_1(s)]\cos(2\pi f_c t + \theta_0) \cos(2\pi f_c s+\theta_0)dtds$$

$$=\frac{1}{T_b^2}\int_0^{T_b}\int_0^{T_b} \frac{N_0}{2} \delta(t - s)E[a_1(t) a_1(s)]\cos(2\pi f_c t + \theta_0) \cos(2\pi f_c s+ \theta_0)dtds$$

$$=\frac{N_0}{2T_b^2}\int_0^{T_b} E[a_1^2(t)]\cos^2(2\pi f_c t + \theta_0)dt$$

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

(3). The intracell interference

$$\sqrt{P_d/2}\, (1/G_p) \sum_{k=2}^K s_{k,l} \sum_{l=1}^{K_p} a_{1,l} a_{k,l}$$

Where $G_p = T_b / T_c$ (assumed to be an integer) is the processing gain. If $s_{k,1}$ takes on the values of -1 and +1 with equal likelihood, and is independent for different k values, $s_{k,1} \sum_{l=1}^{G_p} a_{1,l} a_{k,l}$ are random variables for different k values. If K >>1, then based on the central limit theorem,

the interference component can be modeled as a Gaussian random variable with zero mean and variance,

$$\frac{P_d}{2G_p{}^2} E\left\{\left[\sum_{k=2}^{K} s_{k,l} \sum_{l=1}^{G_p} a_{1,l}a_{k,l}\right]\left[\sum_{k'=2}^{K} s_{k',l} \sum_{l=1}^{G_p} a_{1,l'}a_{k',l'}\right]\right\}$$

$$= \frac{P_d}{2G_p{}^2} \sum_{k=2}^{K} E[s^2{}_{k,l}] \sum_{l=1}^{G_p} E[a^2{}_{1,l}]E[a^2{}_{k,l}]$$

$$= \frac{(K-1)P_d}{2G_p}$$

In summary the demodulator output is a Gaussian random variable with mean $\sqrt{(P_d/2)}s_{1,1}$ and variance $\frac{N_0}{4T_b} + \frac{(K-1)P_d}{2G_p}$. $s_{1,1}$ was sent before. Similar to the derivation of the BER for coherent BPSK in an AWGN channel, the probability of bit error is

$$P_{b=}Q\left[\frac{\sqrt{(P_d/2)}}{\sqrt{\frac{N_0}{4T_b}+\frac{(K-1)P_d}{2G_p}}}\right]$$

$$=Q\left[\sqrt{\frac{2E_b}{N_0+2\,(K-1)E_b/G_p}}\right]$$

Where E_b (= P_dT_b) is the received signal bit energy. If there is no multiple access interference (K = 1), the probability of error is the same as BPSK in AWGN with coherent detection. On the other hand, if there is no background noise (N_0 = 0), then the probability of error is $Q(\sqrt{[G_p/(K-1)]})$, where the effective signal-to- interference ratio is the product of the processing gain G_p and the ratio of the desired signal power P_d to the total interference power$(K - 1)P_d$.

2.6 Performance Analysis with Fading

Physical channel represents transmission medium. This is usually represented with the AWGN channel which is assumed to add white noise where we assume no signal fading. Fading occurs when the signal is reflected by obstacles like trees and buildings in the propagation path. This leads to multiple paths of the signal from the transmitter to the receiver.

Direct Wave

Reflected Wave
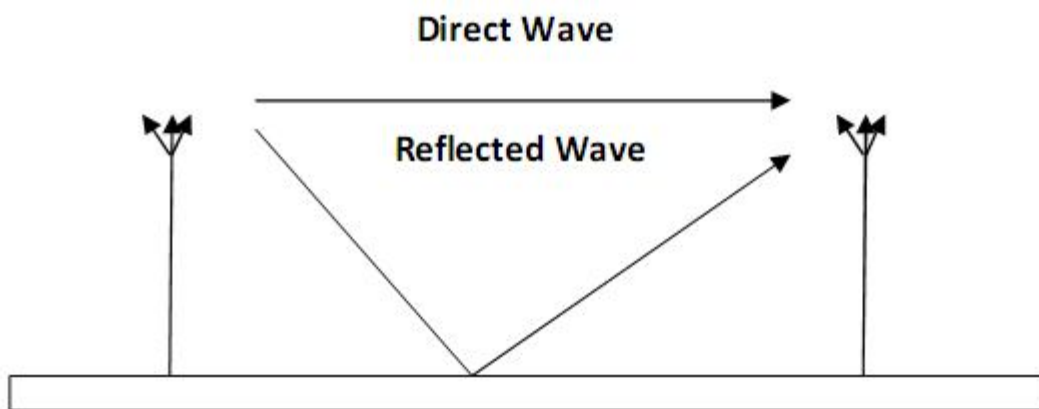
Figure 20: Diagram Showing the Multiple Faded Signals.

Rayleigh fading channel represents multipath propagation which leads to inter symbol interference (ISI). It also results in time varying fading.

For the AWGN channel probability of receiving the signal in error P_b is given by

$$P_b = \frac{1}{2} \exp \sqrt{\frac{E_s}{N_0}}$$

$$Q \left[\sqrt{\frac{2E_b}{N_0}} \right]$$

Rayleigh fading channel is most applicable when there is no line of sight between the transmitter and receiver. If there is a line of sight, Rician fading is more applicable.

Rayleigh fading with strong line of sight content is said to have a Rician distribution. Rician distribution is a continuous probability distribution with probability density function shown in equation

$$f_{rice} = \frac{x}{\sigma^2} \exp\left(-\frac{x^2 + v^2}{2\sigma^2}\right) I_0 \frac{xv}{\sigma^2}$$

Where x is the signal amplitude

σ^2 is the average fading power

v is the peak value of the directly received signal

$I_0(z)$ the modified Bessel function of the first kind

For the flat Rayleigh fading channel probability of bit error (Pb) is given by equation

$$P_b = \frac{1}{2}\left[1 - \sqrt{\frac{E_s/N_0}{1 + E_s/N_0}}\right]$$

From the above equations it is clear that the probability of error for fading channels will be higher than that of AWGN channel.

Chapter: Three

Results and Discussions

The research thesis is started with literature review on performance of CDMA DS, W-CDMA, and fading effects on channel. Then, a generic model of DS W-CDMA as it is shown in figure 3.1 is simulated using QPSK and it is followed by BPSK. QPSK and BPSK are chosen in this thesis because they are the primary candidates to deliver higher performance of wireless DS-CDMA system with fading. The simulation is done under noise and multipath fading channel using MATLAB 7.0.0.19156a.

As it is shown in figure 3.1, the user data is assumed to be Bernoulli distributed and it is represented as bn(t). Each user data is then multiplied with independent or different PN code produced by a PN generator using XOR logical operator. The multiplied signal of each user is represented as sn(t) after the signal is modulated by either QPSK or BPSK. Each signal is added before it is subjected to the channel. At the receiver, the signal sk(t) is demodulated before the user data is separated from PN code by XOR logical operator.

Finally, when the necessary simulations are done, tables and graphs of BER as a function of SNR for various parameters are plotted. Analysis, comments and conclusion will be drawn based on the simulation results.

AWGN and Rayleigh fading are chosen to represent fading effect in the channel because we want to make a comparison of WCDMA system models in two extreme channel conditions.

There are many fading effects that can be categorized as large-scale and small-scale fading. Rayleigh fading represents the worst case of multipath fading where it represents small-scale fading due to small changes in position. On the other hand, AWGN represents the thermal noise generated by electrical instruments.

3.1   Simulation Methodology

Computer simulation is the most suitable, powerful and efficient way to represent the actual or real situation of mobile radio system. Thus, MATLAB 7.0.0.19156a has been identified to simulate W-CDMA model based on related theories, formulae and parameters.

Two approaches are adopted in this thesis. Firstly, the simulation is simulated using Simulink and it follows with simulation using m files. Throughout this thesis, the bit rate for the signal generator is variable.

There will be three WCDMA wireless cellular system models that will be used in this project. The models are:

1. WCDMA system in AWGN channel
2. WCDMA system in AWGN and Multipath Rayleigh Fading.
3. Multi-user WCDMA system in AWGN and Multipath Rayleigh Fading.
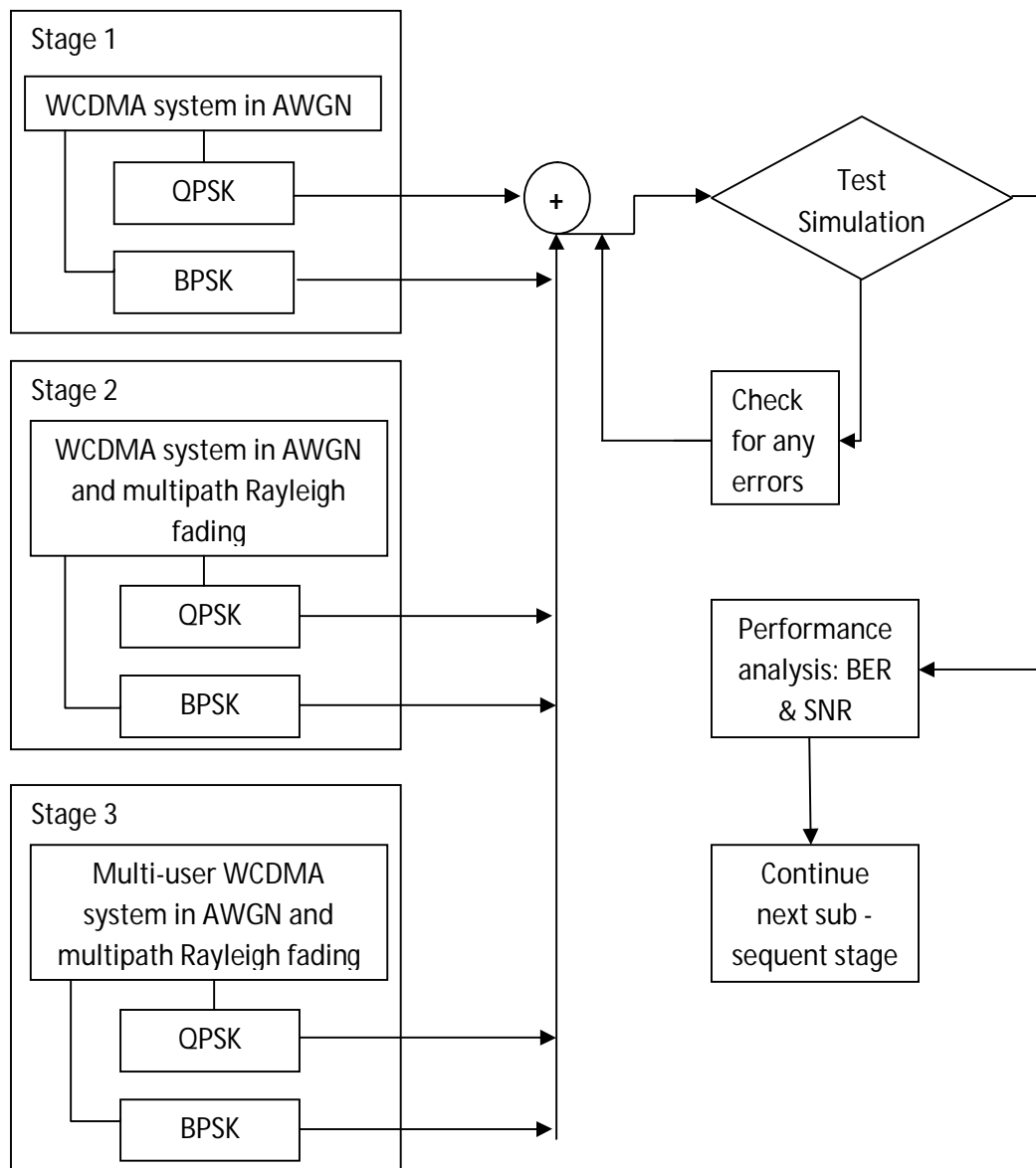
Figure 21: Simulation Flow Chart for W-CDMA System Models Used in Simulink & M Files

3.2 Simulation Using Simulink

Two types of simulation have been chosen to study the performance of modulation techniques of WCDMA subjected to multipath fading in the channel. The project begins with simulation using Simulink. Simulink is a software package that has the capabilities to model, simulate, and

analyze dynamic systems whose outputs and states change with time. Simulink can be used to explore the behavior of a wide range of real-world dynamic systems making it suitable computer software to study the performance of modulation techniques under multipath fading. Simulating a dynamic system is a two-step process with Simulink. First, a graphical model of the system is simulated, using the Simulink model editor. The model depicts the time-dependent mathematical relationships among the system's inputs, states, and outputs. Then, Simulink is used to simulate the behavior of the system over a specified time span. Simulink uses information entered into the model to perform the simulation.

3.3   Simulation in Phase 1: WCDMA System in AWGN Channel

In Phase 1, both transmitter and receiver part are built based on the system model as shown in Figure 3.5. The channel is subjected to AWGN only. This phase is divided into five parts as follows:

1. Assumptions
2. Transmitter part
3. Receiver Part
4. Channel Part
5. Performance Analysis

3.3.1 Assumptions in Phase 1

The assumptions made for this phase of simulation are stated as follows:

- Evaluation of the performance is made on one user in the multi-user environment. It considers the rest of the users contribute the multi user interference to the reference user in the system.
- Decision statistic of the receiver, Z_0 is modeled as Gaussian Random Variable.
- Decision statistic of the desired user, I_0 is deterministic.

- Multi-User Interference (MUI), in the system is assumed as zero-mean Gaussian variables and it is an AWGN. This is based on the ARIB proposal which states that all interference from other users is modeled as Additive White Gaussian Noise (AWGN).

- Thermal noise K is very small and negligible. This is based on the data in ARIB proposal.

- In this simulation, only downlink (base station to mobile station) transmission t is considered.
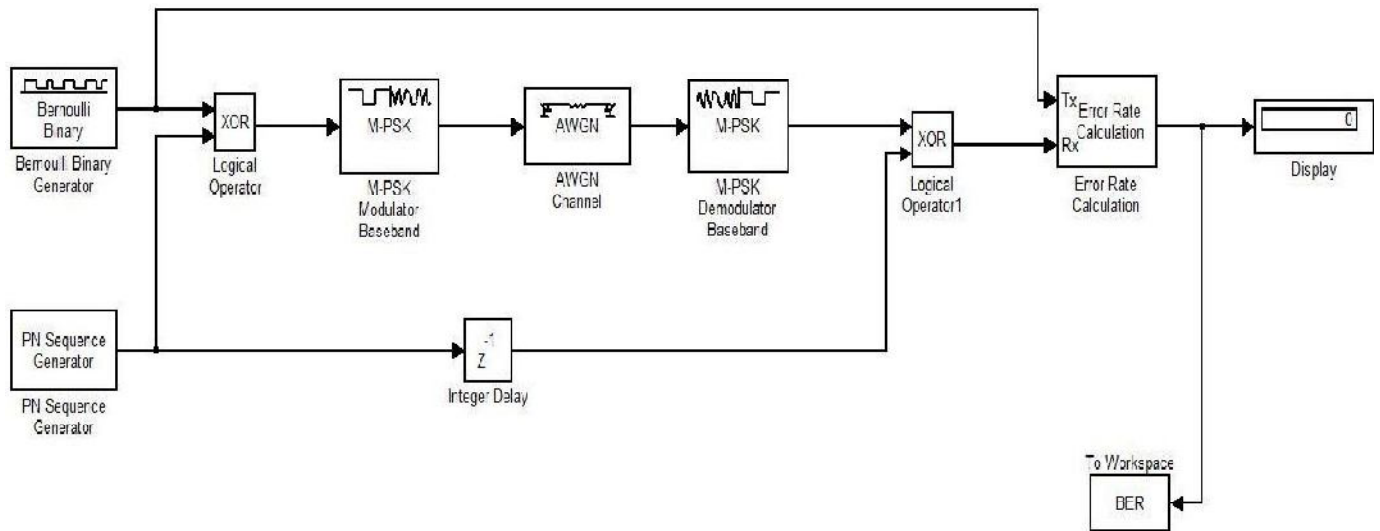
Figure 22: W-CDMA Model Using QPSK Modulation Technique in AWGN Channel

3.3.2 Transmitter Design

3.3.2.1 User Data Sequence Generator

The signal is produced by Bernoulli Data Generator. The Bernoulli Binary Generator block generates random binary numbers using a Bernoulli distribution. The Bernoulli distribution with parameter p produces zero with probability p and one with probability 1-p. The Bernoulli distribution has mean value 1-p and variance p(1-p). The Probability of a zero parameter specifies p, and can be any real number between zero and one. Table below shows the parameters used in Bernoulli Binary Generator block.

