PERFORMANCE ANALYSIS ON MODULATION TECHNIQUES OF W-CDMA IN MULTIPATH FADING CHANNEL

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ABSTRACT

The transmission from base station to mobile or downlink transmission using M-ary Quadrature Amplitude modulation (QAM) and Quadrature phase shift keying (QPSK) modulation scheme are consider in W-CDMA system. We can analysis the performance of these modulation techniques when the system is subjected to AWGN and multipath Rayleigh fading are consider in the channel. We will use MatLab 7.4 for simulation and evaluation of BER and SNR for W-CDMA system models. We will go for analysis of Quadrature phase shift key and 16-ary Quadrature Amplitude modulations which are being used in wideband code division multiple access system, so that the system can go for more suitable modulation technique to suit the channel quality, thus we can deliver the optimum and efficient data rate to mobile terminal.

Index Terms- AWGN, DSSS, Multipath Rayleigh fading, CDMA, BER, SNR, QPSK, 16-QAM
# LIST OF ABBREVIATION

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AMC</td>
<td>Adaptive Modulation and Coding</td>
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<tr>
<td>AWGN</td>
<td>Additive White Noise Gaussian Noise</td>
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<tr>
<td>BER</td>
<td>Bit Error Rate</td>
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<tr>
<td>dB</td>
<td>Decibel</td>
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<td>GMSK</td>
<td>Gaussian Minimum Shift Keying</td>
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<tr>
<td>GSM</td>
<td>Global System for Mobile Communication</td>
</tr>
<tr>
<td>HSDPA</td>
<td>High Speed Downlink Packet Access</td>
</tr>
<tr>
<td>ISI</td>
<td>Inter-Symbol Interference</td>
</tr>
<tr>
<td>PN</td>
<td>Pesudo-Noise</td>
</tr>
<tr>
<td>PDF</td>
<td>Probability Density Function</td>
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<tr>
<td>QPSK</td>
<td>Quadrature Phase Shift Keying</td>
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<tr>
<td>QAM</td>
<td>Quadrature Amplitude Modulation</td>
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<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunication System</td>
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<tr>
<td>W-CDMA</td>
<td>Wideband Code Division Multiple Access</td>
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Chapter 1

INTRODUCTION

1.1 Background of the Problem

W-CDMA is being used by Universal Mobile Telecommunication System (UMTS) as platform of the 3rd generation cellular communication system. W-CDMA uses noise-like broadband frequency spectrum where it has high resistance to multipath fading where as this was not present in conventional narrowband signal of 2nd generation (2G) communication system. High data rate signal transmission can be transmitted over the air by using W-CDMA system, thus enabling of multimedia rich applications such as video streams and high resolution pictures to end users. Thus, we need suitable modulation technique and error correction mechanism to be used in W-CDMA system.

In 2G networks, GMSK modulation scheme is widely used in GSM (Global System for Mobile Communication). This modulation can only transmit data rate of 1 bit per symbol. So it is quite sure that this kind of modulation scheme is not suitable for the next generation communication system. So, there is a need to study the performance of new modulation technique that could deliver higher data rate effectively in a multipath fading channel.

1.2 Problem Statement

High data rate modulation scheme is one of the important criteria besides good error coding, to deliver multimedia content application over the cellular networks. However, the implementation of high data rate modulation techniques that have good bandwidth efficiency in W-CDMA cellular communication requires perfect modulators, demodulators, filter and transmission path that are difficult to achieve in practical radio environment. Modulation schemes which are capable of delivering more bits per symbol are more immune to errors caused by noise and interference in the channel. Moreover, errors can be easily produced as the number of users is increased and the mobile terminal is subjected to mobility.
1.3 Project Objective