Table 1: Parameters for Bernoulli Binary Generator Block

Parameter	Value
Probability of Zero	0.5
Initial Seeds	12345
Sample Time	Tsample
Frame-based Output	unchecked
Interpret Vector Parameter as 1-D	unchecked

Parameters for Bernoulli Binary Generator Block

- Probability of Zero: The probability with which a zero output occurs. The value of 0.5 means the random binary numbers generated having equal amount of '0' and '1'.

- Initial Seeds: The initial seed value for the random number generator. 12345 has been chosen.

- Sample Time: The period of each sample-based vector or each row of a frame-based matrix. Here, Tsample is declared in the associated m file (chk_QPSK_no_noise.m) and it has a value of 1/384000 seconds.

- Attribute of Output Signal. In this block, we declare the signal to be sample-based where the frame-based outputs box is unchecked.

3.3.2.2 Spreading Sequence Generator

The PN Sequence Generator block generates a sequence of pseudorandom binary numbers. A pseudo-noise sequence can be used in a pseudorandom scrambler and descrambler. It can also be used in a direct-sequence spread-spectrum system. The PN Sequence Generator block uses a shift register to generate sequences. Table 3.2 below shows the parameter that has been used in the simulation.

Table 2: Parameters used in PN Sequence Generator Block

Parameter	Value
Generator Polynomial	[1 0 0 0 0 1 1]
Initial States	[1 0 0 0 0 1]
Shift (or mask)	0
Sample time, Tc	Tchip
Attribute of Output Signal	Sample-based output

Parameters Specific to PN Sequence Generator

a) The Generator polynomial parameter has been specifying using this format:

- A vector that lists the coefficients of the polynomial in descending order of powers. The first and last entries must be 1. Note that the length of this vector is one more than the degree of the generator polynomial. It is known that the degree of the generator polynomial is 6 so the length of the vector is 7. So, in this simulation, the value of Generator Polynomial specifies as [1 0 0 0 0 1 1] represent the same polynomial, $p(z) = Z^6 + Z^1 + 1$ to fulfill the format above.

b) The initial states parameter is a vector specifying the initial values of the registers. The initial states parameter must satisfy these criteria:

- All elements of the Initial states vector must be binary numbers.
- The length of the Initial states vector must equal the degree of the generator polynomial.
- At least one element of the Initial states vector must be nonzero in order for the block to generate a nonzero sequence. That is, the initial state of at least one of the registers must be nonzero.

So, in this simulation, the value of initial states specifies as [1 0 0 0 0 1] to satisfy the criteria above.

c) Sample time: Tc in this case is equal to chip period. In this simulation chip period 260.4167 ns inverse of chip rate, 3.84 M chips per second (Mcps) is used and it is declared in the (chk_QPSK_no_noise.m) file. In the sample time parameter check box of the (QPSK_no_noise.mdl) file, it is declared as Tchip.

d) Attribute of Output Signal: In Simulink, each matrix signal has a frame attribute that declares the signal to be either frame-based or sample-based, but not both. (A one-dimensional array signal is always sample-based, by definition.) Simulink indicates the frame attribute visually by using a double connector line in the model window instead of a single connector line. In general, Simulink interprets frame-based and sample-based signals as follows:

- A frame-based signal in the shape of an M-by-1 (column) matrix represents M successive samples from a single time series.
- A frame-based signal in the shape of a 1-by-N (row) matrix represents a sample of N independent channels, taken at a single instant in time.
- A sample-based matrix signal might represent a set of bits that collectively represent an integer, or a set of symbols that collectively represent a code word, or something else other than a fragment of a single time series.

So, in this block, we declare the signal to be sample-based with unchecked the frame-based outputs box.

3.3.2.3 Spreader

XOR block has been used to operate like a spreader. Spreader causes the data symbols to be spread to a higher bandwidth, by multiplying the random binary data symbols, bit rate equal to Tb with a high bit rate code sequence (pseudo noise chip sequence), chip rate equal to Tc.

Parameters Specific to Logical Operator Block

a) Operator. XOR has been selected.

b) Number of input ports = 2

c) 'Show additional parameters' box is checked.

d) 'Require all inputs and output to have same data type' box is checked.

e) Output data type mode. Logical has been selected. To avoid any data or signal incompatibility, the following steps are taken. Go to the menu bar of simulation/simulation parameters/Advanced tab. Select Boolean Logic Signals to off, then the output data type will match the input data type, which may be Boolean or double.

3.3.3 Modulation Techniques

3.3.3.1 QPSK Modulator

In this simulation, Quadrature Phase Shift Keying (QPSK) Passband modulator has been used. The M-PSK Modulator Passband block modulates using the M-ary phase shift keying method. The output is a passband representation of the modulated signal. The M-ary number parameter, M, is the number of points in the signal constellation.

This block uses the baseband equivalent block, M-PSK Modulator Baseband, for internal computations and converts the resulting baseband signal to a passband representation. The following parameters in this block are the same as those of the baseband equivalent block:

- M-ary number
- Input type
- Constellation ordering

The input must be sample-based. If the Input type parameter is Bit, then the input must be a vector of length log2 (M). If the Input type parameter is Integer, then the input must be a scalar.

This block uses a baseband representation of the modulated signal as an intermediate result during internal computations.

Table 3.3 below shows the parameter that has been used in the simulation.

Table 3: Parameters used in QPSK Modulator Passband Block

Parameter	Value
M-ary number	4
Input type	Integer
Symbol period (s)	1 / 3840000 Hz
Baseband samples per symbol	1
Carrier frequency (in Hz)	15000000
Carrier initial phase (in rad)	pi/4
Output sample time (s)	1 / 38000000 Hz

Parameters Specific to Passband Simulation

a) M-ary number is set up to 4 means it using four points in the signal constellation. This setting also indicates the modulator to function as a QPSK modulator.

b) Input type parameter is set up to integer means the input must be a scalar.

c) The Symbol period parameter must equal the sample time of the input signal. The sample time of the input signal is equal to Tc = 260.4167 ns. So, the symbol period equal to 260.4167 ns or inverse of 1/3840000 Hz.

d) Baseband samples per symbol. The Baseband samples per symbol parameter indicates how many baseband samples correspond to each integer or binary word in the input, before the block converts them to a passband output. In this simulation, baseband samples per symbol specify to one baseband sample per symbol.

e)Passband simulation uses a carrier signal. Carrier frequency (fc), 15,000,000 Hertz (Hz) has been used. The actual carrier frequency that should be used is 2 GHz to fulfill the third generation requirements. Smaller frequency is used because of the computer ability to simulate larger value of the carrier frequency. Simulation runs very slow when value 2 GHz applied. The assumption made for simulation environment, the differences between values of carrier frequency does not affect the system.

f) Carrier initial phase in radians specify the initial phase of the carrier signal. In this simulation, the initial phase = (pi/4) or S/4 indicates the initial phase for QPSK modulation scheme.

g) Output sample time. The Output sample time parameter determines the sample time of the output signal. The timing-related parameters must satisfy these relationships:

- Symbol period > (Carrier frequency)$^{-1}$
- Output sample time < [2 * Carrier frequency + 2/(Symbol period)]$^{-1}$

3.3.4 Channel Design

The AWGN Channel block adds white Gaussian noise to a real or complex input signal. When the input signal is real, this block adds real Gaussian noise and produces a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. This block inherits its sample time from the input signal. This block uses the Signal Processing Blockset's Random Source block to generate the noise. The Initial seed parameter in this block initializes the noise generator. Initial seed can be either a scalar or a vector whose length matches the number of channels in the input signal.

The following table 3.5 shows the parameters used in AWGN block.

Table 4: Parameters used in AWGN block

Parameter	Value
Initial seeds	1237
Mode	Signal to Noise ratio (Es/No)

Es/No	EbNo
Input Signal Power (Watt)	1
Symbol-period (s)	Tchip

In the generic m file, the EbNo will produce a sequence of 2 EbNo intervals for 12 EbNo. The symbol period of AWGN block is Tchip that is equivalent to 1/38e6.

3.3.5 Receiver Design

3.3.5.1 QPSK Demodulator

The M-PSK Demodulator Passband block demodulates a signal that was modulated using the M-ary phase shift keying method. The input is a passband representation of the modulated signal. The M-ary number parameter, M, is the number of points in the signal constellation. This block converts the input to an equivalent baseband representation and then uses the baseband equivalent block, M-PSK Demodulator Baseband, for internal computations. The following parameters in this block are the same as those of the baseband equivalent block:

- M-ary number
- Output type
- Constellation ordering

The input must be a sample-based scalar signal. Similar parameters for QPSK Demodulator will be used as QPSK Modulator except for parameter input sample time. In this simulation, input sample time is equal to output sample time of QPSK Modulator.

Table3.6 below shows the parameter that has been used in the simulation.

Table 5: Parameters used in QPSK Demodulator Passband Block

Parameter	Value
M-ary number	4
Input type	Integer
Symbol period (s)	1 / 3840000 Hz
Baseband samples per symbol	1
Carrier frequency (in Hz)	15000000
Carrier initial phase (in rad)	pi/4
Output sample time (s)	1 / 38000000 Hz

3.3.5.2 Delays from QPSK Demodulation

Digital modulation and demodulation blocks sometimes incur delays between their inputs and outputs, depending on their configuration and on properties of their signals. Refer to the Release Notes 'Communication Blockset for Use with Simulink', all passband demodulators except OQPSK will experience delays in amount of one output period. So, QPSK passband demodulator causes delays of one ouput period occur in this simulation block.

To calculate the bit error rate correctly, additional delay of 1 second to the transmitted signal to synchronize it with the received signal. This is done directly in the mask for the Error Rate Calculation block by setting the Receive delay to 1.

For the same reason, the PN chip sequence and received signals need to be synchronizing before they enter the Despreader block. In this case, Integer Delay block has been used, which delays a signal by the number of sample periods specified by the Delay parameter. Set the Delay to 1. This is indicated by the exponent -1 on the block. The delay synchronizes the PN chip sequence signal with the received signal so that the Despreader block can recovered back the original data symbols correctly.

3.3.6 Despreader

In order to recover the data symbols from the spreading signal, the process of dispreading is applied. This is done by 'XOR' the high bit rate noise-like signal with a local spreading chip code that has the same sequence with the transmitting code. When this right code is chosen with right synchronization, in this case delay is one output period; the output from the 'XOR' block will be exactly the same as the source signal. Parameters for Despreader block are same like the Spreader block.

3.3.7 Error Rate Calculation

The Error Rate Calculation block compares input data from a transmitter with input data from a receiver. It calculates the error rate as a running statistic, by dividing the total number of unequal pairs of data elements by the total number of input data elements from one source.

Table 3.8 below shows the parameter that has been used in the simulation.

Table 6: Parameters used in Error Rate Calculation Block

Parameter	Value
Receive delay	1
Computation delay	0
Computation mode	Entire frame
Output data	Port
Reset port box	Unchecked
Stop simulation box	Checked
Target number of errors	5000
Maximum number of symbols	5000

a) Receive delay set up to 1 due to delay causes by QPSK Demodulator. Refering to the release notes 'Communication Blockset for Use with Simulink', the delay should be put as 1 to ensure the transmitted signal synchronize with the received signal.

b) Computation mode is set to entire frame. Then the block compares the entire transmitted frame with the entire received frame.

c) Output Data. This block produces a vector of length three, whose entries correspond to:

- The error rate.
- The total number of errors, that is, comparisons between unequal elements.
- The total number of comparisons that the block made.

Output data parameter is set to Port, and then an output port appears. This output port contains the running error statistics. Output port from this block connected to the Display.

d) The simulation stops when the maximum number of symbols is reached at 5000 data symbols even the target number of errors not reached 5000 errors.

3.3.8 Display

The Display block shows the value of its input, the amount of data displayed and the time steps at which the data is displayed are determined by block parameters:

- The display format can be control by selecting a Format choice: short, which displays a 5-digit scaled value with fixed decimal point
- The Decimation parameter enables you to display data at every nth sample, where n is the decimation factor. The default decimation, 1, displays data at every time step.
- The Sample time parameter enables you to specify a sampling interval at which to display points. This parameter is useful when you are using a variable-step solver where the interval between time steps might not be the same. The default value of 1

causes the block to ignore the sampling interval when determining the points to display.

Table 3.9 below shows the parameter that has been used in the simulation.

Table 7: Parameters used in Display Block

Parameter	Value
Format	Short
Decimation parameter	1
Floating display cox	unchecked
Sample time	-1

The display block shows the bit error rate, the number of errors and the total number of bits that are transmitted.

3.3.9 Performance Analysis for Phase 1

In this simulation, a generic m file is used together with simulink to simulate the BER vsEb/No graphs (refer to Appendix, section 1.1). This m file declares the parameters defined in the simulink's block diagram check box. For example, variable Tsample declared in the m file is the sampling time of Bernoulli Binary Generator. Tchip, on the other hand, is the sampling time of spreading sequence generator. EbNoVec is signal to noise ratio and it is taken at 6 evenly points starting from 0. Then, for loop is used to calculate the BER for every EbNoVec assigned to it. The value of EbNo will be stored in the work space. Command sim is used to simulate simulink mdl file. Finally, command semilog is used to create the graph for BER vsEb/No.

First, the simulation is done by running the concerned mdl file. Once the output values are stored in the workspace, the associated m file is typed under the command window and it is run. Finally, BER graph vsEbNo graphs are obtained once the simulation is completed.

The generic m file used to generate BER vsEb/No graph

```
M = 4;

Tsample = 1/384000;        % Bernoulli Binary Sampling time

Tchip= 1/3840000;          % Chip sampling time

BERVec = [];

EbNoVec = [0:2:12];

        for n=1:length(EbNoVec);

        EbNodB = EbNoVec(n);

        sim('WCDMA_QPSK_baseband');

        BERVec(n,:) = BER;

        end;

semilogy(EbNoVec,BERVec(:,1),'+');

legend('Bit error rate');

xlabel('Eb/No (dB)'); ylabel('Error Probability');

title('Bit Error Probability');
```

In this phase, the system is simulated based on the following conditions

1. Bit Error Rate (BER) versus Signal-to-Noise ratio (SNR) in AWGN channel for QPSK modulation technique.

3.4 Simulation Phase 2: WCDMA system in AWGN and Multipath Rayleigh Fading

In Phase 2, both transmitter and receiver part are built based on the system model as shown in figure 3.2 and figure 3.3. In this model, multipath Raleigh fading channel block is added in the system. The rest of system blocks and parameters are unchanged.

In this phase of simulation, the model is simulated in the baseband simulation environment. The input of multipath Raleigh fading block requires complex signal which can be obtained through baseband simulation only.

Moreover, in passband simulation, the simulation models the carrier frequency. Since the carrier frequency is usually a high frequency signal, modeling passband communication systems involves high computational loads. To alleviate this problem, baseband simulation techniques are used.
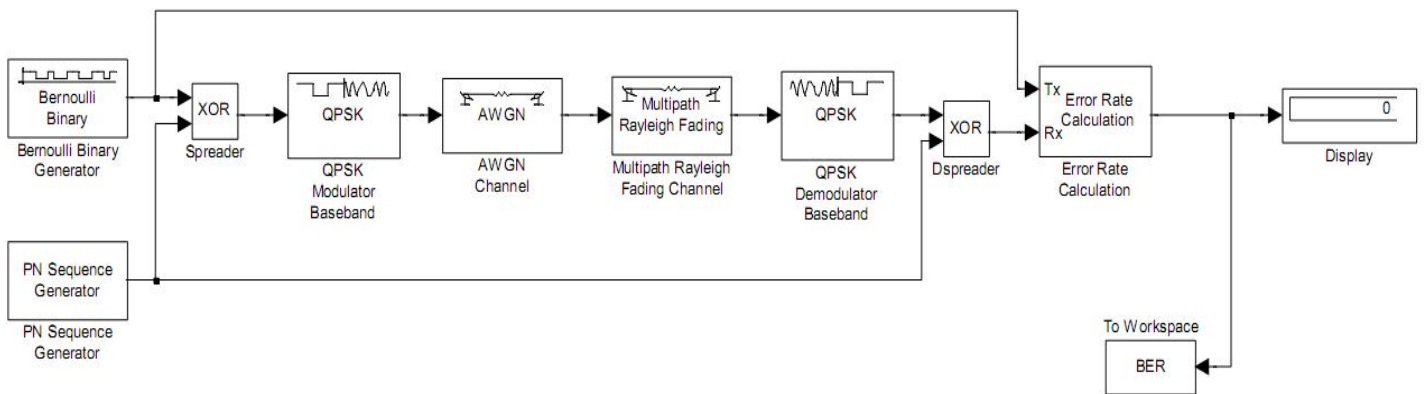

Figure 23: W-CDMA Model with Multipath Raleigh Fading Channel and AWGN Channel Using QPSK Modulation

3.4.1 Channel

The Multipath Rayleigh Fading Channel block implements a baseband simulation of a multipath Rayleigh fading propagation channel. This block is useful for modeling mobile wireless communication systems.

Table 3.10 below is used to initialize the parameters in the multipath Rayleigh fading block.

Table 8: Parameters used in multipath Rayleigh fading channel

Parameter	Value
Maximum Doppler shift (Hz)	55.56 / 83.33 / 111.111
Sample time (s)	1/3840000
Delay vector (s)	2-ray [0 2e-6]
	3-ray [0 2e-6 3e-6]
Gain vector (s)	2-ray [0 -3]
	3-ray [0 -3 1]
Normalize gain vector to 0 dB overall gain box	Checked
Initial seed	40

a) Maximum Doppler shift (Hz): Relative motion between the transmitter and receiver causes Doppler shifts in the signal frequency. The Jakes PSD (power spectral density) determines the spectrum of the Rayleigh process. This implementation is based on the direct form simulator described in reference [1]. Some wireless applications, such as standard GSM (Global System for Mobile Communication) systems, prefer to specify Doppler shifts in terms of the speed of the mobile. If the mobile moves at speed v making an angle T of with the direction of wave motion, then the Doppler shift is

$$F_d = \left(\frac{vf}{c}\right)\cos\theta$$

Where, f is the transmission carrier frequency and c is the speed of light. The Doppler frequency is the maximum Doppler shift arising from motion of the mobile. In this project, to determine maximum Doppler shift for third generation systems, we assume that the transmission carrier frequency, f = 2GHz. We assume mobile moves at three different speed, v = 60 km/hr, v = 90 km/hr and v = 120 km/hr. Different speeds modeling the system in three different situations; in the middle of town, in the main road and in the highway. Angle T set to 60 degree.

Based on the assumptions above, the maximum Doppler shift for every speed value is:

When v = 60 km/hr;   then Fd = 55.56

When v = 90 km/hr;   then Fd = 83.33

When v = 120 km/hr; then Fd = 111.111

b) Sample time equal to chip code rate, Tc = 3840000 Hz.

c) Delay vector is a vector that specifies the propagation delay for each path. In this project, we assume the delays for 2 paths are 0 second and 2e-6 second and the delays for 3 paths are 0 second, 2e-6 second and 3e-6 second.

d) Gain vector is a vector that specifies the gain for each path. The gains for 2 paths are 0 dB and -3 dB. The gains for 3 paths are 0 dB, -3 dB and 1 dB.

e) Normalize gain vector to 0 dB overall gain box. Checking this box causes the block to scale the Gain vector parameter so that the channel's effective gain (considering all paths) is 0 decibels.

3.4.2 Performance Analysis for Phase 2

Same procedures are used to do the performance analysis for phase 2 as they are done in phase 1. Performance analysis for this system is based on the following conditions:

1. BER versus SNR in AWGN and multipath Rayleigh fading channel with Doppler shift (60kmph, 90kmph and 120kmph) for QPSK modulation technique.

In summary, there are six procedures to be based on for simulation in phase 1 and phase 2 as they are shown as follows:

1. Bit Error Rate (BER) versus Signal-to-Noise ratio (SNR) in AWGN channel for QPSK modulation technique.

2. BER versus SNR in AWGN and multipath Rayleigh fading channel with Doppler shift (60kmph, 90kmph and 120kmph) for QPSK modulation technique.

3. BER versus SNR to compare between AWGN channel and multipath Raleigh fading channel for different number of user for QPSK modulation technique.

3.5 Simulation Using M file

Another method is simulation using M-files. A script can be written in MATLAB editor or another text editor to create a file containing the same statements that can be typed at the MATLAB command line. The file is saved under a name that ends in .m. The MATLAB language used in m file is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both simple and complicated programs to simulate all real-time situations.

3.5.1 Generation of Spreading Code

In CDMA, the choice of code sequence is very important in respect to multiuser and multipath interference encountered by the signal in the channel. To combat these interferences, the code has to have the following properties:

1. Each code sequence generated from a set of code-generation functions must be periodic with a constant length.

2. Each code sequence generated from a set of code-generation functions must be easy to distinguish from its shifted code.

3. Each code sequence generated from a set of code-generation functions must be easy to distinguish from other code sequences.

3.5.2 Assumption and Limitation

DS-CDMA is the main system model to study the performance of modulation techniques in multipath channel. There will be no error correction scheme (channel coding) used in this project. Also, there will be no equalization as well as interleaving employed in the W-CDMA system model. The receiver is assumed not a RAKE receiver neither MIMO receiver. The channel is subjected to AWGN and Rayleigh fading only. Furthermore, the BER in AWGN for this model is based on the Simplified Improved Gaussian Approximation (SIGA). On the other hand, BER for Rayleigh fading is based on either synchronous or asynchronous transmissions. For asynchronous transmission, the assumption is that the Multi Access Interference (MAI) on the flat Rayleigh fading channel has a Gaussian first-order distribution. However, characteristic function,), is used in asynchronous transmission to determine the total MAI, I, and therefore the BER can be computed based on these variables.

3.5.3 Performance Analysis on W-CDMA

Based on data generated by computer simulation of W-CDMA models, relationship for multiple rays using QPSK and BPSK modulation techniques between BER as a function of the following parameters are obtained. They are:

1. Bit Error Rate (BER) versus Signal-to-Noise ratio (SNR) in AWGN channel for QPSK modulation technique.

2. BER versus SNR in AWGN and multipath Rayleigh fading channel with Doppler shift (60kmph, 90kmph and 120kmph) for QPSK modulation technique.

3. BER versus SNR to compare between AWGN channel and multipath Raleigh fading channel for different number of user for QPSK modulation technique.

The performance analysis begins with simulation using Simulink. In this section, discussion of the performance analysis is made for QPSK and BPSK. However, close to unsatisfactory results are discovered when the system is simulated using BPSK particularly in multipath Rayleigh fading channel. The performance for this modulation technique does not yield the desired BER graph.

To overcome this problem, the simulation is followed by using m file. In this approach, the simulation is successfully done using QPSK modulation technique. The desired BER graphs are obtained for simulation in AWGN channel. Also, satisfactory result is obtained when the system is simulated in AWGN and multipath Fading channel subjected to Doppler Shift with mobile terminal moving at 60kmph, 90kmph and 120kmph. However, the simulation does not yield the desired outcome when BPSK is employed as the modulation technique in the WCDMA system. The results of these two approaches are discussed in this chapter.

3.6 Simulation Using Simulink

3.6.1   DSSS of CDMA code generation
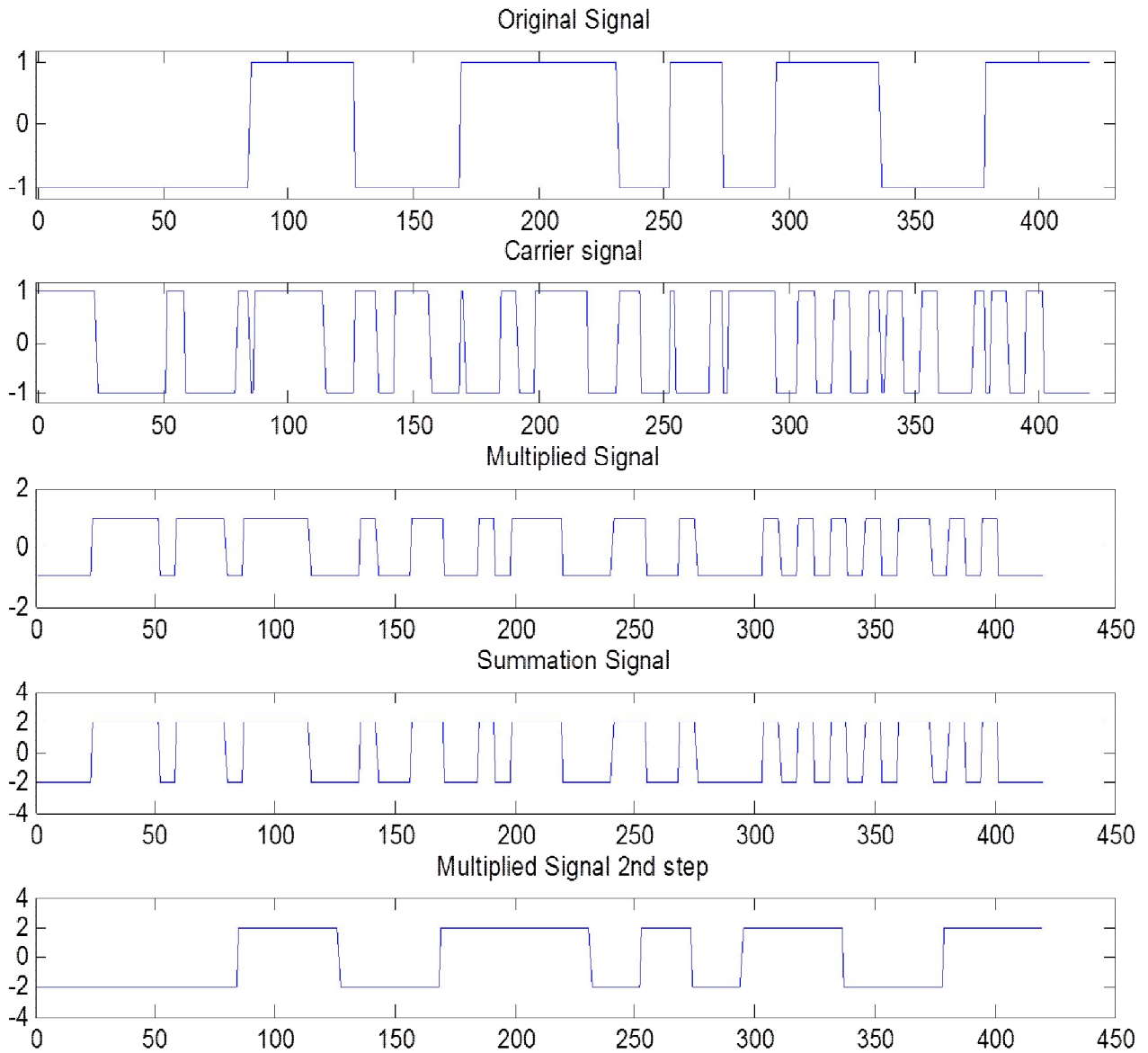
3.6.1(a)   Type-1: Single User System

Fig 24: Single user CDMA system (code generating technique)
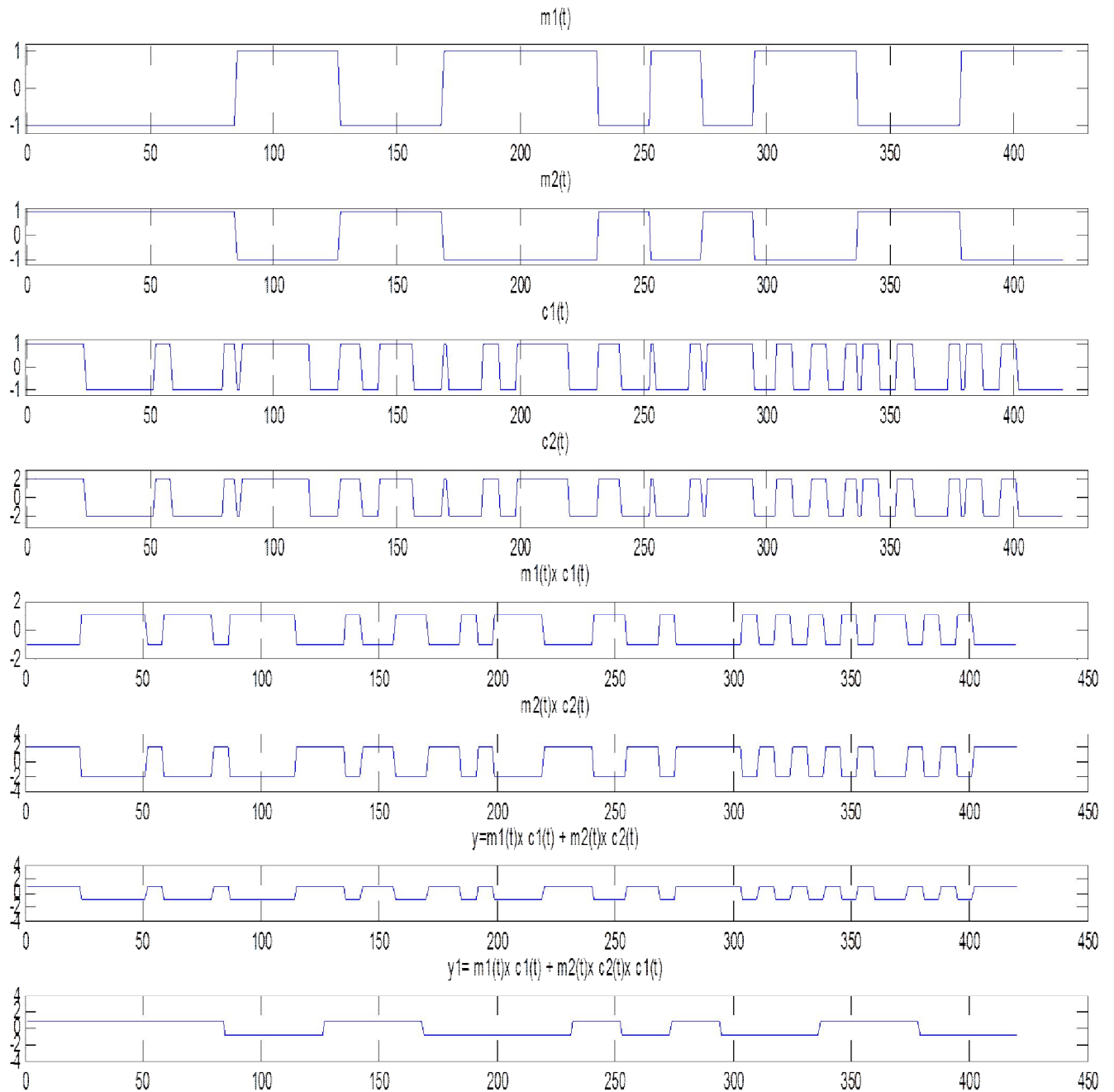
3.6.1(b)   Type-1: Multi-User CDMA System