The research of this project is focus on the study and the performance measurement of high data rate modulation schemes at those channels which are subjected to Multipath Rayleigh Fading and Additive White Gaussian Noise (AWGN). Modulation Schemes that will be studied are 16-ary QAM (Quadrature Amplitude Modulation) and QPSK (Quadrature Phase Shift Keying). The performance study will be carried out by varying the chip rate of pseudo-noise generator. W-CDMA (Wideband Code Division Multiple Access) scheme will also be studied by comparing some certain number of users under static and dynamic environment that are subjected to AWGN and multipath Rayleigh fading. The performance of fading channels in W-CDMA system are based on Bit Error Rate (BER) W-CDMA system at downlink transmission and Signal-to-Noise ratio (SNR). There will be three W-CDMA wireless cellular system models that will used in this project. The models are

1. W-CDMA system in AWGN channel.
2. W-CDMA system in AWGN and Multipath Rayleigh Fading.

There are some parameters for multiple rays using QPSK and QAM in W-CDMA system models that will be obtained using MatLab. They are

1. Bit Error Rate (BER) versus Signal-to-Noise ratio (SNR) in AWGN channel for QPSK modulation technique.
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6. BER versus SNR to compare between AWGN channel and Rayleigh fading channel for different number of user for QPSK modulation technique.

1.4 Scope of Work

This research thesis is based on study and simulation using scientific computer simulation software, MatLab 7.4. The simulation will be done using m files of MatLab. It will be simulated in multi-user environment based on Direct Sequence Spread Spectrum (DSSS), Wideband-Code Division Multiple Access (W-CDMA). There will be no error correction coding or channel coding employed for this simulation models.

There are two extreme cases of channel noise and fading that will be subjected to the W-CDMA system models. First, the model is simulated with different modulation techniques under thermal noise, represented by Additive White Gaussian Noise (AWGN). Then, the channel is simulated with various different parameters using Non-line of sight (N-LOS) multiple reflected rays representing multipath Rayleigh Fading.

The performance of the modulation schemes are studied when the mobile terminal is static and dynamic with different speeds. The performance analysis is based on BER and Signal-to-Noise ratio. Thus, suitable modulations techniques will be determined and concluded based on BER that will be plotted as a function of SNR.

The current development to achieve high data rate cellular communication drives the interest of this research. There are many significant areas that could give boost to the improvement of W-CDMA system such as modulation scheme and error correction and so on.

There are many modulation techniques that have the potential to deliver higher data rate but there is a tradeoff between data rate and multipath environment. Recently, there is growing research about Adaptive Modulation Coding (AMC) [1]-[3]. The principle of AMC is to change the modulation and coding format in accordance with instantaneous variations in the channel conditions, subject to system restrictions. AMC extends the system’s ability to adapt to good channel conditions. Channels conditions should be estimated based on feedback from receiver. For a system with AMC, users closed to the cell site are typically assigned higher order modulation with higher data rates (e.g. 64 QAM with R=3/4 Turbo codes). On the other hand, users closed to cell boundary, are assigned lower order modulation with lower order code rates (e.g. QPSK with R=1/2 Turbo Codes). AMC allows different data rates to be
assigned to different users depending on their channel conditions. Since the channel conditions vary over time, the receiver collects a set of channel statistics which are used both by the transmitter and the receiver to optimize system parameters such as modulation and coding, signal bandwidth, signal power, training period, channel estimation filters, automatic gain control, etc [4].

Thus, this thesis will analyze suitable modulation techniques that are capable of delivering higher data rate without compromising errors in multipath fading environment. The performance of these modulation techniques will be simulated by using computer simulation tool, MatLab 7.4.
Chapter 2

MODULATION SCHEMES IN W-CDMA

The evolution objective of wireless cellular technology from 1G to 3G is capable of delivering high data rate signal so that it can transmit high bit rate multimedia content in cellular mobile communication. Thus, it has driven many researches into the application of higher order modulations [5]-[10].