Fig 25: Multi-user CDMA system (code generating technique)

3.7. Performance Analysis

3.7.1 Performance Analysis of QPSK modulation technique of WCDMA in AWGN
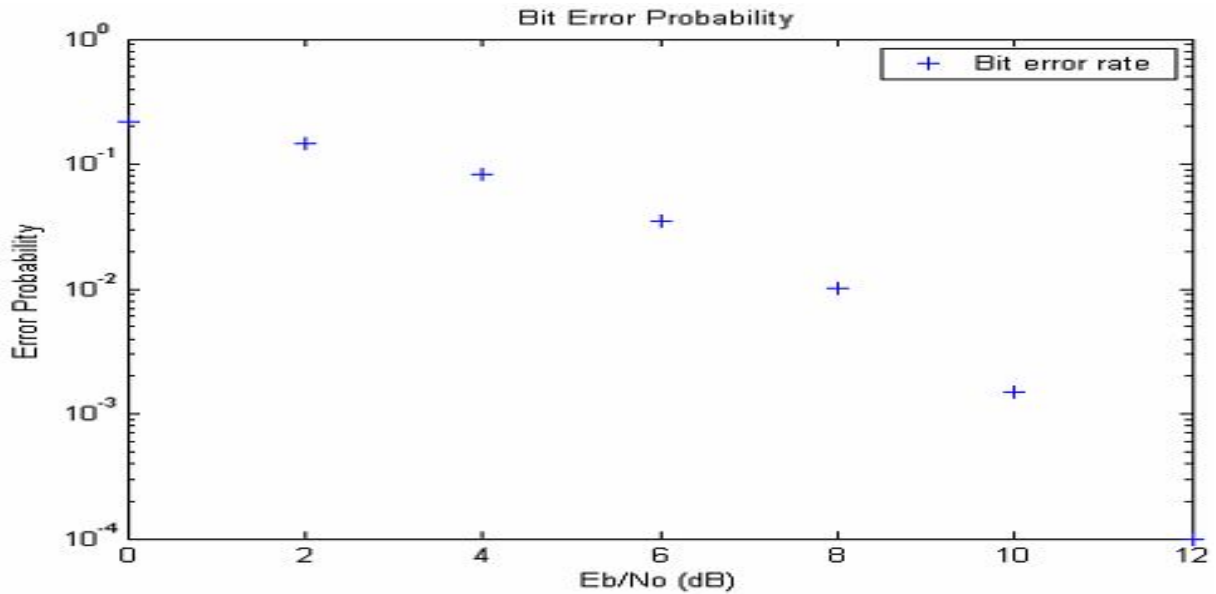

Figure 26: Performance of WCMA System Using QPSK in AWGN Channel

3.7.2 Performance Analysis of QPSK modulation technique of WCDMA in AWGN and Multipath Fading Channel
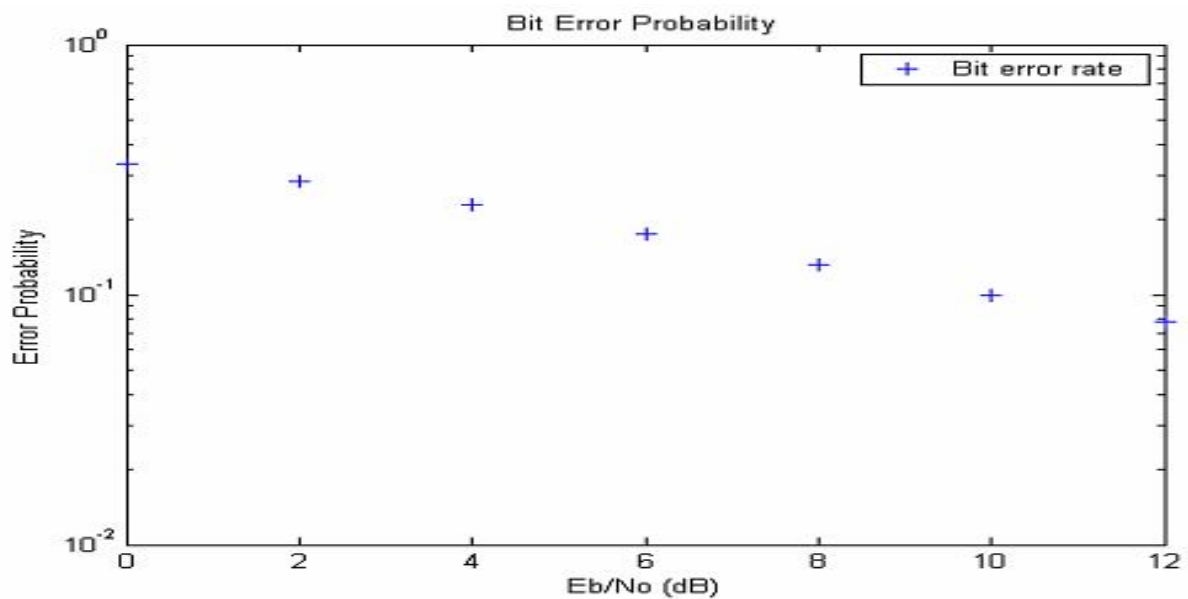

Figure 27: Performance of WCDMA System Using QPSK in Multipath Fading Channel at 60 kmph
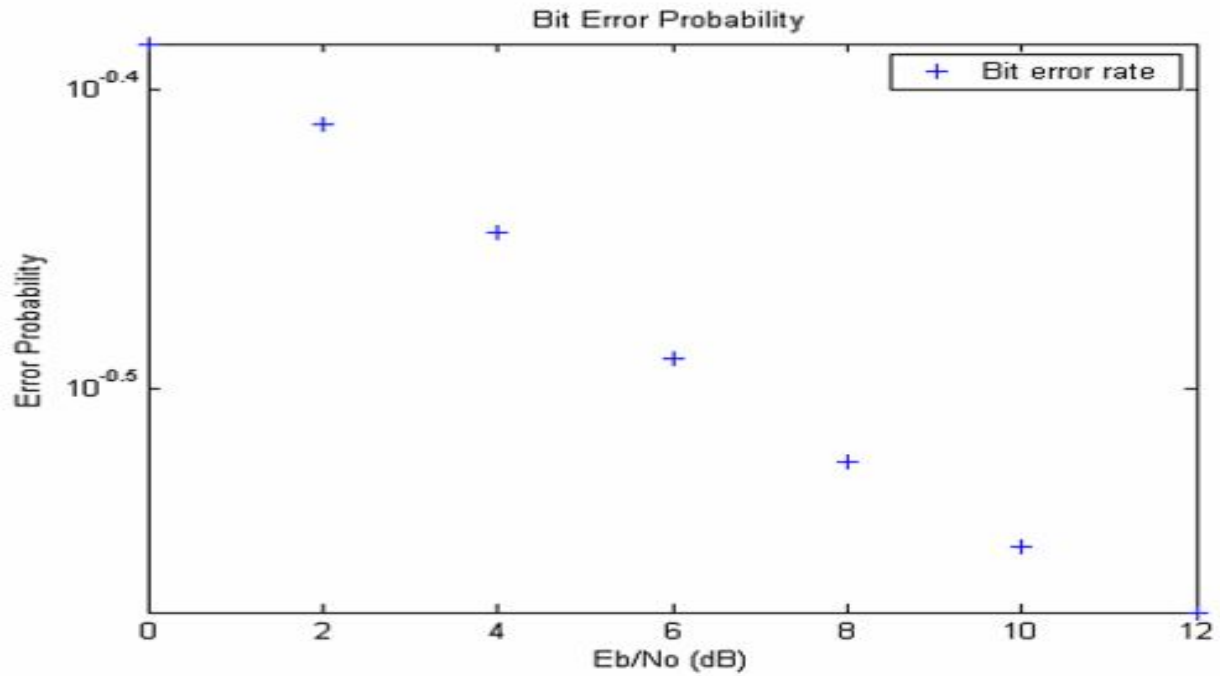
Figure 28: Performance of WCDMA System Using QPSK in Multipath Fading Channel for 90kmph
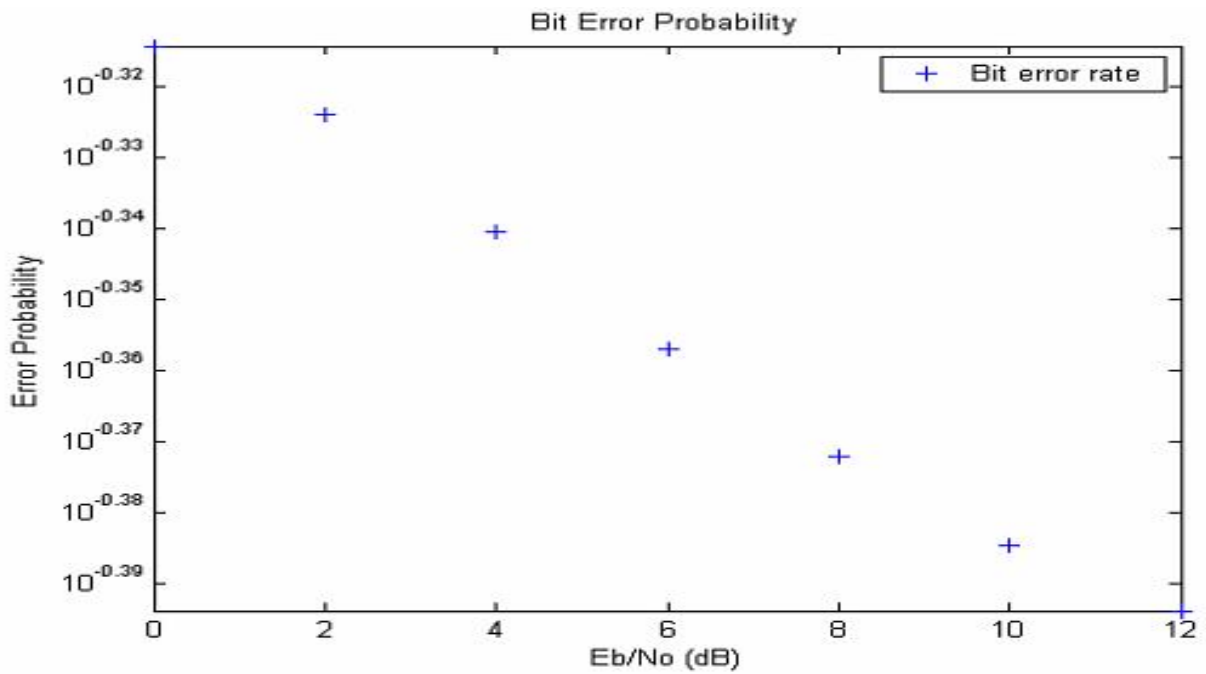

Figure 29: Performance of WCDMA System Using QPSK in Multipath Fading Channel at120kmph

3.8 Simulation Using M files

3.8.1 Performance Analysis of QPSK modulation technique of WCDMA in AWGN

Simulation result for evaluation on BER vs. SNR for 2-ray AWGN channel for 1 user when the number of data is 200,000

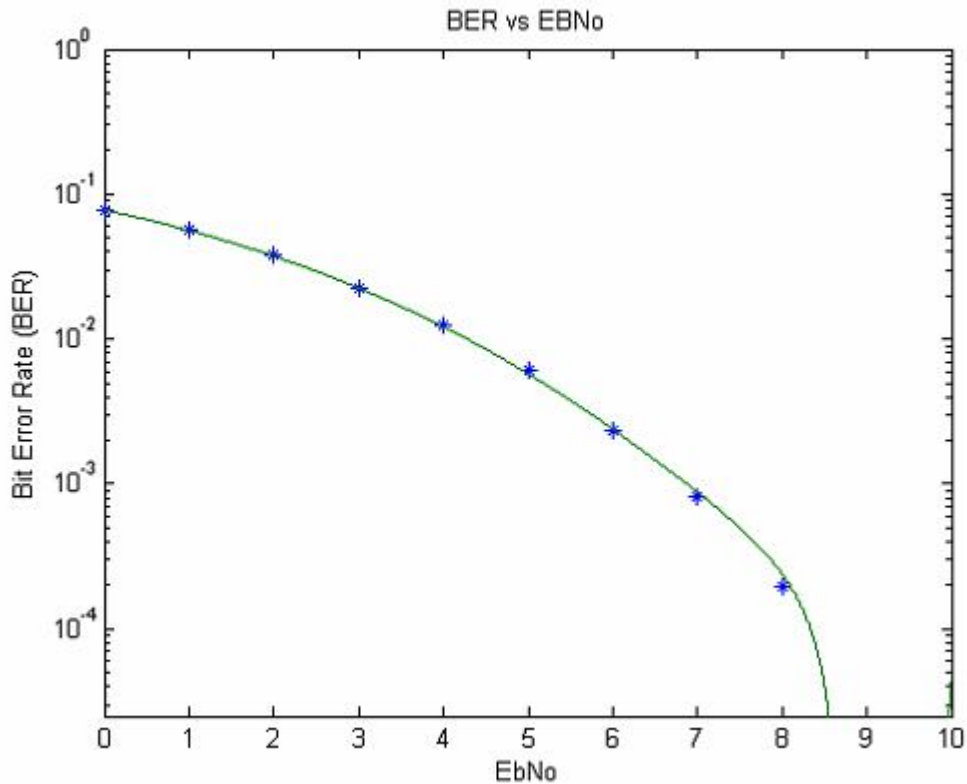Figure 30: Performance of WCDMA in 2-Rays AWGN Channels for 1 User

3.8.2 Performance Analysis of QPSK modulation technique of WCDMA in AWGN and Multipath Fading Channel

The simulation of BER is done in the range of 0 to 20 of EbNo. The BER graphs of various Doppler shifts are simulated on the same graph as it is shown in figure 4.10. The y axis of BER is blown up to depict the behavior in Doppler shift environment.

Simulation results for evaluation on BER vs. SNR for 2-ray Multipath Rayleigh Fading channel for 1 user when the number of data is 200,000 at 60, 90,120 kmph
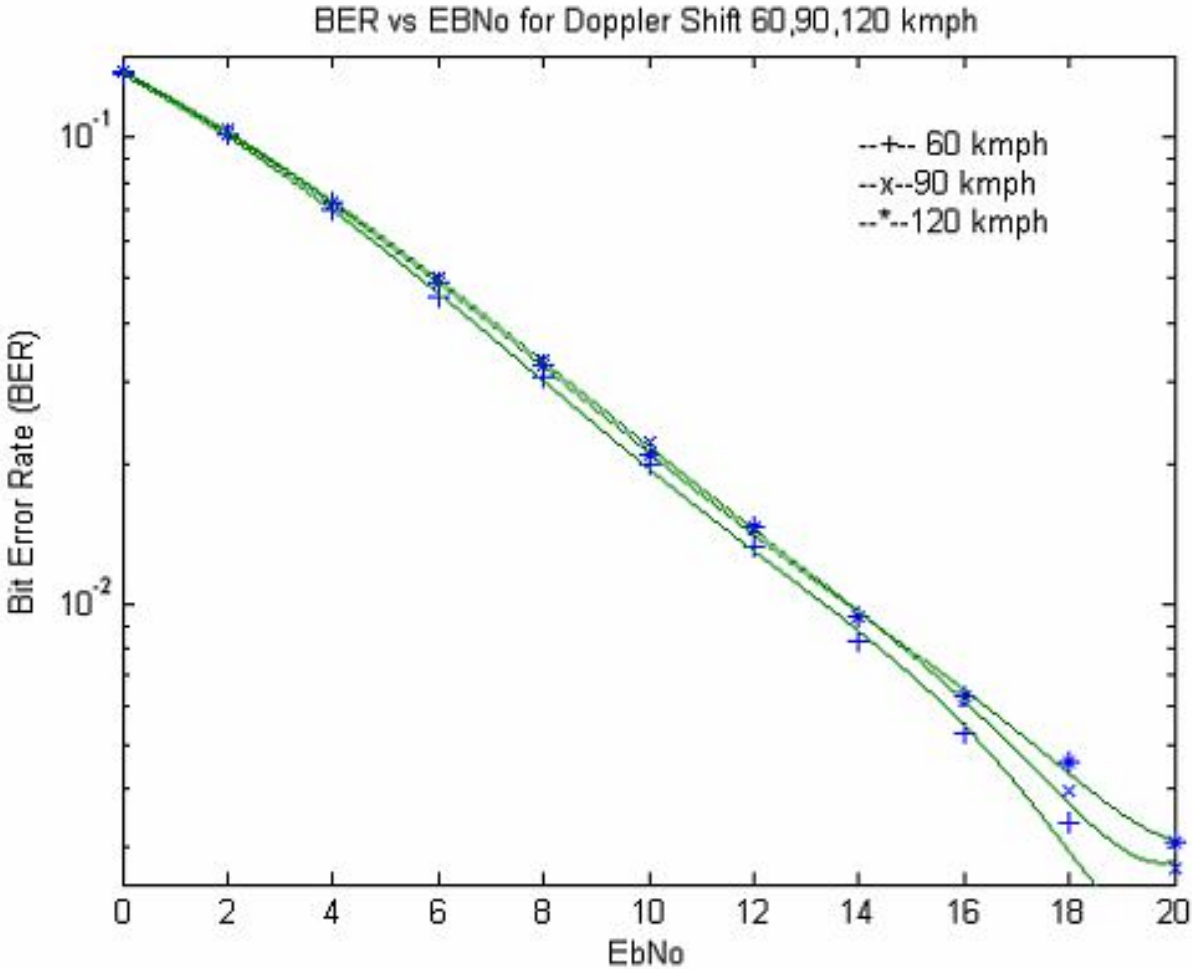

Figure 31: Performance of WCDMA in 2-Rays Multipath Rayleigh Fading Channels

for 1 User

3.8.3 Performance Analysis Comparison of QPSK modulation technique of WCDMA between AWGN and Rayleigh Fading Channel

Simulation result for evaluation on BER vs. SNR for 2-ray AWGN channel and Multipath Rayleigh channel for 1 user when the number of data is 200,000 and for 5 user when the number of data is 100,000

(a)

(b)
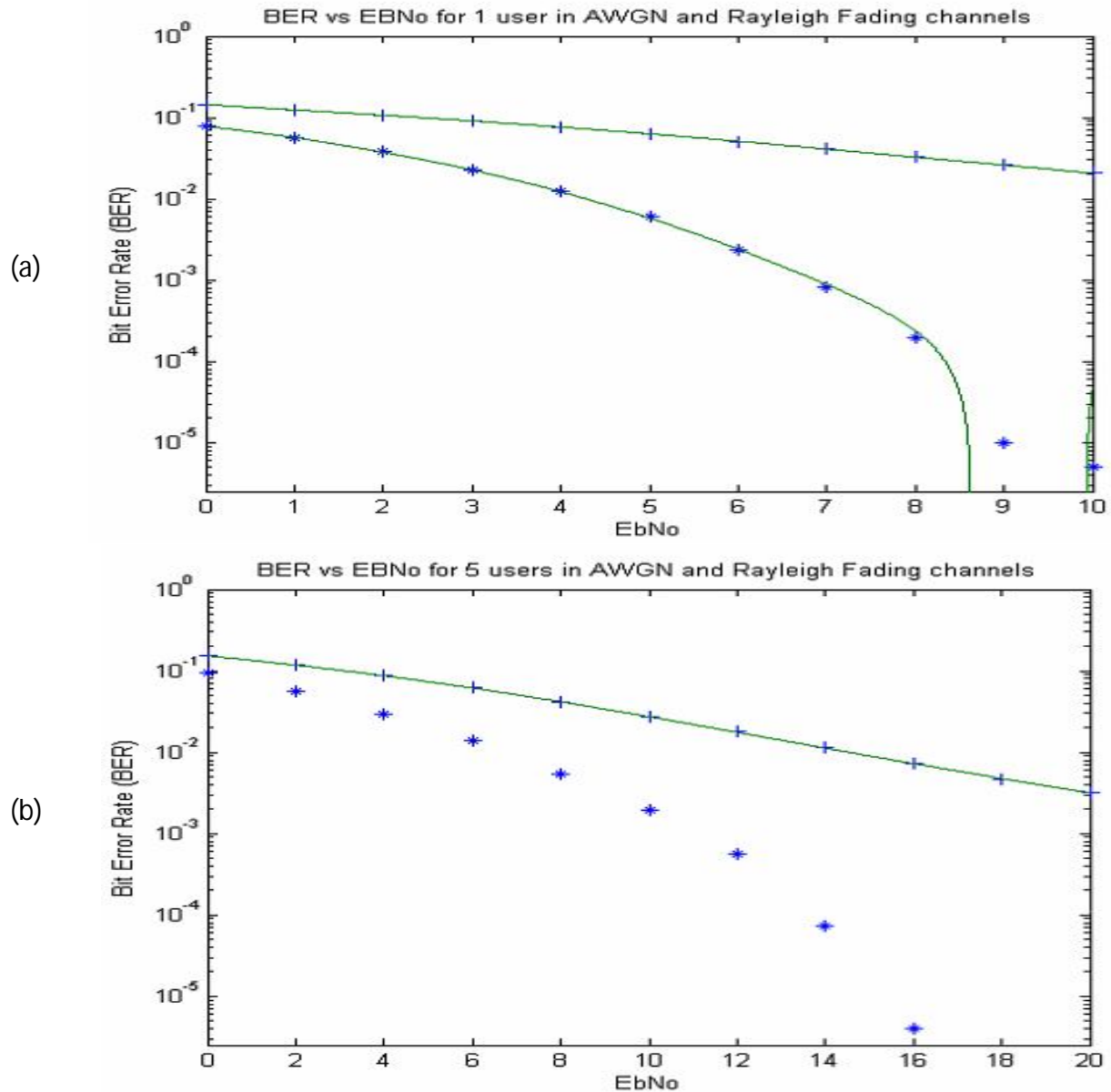
Figure 32: (a) Performance Comparison of WCDMA in 2-Rays between AWGN and Multipath Rayleigh Fading Channels for 1 user (b) Performance Comparison of WCDMA in 2-Rays between AWGN and Multipath Rayleigh Fading Channels for 5 User