The previous second generation Global System for Mobile Communication (GSM) system provides data services with 14.4 kbps for circuit-switched data and up to 22.8 kbps for packet data. High-Speed Circuit Switched Data (HSCSD) and General Packet Radio Services (GPRS) with multi-slot operation can only slightly increase the data rate due to the Gaussian Minimum Shift Keying (GMSK) modulation, which they are using. Enhance Data Rate for the GSM Evolution (EDGE) is proposed as a transition to 3G as a new Time Division Multiple Access (TDMA) based radio access using the current (800, 900, 1800 and 1900 MHz) frequency bands. EDGE enables significantly higher peak rates and approximately triples the spectral efficiency by employing 8-Phase Shift Keying (8PSK) modulation.

W-CDMA is another 3G-system operation in 5MHz bandwidth to support both high-rate packet data and circuit-switched data. High Speed Downlink Packet Access (HSDPA) is currently being developed as the evolution of W-CDMA systems to considerably increase the data rate by using adaptive modulation and coding (AMC), hybrid automatic repeat request (HARQ), fast cell selection (FCS) and multiple input multiple output (MIMO) antenna processing [8].

In cellular system, different users have different channel qualities in terms of signal to noise ratio (SNR) due to differences in distance to the base station, fading and interference. Link quality control adapts the data protection according to the channel quality so that an optimal bit rate is obtained for all the channel qualities [5-8]. Thus, the system adopts AMC to suit the
link quality. W-CDMA systems can employ the high order modulation (8PSK or M-QAM) to increase the transmission data rate with the link quality control.

However, there is a trade off in employing bandwidth efficient M-QAM modulation scheme. The complexity of the receiver increases linearly with M (number of orthogonal sequences) and exponentially with the number of bits per symbol. The achievable bandwidth efficiency of the system is limited by the maximum possible number of orthogonal sequences and by acceptable complexity of the receiver [6].

To minimize Inter-symbol Interference (ISI), noise and channel fading, a wireless system needs to have a robust system to minimize, if not to eliminate, these unfavorable effects. A typical W-CDMA transmitter system consists of bit generator, TC (Tele command) encoder, rate matcher, interleaver, spreader, modulator, scrambler, and pulse shaper. On the other hand, a receiver consists of a matched filter, channel estimator, rake receiver, despread, demodulate, deinterleaver, and TC decoder. Maximal ratio combining of rake results amplitude boost is very favorable for M-PSK demodulation due to its greater separation of the received symbol constellation. However, it is not the case for the MQAM.

For an amplitude-modulated signal (M-QAM), amplitude change could produce incorrect symbol detection [5].

### 2.1 Bit Rate and Symbol Rate

To understand and compare different modulation format efficiencies, it is important to understand the difference between bit rate and symbol rate. The signal bandwidth for the communications channel depends on the symbol rate or also known as band rate.

\[
\text{Symbol rate} = \frac{\text{Bit rate}}{\text{Number of bits transmitted per symbol}} \tag{1}
\]

Bit rate is the sampling frequency multiplied by the number of bits per sample. For example, a radio with an 8-bit sampler is sampled at 10 kHz for voice. The bit rate, the basic bit stream rate in the radio, would be 8 bits multiplied by 10k samples per second giving 80 kbps. In this example, extra bits required for synchronization, error correction, etc are ignored for simplicity. In GMSK, only one bit can be transmitted for each symbol. Thus, the symbol rate for this modulation technique is 80 kbps. However, high data rate like 8-PSK, as it will be reviewed in the next section, can transmit 3 bits per symbol. Thus, the symbol rate, if this
modulation scheme is employed, is 26.7 kbps. The symbol rate for 8-PSK is three times smaller than that of GMSK. In other words, 8-PSK or any high order (M) modulation scheme can transmit same information over a narrower piece of RF spectrum.

2.2 Bit Error Rate (BER)

BER is a performance measurement that specifies the number of bit corrupted or destroyed as they are transmitted from its source to its destination. Several factors that affect BER include bandwidth, SNR, transmission speed and transmission medium.