3.9 Matlab Script Coding Using M files

3.9.1 Performance Analysis of BPSK modulation technique of WCDMA in AWGN
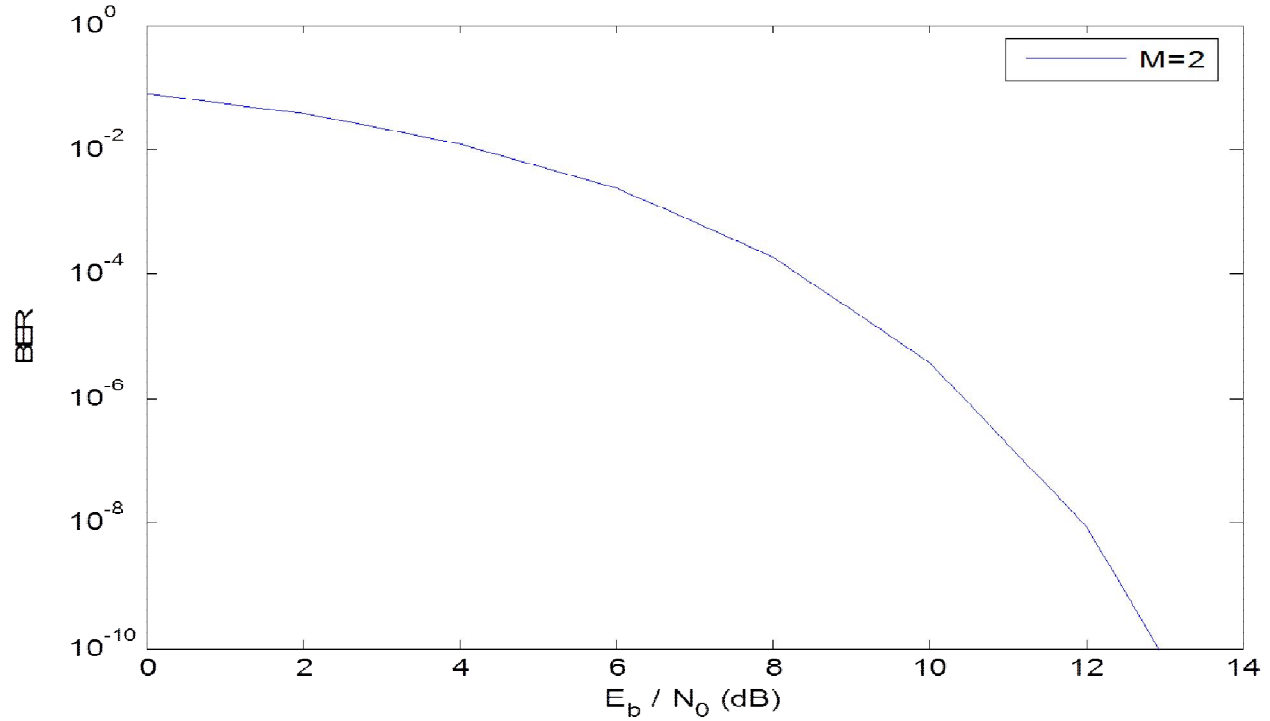
Fig 33: BER vs. SNR for user, M=2 without fading using AWGN channel
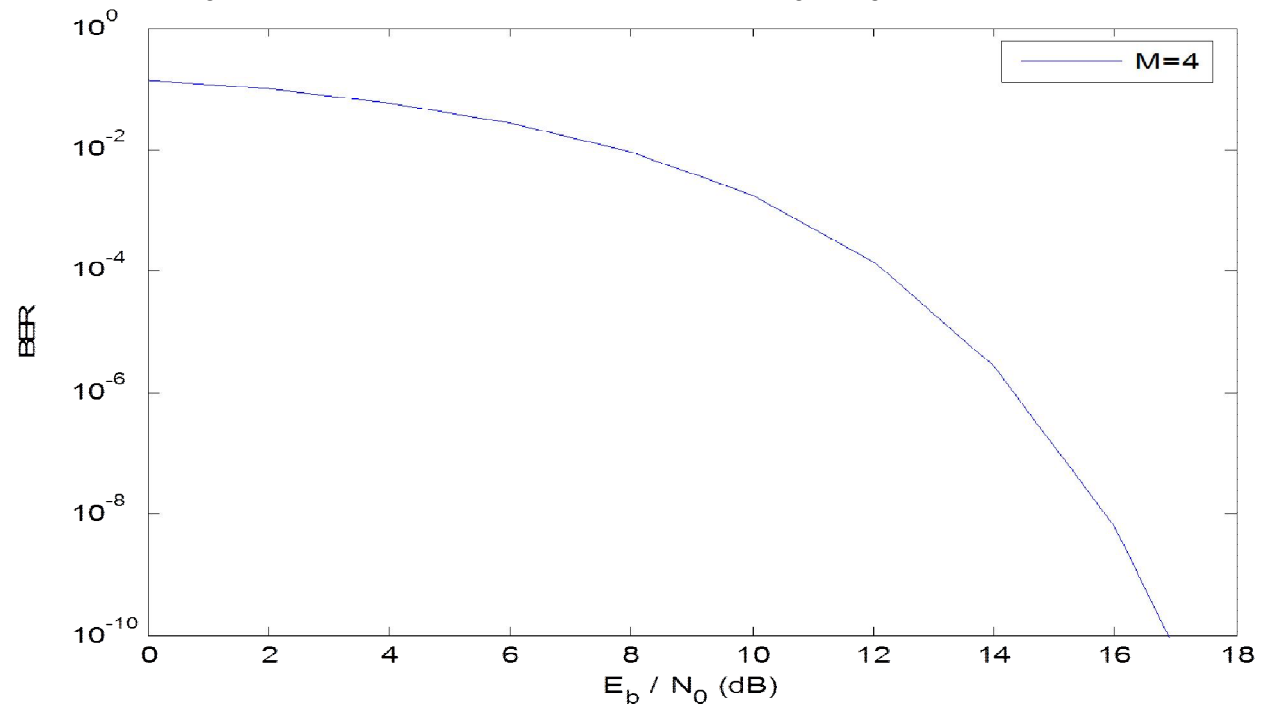
Fig 34: BER vs. SNR for user, M=4 without fading using AWGN channel
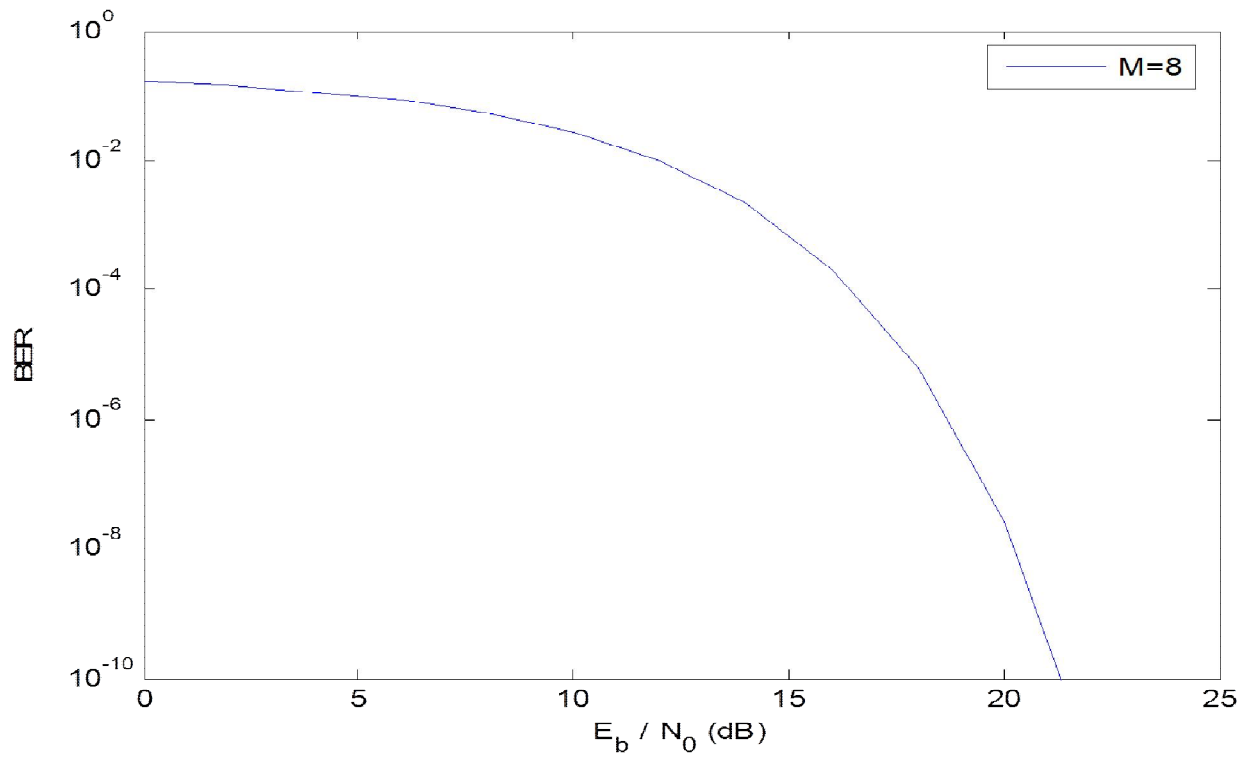
Fig 35: BER vs. SNR for user, M=8 without fading using AWGN channel
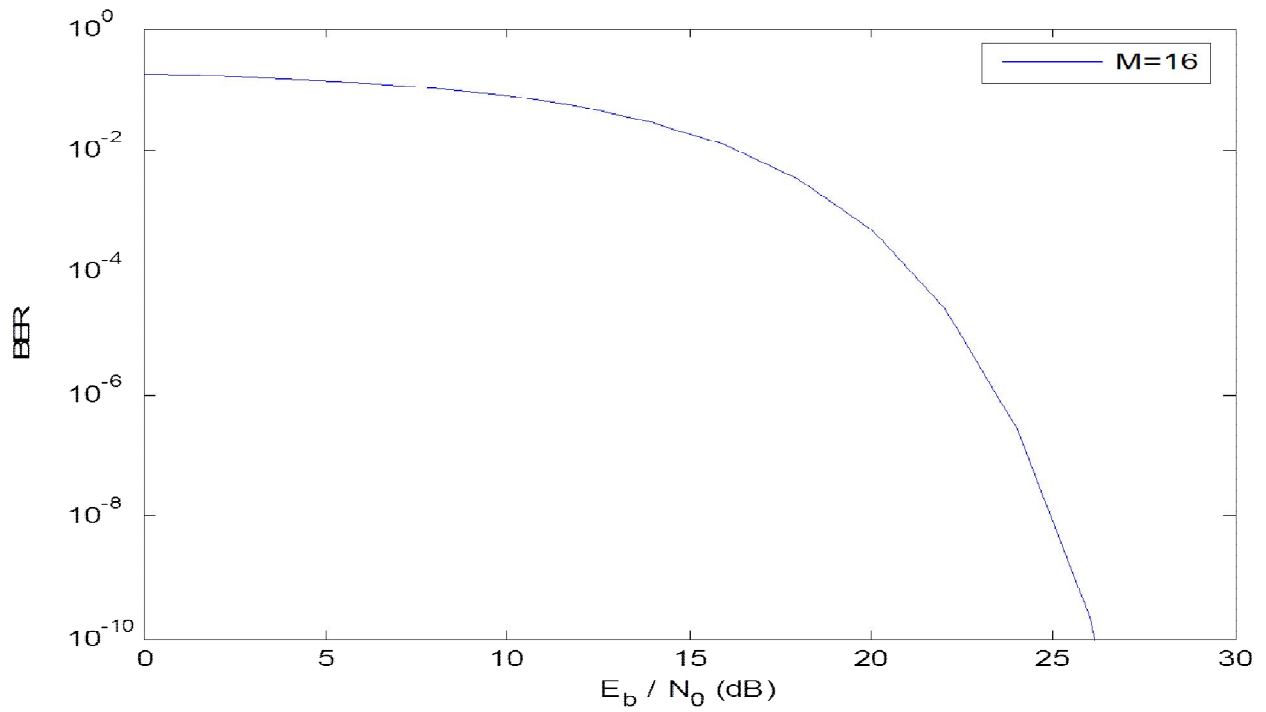
Fig 36: BER vs. SNR for user, M=16 without fading using AWGN channel
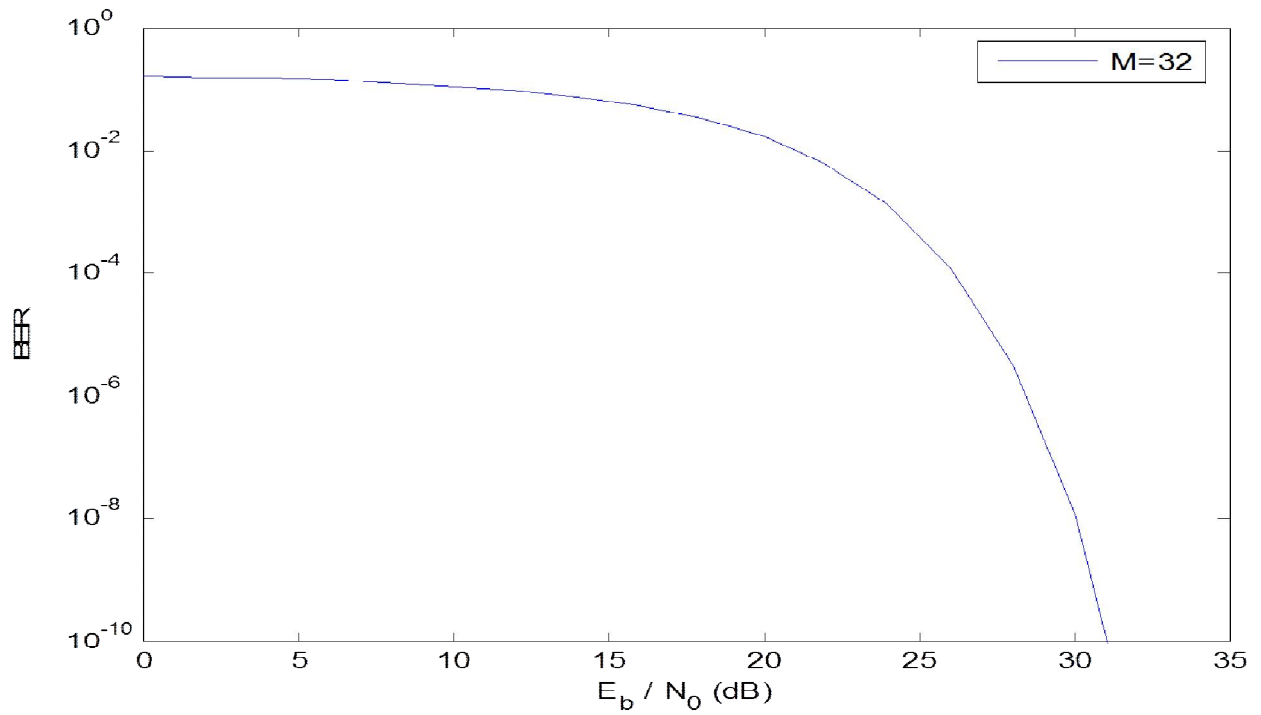
Fig 37: BER vs. SNR for user, M=32 without fading using AWGN channel
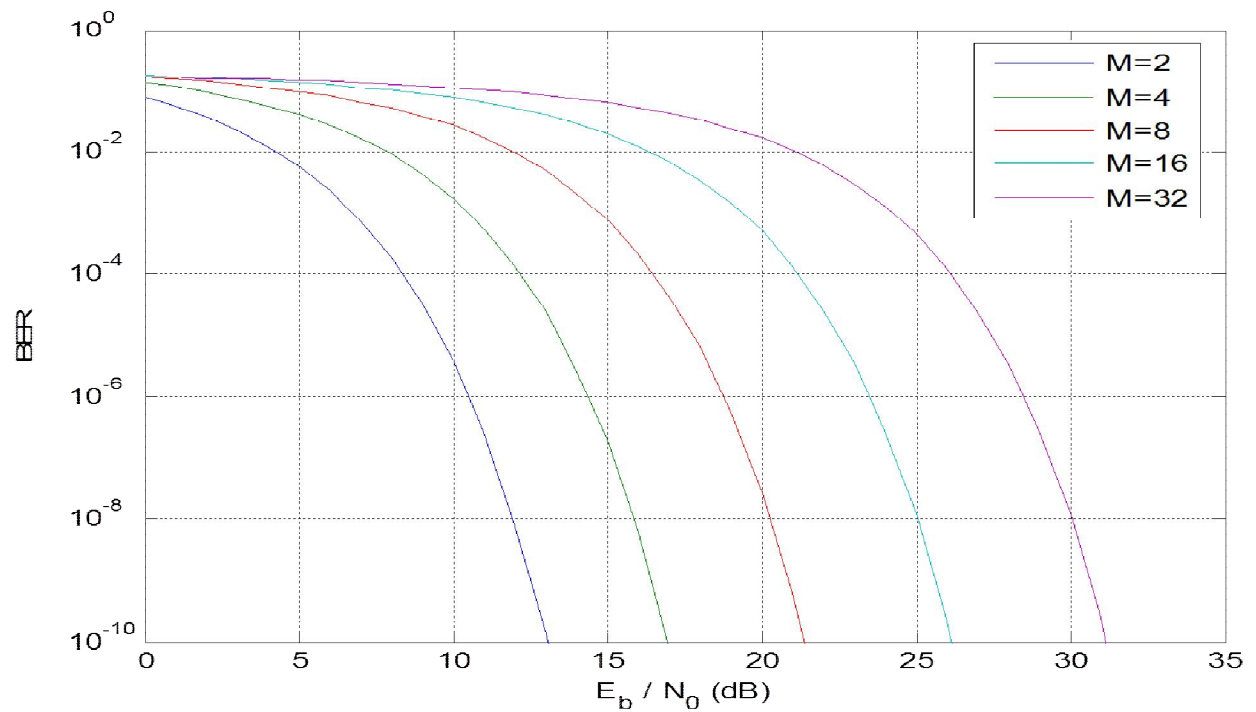
Fig 38: Comparison of BER vs. SNR in between different number of user without fading using AWGN channel

3.9.2 Performance Analysis of BPSK modulation technique of WCDMA in presence of Rayleigh fading channel
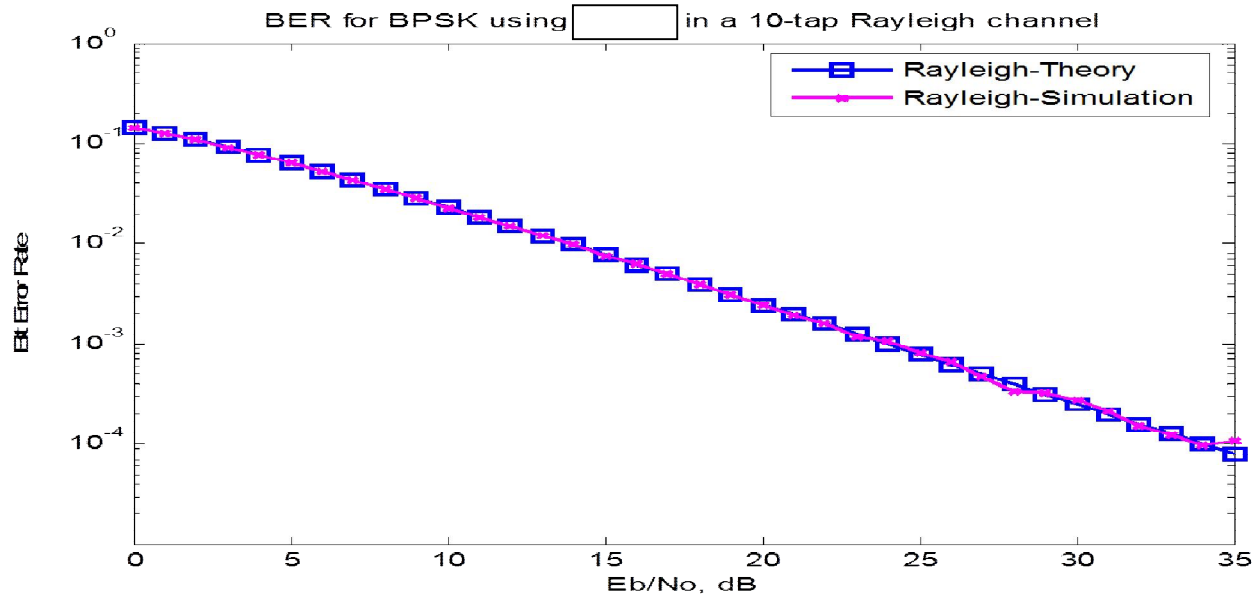
Fig 39: BER vs. SNR in with Rayleigh fading channel in BPSK modulation technique

3.9.3 Comparison of Performance Analysis of BPSK modulation technique of WCDMA without and with fading
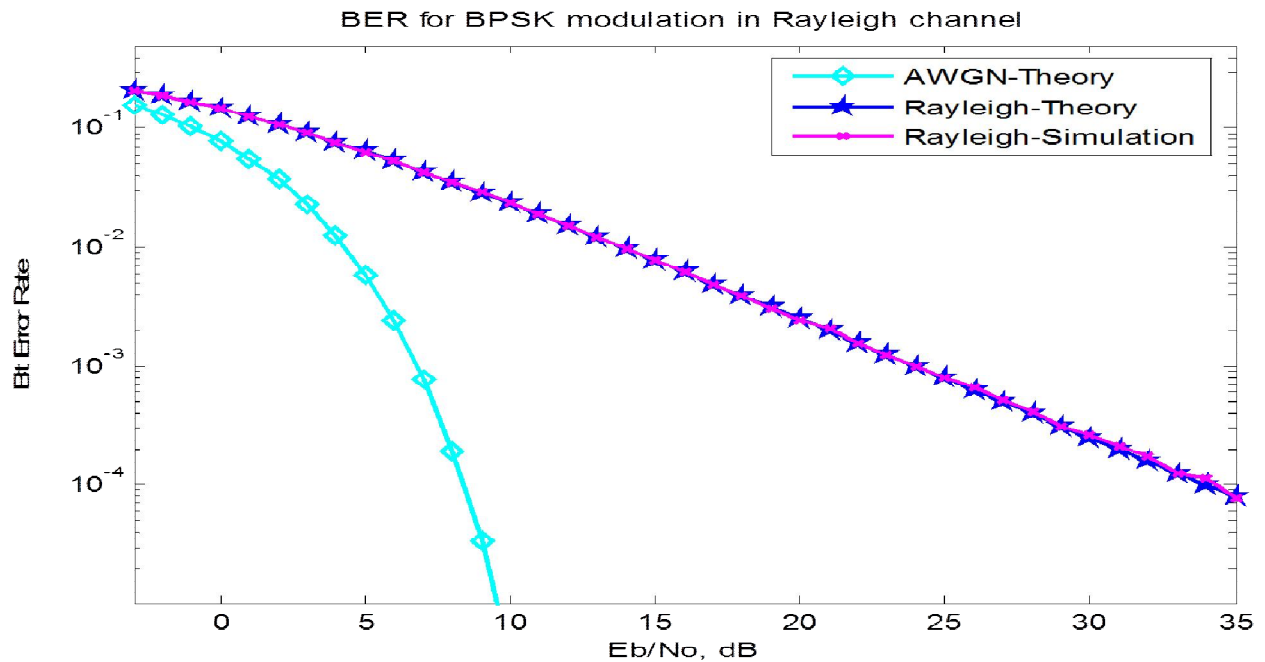
Fig 40: Comparison of BER vs. SNR in without and with Rayleigh fading channel in BPSK

3.10 BER vs. No. of user (M)
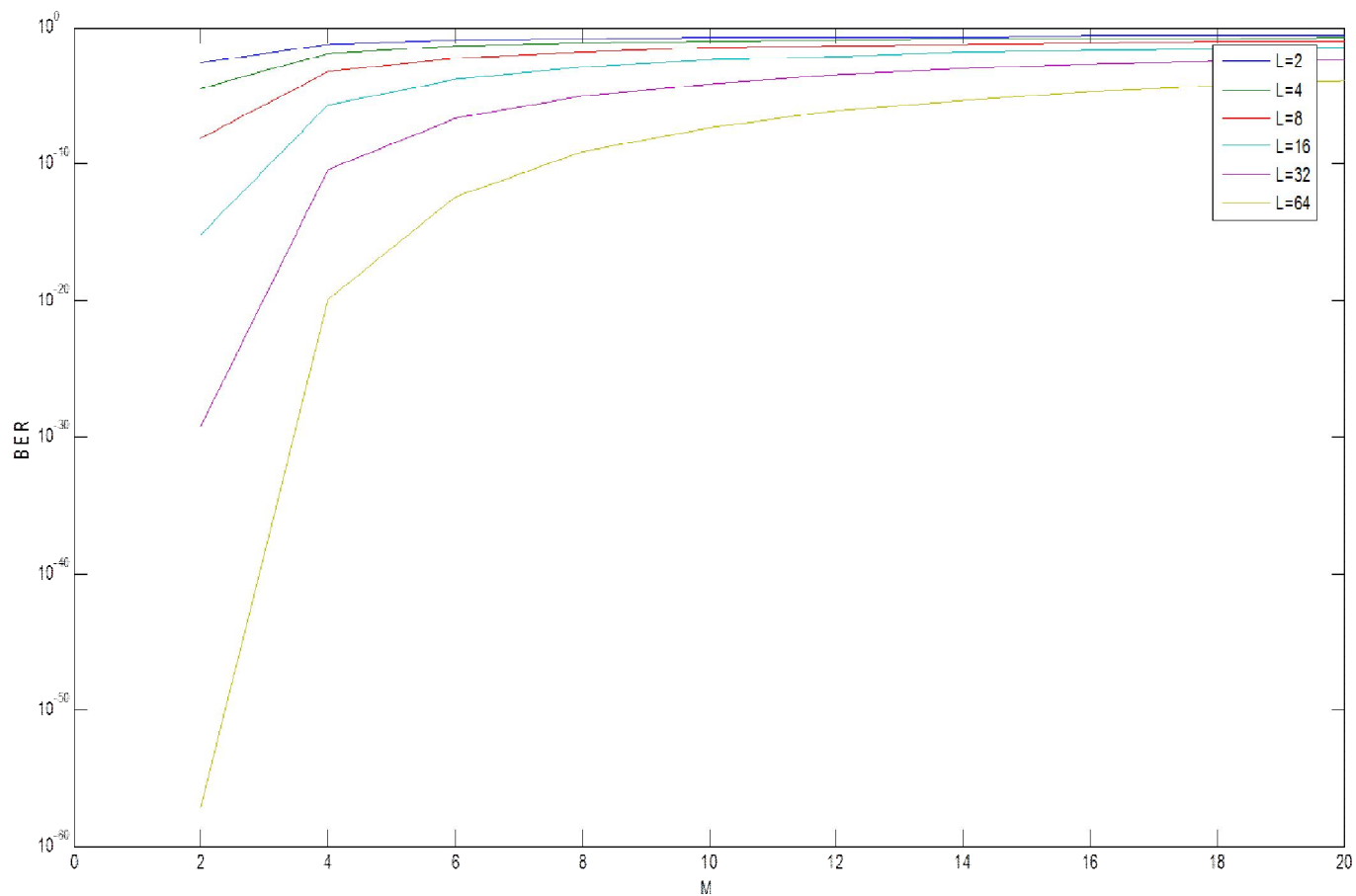
Fig 41: BER vs. No. of user (M)

Chapter: Four

Conclusion and Future Works

4.1 Conclusions

In this thesis we investigated the performance of DS-CDMA network in the noisy AWGN channel. The basic principles of spread spectrum communications and the implementation of direct sequence code division multiple access were evaluated. The performance of BPSK modulation schemes was considered and analyzed through the simulation results. We ran the simulation for a single user and the effects of increasing the number of users in the network were also evaluated. Simulation and practical results were compared using BER Vs SNR graphs. The diagrams show the implementation of the modeled systems. Finally the conclusions as well as future investigation are drawn.

In telecommunication field the major challenges is to convey the information as efficiently as possible through limited bandwidth, though some of the information bits are lost in most of the cases and signal which is sent originally will face fading. To reduce the bit error rate the loss of information and signal fading should be minimized.

In our thesis we analyze QPSK modulation technique, to reduce the error performance of the signal through Rayleigh Fading Channel in the presence of AWGN.

The performance of W-CDMA system in AWGN channel shows that QPSK modulation technique has a better performance. Furthermore, similar trend is found when the channel is subjected to multipath Rayleigh fading with Doppler shift. The performance of QPSK modulation technique

in W-CDMA system degrades as the mobility is increased. However, QPSK shows better performance in LOS channel and multipath Rayleigh fading channel.

As the number of users is increased, the QPSK modulation technique performs poorly in W-CDMA system. In general, the reason that causes poor performance of W-CDMA system when the number of users in increased is because the value of cross correlation between the codes is not 0 and thus it causes interference. Higher data rate modulation scheme suffers significant degradation in noise and Multipath Rayleigh fading channel compared to lower data rate modulation technique (e.g. QPSK). The errors are resulted from interference between adjacent carriers phase.

Larger value of M of M-ary QAM suffers more signal degradation. Thus, it is suggested that high data rate modulation technique needs an error correction coding such as convolutional coding or turbo coding so that the interference from the adjacent carrier phase can be eliminated if not minimized.

4.2 Comparison between with and without Fading

Without fading channels

In wireless communication, transmission of information can be characterized over additive white Gaussian noise (AWGN) channels. Noise and interference are the main causes of disturbance in the channel. The received signal is the transmitted signal and is corrupted by noise component with zero mean and variance σ2 is equal to $N_0/2$.

Fading channels

Multipath fading results from signal scattering due to reflections from buildings trees, hills, and other objects and atmospheric effects. This is illustrated in figure below. The reflected waves interfere with the direct wave which affects the performance of the network. When there is no

line of sight between the transmitter and the receiver, Rayleigh fading is most applicable. Rician fading channel is used if there is a line of sight. For fading channels, there is also a multiplicative noise in addition to AWGN. Assuming BPSK transmission, the received signal is the transmitted signal multiplied with a factor α and is corrupted by noise component with zero mean and variance $\sigma 2 = N0/2$.

Here α is the factor that controls path loss which influences interference. As α is increased, the path loss becomes more vital and the effect of interference decreased. Rice factor K is the power ratio between line of sight path and scattered paths. For K=0 the model corresponds to the Rayleigh fading model which is common in mobile communications when there is no line of sight path between transmitter and receiver. As K is increased towards infinity, the channel converges towards an AWGN channel.

4.3 Suggestion for future work

Our study focused only on AWGN propagation channels, but further results can be obtained by including Rician fading channel in addition of AWGN and multipath Rayleigh fading channel. Then, comparison can be made between these channels.

Implement error correction scheme such as convolution coding and turbo coding ensures higher chances of signal survivability in AWGN and multipath Rayleigh channel and thus enhances the performance of the system.

Also, other sequence generator can be employed to generate unique chip code and spread the bandwidth of W-CDMA system beside the PN Sequence Then, comparison can be made to determine which one is having a better performance and good BER characteristics.

A RAKE receiver or a smart antenna (Multiple Input and Multiple Output) can be used in this system to exploit the delayed signals arrived at the antenna caused by Multipath Rayleigh fading.

Due to time constraint, the thesis assumed perfect power control to minimize interference between users. Power control algorithm could be further studied and revised by implementing power control techniques.

As a future research subject, the DS-CDMA system performance analysis with an adaptive array in a Rayleigh fading and log-normal slow fading environment can be extended to a system with a circular array antenna. Two-dimensional or even three dimensional time and an angle-of-arrival geometric model can also be incorporated into the system's performance analysis.

APPENDIX

MATLAB SOURCE CODES

5.1 Matlab Source Codes for Simulation Using MATLAB 7.0

5.1.1 Source code for computing DSSS of CDMA:

5.1.1.1 Type-1(single user system):

```
R = 20;

S = 21;

b1 = round(rand(1,R));

m1 = zeros(1,S*R);


for i = 1:R

if b1(1,i)== 0

m1(1+(i-1)*S : i*S) = -1;

else

m1(1+(i-1)*S : i*S) =  1;

end

end


subplot(511)

plot(m1);
```

```
axis([-1 S*R+10 -1.2 1.2]);

title('Original Signal');

pn_seq = round(rand(1,60));


t = 0:2*pi/6:2*pi;

c = sin(t);

carrier=[];

pn_sig_txr1 = zeros(1,S*R);


for i = 1:60

ifpn_seq(1,i)==0

    pn_sig_trx1(1+(i-1)*7:i*7) = -1;

else

    pn_sig_trx1(1+(i-1)*7:i*7) =  1;

end

carrier=[carrier c];

end


K = round(rand(1,1)*420);

pn_sig_trx = [pn_sig_trx1(K:end) pn_sig_trx1(1:K-1)];

c1 = m1 .* pn_sig_trx;

subplot(512);plot(c1);axis([-1 S*R+10 -1.2 1.2]);title('Carrier signal');

f=m1.*c1

subplot(513);plot(f);axis([0 450 -2 2]);title('Multiplied Signal');

sum=f+f;

subplot(514);plot(sum);axis([0 450 -4 4]);title('Summation Signal');

mult=sum.*c1
```

```
subplot(515);plot(mult);axis([0 450 -4 4]);title('Multiplied Signal 2nd step');
```

5.1.1.2   Type-2(multi-user system):

```
R = 20;

S = 21;

b1 = round(rand(1,R));

m1 = zeros(1,S*R);


for i = 1:R

if b1(1,i)== 0

m1(1+(i-1)*S : i*S) = -1;

else

m1(1+(i-1)*S : i*S) =  1;

end

end


subplot(611); plot(m1); axis([-1 S*R+10 -1.2 1.2]); title('m1(t)');

m2=(-1.)*m1;

subplot(812);plot(m2);axis([-1 S*R+10 -1.2 1.2]);title('m2(t)');


pn_seq = round(rand(1,60));

t = 0:2*pi/6:2*pi;

c = sin(t);

carrier=[];
```

```
pn_sig_txr1 = zeros(1,S*R);


for i = 1:60

ifpn_seq(1,i)==0

    pn_sig_trx1(1+(i-1)*7:i*7) = -1;

else

    pn_sig_trx1(1+(i-1)*7:i*7) =  1;

end

carrier=[carrier c];

end


K = round(rand(1,1)*420);

pn_sig_trx = [pn_sig_trx1(K:end) pn_sig_trx1(1:K-1)];

c1 = m1 .* pn_sig_trx;

subplot(612); plot(c1); axis([-1 S*R+10 -1.2 1.2]); title('c1(t)');

c2=(2).*c1;

subplot(814);plot(c2);axis([-1 S*R+10 -3.2 3.2]);title('c2(t)');

f1=m1.*c1

subplot(613); plot(f1); axis([0 450 -2 2]); title('m1(t)x c1(t)');

f2=m2.*c2;

subplot(614); plot(f2); axis([0 450 -4 4]); title('m2(t)x c2(t)');

sum=f1+f2;

subplot(615); plot(sum); axis([0 450 -4 4]); title('y=m1(t)x c1(t) + m2(t)x c2(t)');

mult=sum.*c1

subplot(616); plot(mult); axis([0 450 -4 4]); title(' y1= {m1(t)x c1(t) + m2(t)x c2(t)}x c1(t)');
```

5.2.1 Source code for computing QPSK of CDMA:

5.2.1.1 Source Codes for Simulation of QPSK of WCDMA System in AWGN Channel

```
x=[0 1 2 3 4 5 6 7 8 9 10];

y=[7.807500e-002 5.667000e-002 3.760000e-002 2.242000e-002 1.244500e-002

6.025000e-003 2.310000e-003 8.250000e-004 1.950000e-004 1.000000e-005

5.000000e-006];

n=5;

p=polyfit(x,y,n);

xi=linspace(0, 10, 100000);

yi=polyval(p, xi);


% Plotting the graph BER over EbNo


semilogy(x, y, '*', xi, yi, '-')

axis manual; axis([0 10 0.000025 1]);

xlabel('EbNo'); ylabel('Bit Error Rate (BER)');

title('BER vsEBNo');
```

5.2.1.2 Source Codes for Simulation of QPSK of WCDMA System in Multipath Rayleigh Fading Channel with Doppler Shift (60kmph, 90kmph & 120kmph)

```
x=[0 2 4 6 8 10 12 14 16 18 20];

y=[1.394450e-001 1.022050e-001 7.264500e-002 4.871000e-002 3.247000e-002 2.098500e-002
1.463000e-002 9.440000e-003 6.305000e-003 4.580000e-003 3.070000e-003];

n=5;
```

```
p=polyfit(x,y,n);

xi=linspace(0, 20, 100000);

yi=polyval(p, xi);


semilogy(x, y, '*', xi, yi, '-')

hold on;


x=[0 2 4 6 8 10 12 14 16 18 20];

y=[1.373200e-001 1.010650e-001 7.023000e-002 4.573000e-002 3.073500e-002 1.991500e-002
1.324500e-002 8.310000e-003 5.295000e-003 3.405000e-003 2.075000e-003];

n=5;

p=polyfit(x,y,n);

x90=linspace(0, 20, 100000);

y90=polyval(p, x90);


semilogy(x, y, '+', x90, y90, '-')

hold on;


x=[0 2 4 6 8 10 12 14 16 18 20];

y=[1.396000e-001 1.041000e-001 7.285000e-002 4.999000e-002 3.354000e-002 2.218000e-002
1.444500e-002 9.390000e-003 6.200000e-003 3.970000e-003 2.715000e-003];

n=5;

p=polyfit(x,y,n);

x120=linspace(0, 20, 100000);

y120=polyval(p, x120);
```

% Plotting the graph BER over EbNo

semilogy(x, y, 'x', x120, y120, '-')

axis manual; axis([0 20 0.0025 0.15]);

xlabel('EbNo'); ylabel('Bit Error Rate (BER)');

title('BER vsEBNo for Doppler Shift 60,90,120 kmph');

5.2.1.3 Source Codes for Simulation of QPSK of WCDMA System for AWGN vs Multipath Rayleigh Fading Channel

x=[0 2 4 6 8 10 12 14 16 18 20];

y=[1.394450e-001 1.022050e-001 7.264500e-002 4.871000e-002 3.247000e-002 2.098500e-002 1.463000e-002 9.440000e-003 6.305000e-003 4.580000e-003 3.070000e-003];

n=5;

p=polyfit(x,y,n);

xi=linspace(0, 20, 100000);

yi=polyval(p, xi);

semilogy(x, y, '*', xi, yi, '-')

hold on;

x=[0 2 4 6 8 10 12 14 16 18 20];

y=[1.373200e-001 1.010650e-001 7.023000e-002 4.573000e-002 3.073500e-002 1.991500e-002 1.324500e-002 8.310000e-003 5.295000e-003 3.405000e-003 2.075000e-003];

n=5;

p=polyfit(x,y,n);

x90=linspace(0, 20, 100000);

y90=polyval(p, x90);

semilogy(x, y, '+', x90, y90, '-')

hold on;

x=[0 2 4 6 8 10 12 14 16 18 20];

y=[1.396000e-001 1.041000e-001 7.285000e-002 4.999000e-002 3.354000e-002 2.218000e-002
1.444500e-002 9.390000e-003 6.200000e-003 3.970000e-003 2.715000e-003];

n=5;

p=polyfit(x,y,n);

x120=linspace(0, 20, 100000);

y120=polyval(p, x120);

% Plotting the graph BER over EbNo

semilogy(x, y, 'x', x120, y120, '-')

axis manual; axis([0 20 0.0025 0.15]);

xlabel('EbNo'); ylabel('Bit Error Rate (BER)');

title('BER vsEBNo for Doppler Shift 60,90,120 kmph');

5.2.1.4   Source Codes for Simulation of QPSK of WCDMA System for AWGN vs Multipath Rayleigh Fading Channel for a Single User

x=[0 1 2 3 4 5 6 7 8 9 10];

y=[7.807500e-002 5.667000e-002 3.760000e-002 2.242000e-002 1.244500e-002

```
6.025000e-003 2.310000e-003 8.250000e-004 1.950000e-004 1.000000e-005

5.000000e-006];

n=5;

p=polyfit(x,y,n);

xAWGNuser1=linspace(0, 10, 100000);

yAWGNuser1=polyval(p, xAWGNuser1);

semilogy(x, y, '*', xAWGNuser1, yAWGNuser1, '-')

hold on;


x=[0 1 2 3 4 5 6 7 8 9 10];

y=[1.448950e-001 1.240450e-001 1.073250e-001 9.064000e-002 7.641500e-002

6.300500e-002 5.071500e-002 4.142500e-002 3.251500e-002 2.597000e-002

2.059500e-002];

n=5;

p=polyfit(x,y,n);

xRayleighUser1=linspace(0, 10, 100000);

yRayleighUser1=polyval(p, xRayleighUser1);


% Plotting the graph BER over EbNo

semilogy(x, y, '+', xRayleighUser1, yRayleighUser1, '-')

axis manual; axis([0 10 0.0000025 1]);

xlabel('EbNo'); ylabel('Bit Error Rate (BER)');

title('BER vsEBNo for 1 user in AWGN and Rayleigh Fading channels');
```

5.2.1.5   Source Codes for Simulation of QPSK of WCDMA System for AWGN vs Multipath Rayleigh Fading Channel for a Five (5) Users

```
x=[0 2 4 6 8 10 12 14 16 18 20];

y=[9.468000e-002 5.656300e-002 2.938300e-002 1.367600e-002 5.393000e-003 1.932000e-003
5.520000e-004 7.200000e-005 4.000000e-006 0.000000e+000 0.000000e+000];

n=5;

p=polyfit(x,y,n);

xAWGNuser5=linspace(0, 20, 1);

yAWGNuser5=polyval(p, xAWGNuser5);


semilogy(x, y, '*', xAWGNuser5, yAWGNuser5, '-')

hold on;


x=[0 2 4 6 8 10 12 14 16 18 20];

y=[1.534370e-001 1.181230e-001 8.727300e-002 6.183000e-002 4.187500e-002 2.724800e-002
1.779900e-002 1.130700e-002 7.314000e-003 4.713000e-003 3.210000e-003];

n=5;

p=polyfit(x,y,n);

xRayleighUser5=linspace(0, 20, 100000);

yRayleighUser5=polyval(p, xRayleighUser5);


% Plotting the graph BER over EbNo


semilogy(x, y, '+', xRayleighUser5, yRayleighUser5, '-')

axis manual; axis([0 20 0.0000025 1]);

xlabel('EbNo'); ylabel('Bit Error Rate (BER)');
```

title('BER vsEBNo for 5 users in AWGN and Rayleigh Fading channels');

5.3.1 Source Codes for Simulation of BER vs. Eb/No (SNR) of WCDMA System

5.3.1.1 Source codes for simulation of BPSK of WCDMA system in AWGN for order, M=2:

```
format short e;

EbN0dB = [0:2:32];

EbN0vec = 10.^(EbN0dB / 10);

Mvec = 2;

EbN0 = ones(size(Mvec)) * EbN0vec;

M = Mvec * ones(size(EbN0vec));

BER = 2 * (M-1) .* normcdf(-sqrt(6 * log2(M) .* EbN0 ./ (M.^2-1)), 0, 1)./ (M .* log2(M));


% Plotting the graph BER over EbNo


semilogy(EbN0dB, BER);

ylim([1e-10, 1]);

xlabel('E_b / N_0 (dB)'); ylabel('BER');

legend('M=2');
```

5.3.1.2 Source codes for simulation of BPSK of WCDMA system in AWGN for order, M=4:

```
format short e;

EbN0dB = [0:2:32];

EbN0vec = 10.^(EbN0dB / 10);

Mvec = 4;
```

EbN0 = ones(size(Mvec)) * EbN0vec;

M = Mvec * ones(size(EbN0vec));

BER = 2 * (M-1) .* normcdf(-sqrt(6 * log2(M) .* EbN0 ./ (M.^2-1)), 0, 1)./ (M .* log2(M));

% Plotting the graph BER over EbNo

semilogy(EbN0dB, BER);

ylim([1e-10, 1]);

xlabel('E_b / N_0 (dB)'); ylabel('BER');

legend('M=4');

5.3.1.3   Source codes for simulation of BPSK of WCDMA system in AWGN for order, M=8:

format short e;

EbN0dB = [0:2:32];

EbN0vec = 10.^(EbN0dB / 10);

Mvec = 8;

EbN0 = ones(size(Mvec)) * EbN0vec;

M = Mvec * ones(size(EbN0vec));

BER = 2 * (M-1) .* normcdf(-sqrt(6 * log2(M) .* EbN0 ./ (M.^2-1)), 0, 1)./ (M .* log2(M));

% Plotting the graph BER over EbNo

semilogy(EbN0dB, BER);

ylim([1e-10, 1]);

xlabel('E_b / N_0 (dB)'); ylabel('BER');

legend('M=8');

5.3.1.4 Source codes for simulation of BPSK of WCDMA system in AWGN for order, M=16:

```
format short e;

EbN0dB = [0:2:32];

EbN0vec = 10.^(EbN0dB / 10);

Mvec = 16;

EbN0 = ones(size(Mvec)) * EbN0vec;

M = Mvec * ones(size(EbN0vec));

BER = 2 * (M-1) .* normcdf(-sqrt(6 * log2(M) .* EbN0 ./ (M.^2-1)), 0, 1)./ (M .* log2(M));


% Plotting the graph BER over EbNo


semilogy(EbN0dB, BER);

ylim([1e-10, 1]);

xlabel('E_b / N_0 (dB)'); ylabel('BER');

legend('M=16');
```

5.3.1.5 Source codes for simulation of BPSK of WCDMA system in AWGN for order, M=32:

```
format short e;

EbN0dB = [0:2:32];

EbN0vec = 10.^(EbN0dB / 10);

Mvec = 32;

EbN0 = ones(size(Mvec)) * EbN0vec;

M = Mvec * ones(size(EbN0vec));

BER = 2 * (M-1) .* normcdf(-sqrt(6 * log2(M) .* EbN0 ./ (M.^2-1)), 0, 1)./ (M .* log2(M));
```

```
% Plotting the graph BER over EbNo


semilogy(EbN0dB, BER);

ylim([1e-10, 1]);

xlabel('E_b / N_0 (dB)'); ylabel('BER');

legend('M=32');
```

5.3.1.6   Source codes for simulation of BPSK of WCDMA system in AWGN or without fading:

```
format short e;

EbN0dB = [0:2:32];

EbN0vec = 10.^(EbN0dB / 10);

Mvec = [2; 4; 8; 16; 32];

EbN0 = ones(size(Mvec)) * EbN0vec;

M = Mvec * ones(size(EbN0vec));

BER = 2 * (M-1) .* normcdf(-sqrt(6 * log2(M) .* EbN0 ./ (M.^2-1)), 0, 1)./ (M .* log2(M));


% Plotting the graph BER over EbNo


semilogy(EbN0dB, BER);

ylim([1e-10, 1]);

xlabel('E_b / N_0 (dB)'); ylabel('BER');

legend('M=2', 'M=4', 'M=8', 'M=16' , 'M=32');
```

5.3.2.1 Source code for computing the BER for BPSK modulation in the presence of Rayleigh fading channel:

```
clear all

nFFT       = 64;

nDSC       = 52;

nBitPerSym  = 52;

nSym       = 10^4;

EbN0dB     = [0:35];

EsN0dB     = EbN0dB + 10*log10(nDSC/nFFT) + 10*log10(64/80);


for ii = 1:length(EbN0dB)

        ipBit = rand(1,nBitPerSym*nSym) > 0.5;

        ipMod = 2*ipBit-1;

        ipMod = reshape(ipMod,nBitPerSym,nSym).';

        xF = [zeros(nSym,6) ipMod(:,[1:nBitPerSym/2]) zeros(nSym,1) ipMod(:,[nBitPerSym/2+1:nBitPerSym]) zeros(nSym,5)] ;

        xt = (nFFT/sqrt(nDSC))*ifft(fftshift(xF.')).';

        xt = [xt(:,[49:64]) xt];

        nTap = 10;

        ht = 1/sqrt(2)*1/sqrt(nTap)*(randn(nSym,nTap) + j*randn(nSym,nTap));

        hF = fftshift(fft(ht,64,2));


        forjj = 1:nSym

                xht(jj,:) = conv(ht(jj,:),xt(jj,:));

        end


        xt = xht;
```

```matlab
        xt = reshape(xt.',1,nSym*(80+nTap-1));

        nt = 1/sqrt(2)*[randn(1,nSym*(80+nTap-1)) + j*randn(1,nSym*(80+nTap-1))];

        yt = sqrt(80/64)*xt + 10^(-EsN0dB(ii)/20)*nt;

        yt = reshape(yt.',80+nTap-1,nSym).';

        yt = yt(:,[17:80]);

        yF = (sqrt(nDSC)/nFFT)*fftshift(fft(yt.')).';

        yF = yF./hF;

        yMod = yF(:,[6+[1:nBitPerSym/2] 7+[nBitPerSym/2+1:nBitPerSym] ]);

        ipModHat = 2*floor(real(yMod/2)) + 1;

        ipModHat(find(ipModHat>1)) = +1;

        ipModHat(find(ipModHat<-1)) = -1;

        ipBitHat = (ipModHat+1)/2;

        ipBitHat = reshape(ipBitHat.',nBitPerSym*nSym,1).';

        nErr(ii) = size(find(ipBitHat - ipBit),2);

end


simBer = nErr/(nSym*nBitPerSym);

EbN0Lin = 10.^(EbN0dB/10);

theoryBer = 0.5.*(1-sqrt(EbN0Lin./(EbN0Lin+1)));


% Plotting the graph BER over EbNo


close all; figure

semilogy(EbN0dB,theoryBer,'bs-','LineWidth',2);

hold on

semilogy(EbN0dB,simBer,'mx-','LineWidth',2);

axis([0 35 10^-5 1])
```

legend('Rayleigh-Theory', 'Rayleigh-Simulation');

xlabel('Eb/No, dB'); ylabel('Bit Error Rate')

title('BER for BPSK using in a 10-tap Rayleigh channel');

5.3.2.2 Source code for computing the BER vs SNR for BPSK modulation for comparison between with fading and without fading:


```
Clear

N = 10^6;

ip = rand(1,N)>0.5;

s = 2*ip-1;

Eb_N0_dB = [-3:35];


for ii = 1:length(Eb_N0_dB)

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

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

        y = h.*s + 10^(-Eb_N0_dB(ii)/20)*n;

        yHat = y./h;

        ipHat = real(yHat)>0;

        nErr(ii) = size(find([ip- ipHat]),2);

end


simBer = nErr/N;

theoryBerAWGN = 0.5*erfc(sqrt(10.^(Eb_N0_dB/10)));

EbN0Lin = 10.^(Eb_N0_dB/10);

theoryBer = 0.5.*(1-sqrt(EbN0Lin./(EbN0Lin+1)));
```

% Plotting the graph BER over EbNo

close all

figure

semilogy(Eb_N0_dB,theoryBerAWGN,'cd-','LineWidth',2);

hold on

semilogy(Eb_N0_dB,theoryBer,'bp-','LineWidth',2);

semilogy(Eb_N0_dB,simBer,'mx-','LineWidth',2);

axis([-3 35 10^-5 0.5])

legend('AWGN-Theory','Rayleigh-Theory', 'Rayleigh-Simulation');

xlabel('Eb/No, dB'); ylabel('Bit Error Rate');

title('BER for BPSK modulation in Rayleigh channel');

5.3.2.3   Source codes for simulation of BPSK of WCDMA system (No. of user (M) vs. BER):

[M]=[1 2 4 6 8 10 12 14 16 18 20]

[L]=[2 4 8 16 32 64]

for i=1:11

  for j=1:6

   Pe(i,j)=1/2*(erfc(sqrt(2*(1/(M(i)-1))*L(j))))

  end

  end

% Plotting the graph BER over EbNo

semilogy(K,Pe)

xlabel('M'); ylabel('BER');

legend('L=2', 'L=4', 'L=8', 'L=16' , 'L=32' , 'L=64');

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