2.3 Signal-to-Noise Ratio (SNR)

SNR is defined as the ratio of a signal power to noise power and it is normally expressed in decibel (dB). The mathematical expression of SNR is

\[
SNR = 10 \log_{10} \left( \frac{\text{Signal Power}}{\text{Noise Power}} \right) \text{dB}
\]  

(2)

2.4 Noise and Interference

2.4.1 Additive White Noise Gaussian (AWGN)

The term thermal noise refers to unwanted electrical signals that are always present in electrical systems [11]. 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 [11]. 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

\[
z = a + n
\]

(3)

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

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

(4)
A simple model for thermal noise assumes that its power spectral density $G_n(f)$ is a flat for all frequencies and is denoted as

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

(5)

Where the factor of 2 to indicate that $G_n(f)$ 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.

### 2.4.2 Rayleigh Fading

Since signal propagation takes place in the atmosphere and near the ground, apart form the effect of free path loss, $L_s$, the most notable effect of signal degradation is multipath propagation. The effect can cause fluctuations in the received signal's amplitude, phase and angle of arrival, giving rise to terminology multipath fading.

Generally, there are two fading effects in mobile communications: large-scale and small-scale fading. Large-scale fading represents the average signal power attenuation or path loss due to shadowing effects when moving over large areas. On the other hand, small-scale fading refers to the dramatic changes in signal amplitude and phase that can be experienced as a result of small changes (as small as a half-wavelength) in the spatial separation between a receiver and transmitter. Small-scale fading is also called Rice fading because the envelope of received signal can be represented by a Rice pdf.

The received signal consists of large number of multiple reflective paths and there is no line-of-sight signal component. When there is a dominant non-fading signal component present, such as a line-of-sight propagation path, the small-scale fading envelope is described by a Rician pdf.
The Doppler spread is a measure of the spectral expansion due to the time rate of change (time variant) of the channel parameters. Figure 2.1 (d) shows a Doppler power spectral density, $S(v)$, plotted as a function of Doppler-frequency shift, $v$ based on dense-scattered channel model. For the case of the dense-scattered model, a vertical receive antenna with constant azimuthally gain, a uniform distribution of signals arriving at all arrival angles throughout the range $(0, 2\pi)$, and an unmodulated continuous wave (CW) signal, the signal spectrum at the antenna terminals is

$$s(v) = \frac{1}{\pi f_d \sqrt{1 - \left[\frac{v}{f_c} \right]^2}}$$  \hspace{2cm} (6)$$

Where $f_d$ is Doppler Spread and $f_c$ carrier frequency. The largest magnitude (infinite) of $S(v)$ occurs when the scatterer is directly ahead of the moving antenna platform or directly behind it. Thus, from this situation, the magnitude of the frequency shift is given by

$$f_d = \frac{V}{\lambda}$$  \hspace{2cm} (7)
Where \( V \) is the velocity of waves in the medium and \( \lambda \) is the signal wavelength. \( f_d \) is positive when the transmitter and receiver move towards each other, and negative when moving away from each other. Equation 7 describes the Doppler frequency shift. In a typical multipath environment, the received signal arrives from several reflected paths with different path distances and different angles of arrival, and the Doppler shift of each arriving path is generally different from that of another path. The effect on the received signal is seen as a Doppler spreading or spectral broadening of the transmitted signal frequency, rather than a shift. The Doppler power spectral density is infinite for Doppler components that arrive at exactly 0° and 180°. Thus the angle of arrival is continuously distributed and the probability of components arriving at exactly these angles is zero.

### 2.5 Quadrature Phase Shift Keying (QPSK)

QPSK is one example of M-ary PSK modulation technique (\( M = 4 \)) where it transmits 2 bits per symbol. The phase carrier takes on one of four equally spaced values, such as 0, \( \pi/2 \), \( \pi \) and \( 3\pi/2 \), where each value of phase corresponds to a unique pair of message bits as it is shown in figure 2.2. The basis signal for QPSK can be expressed as

\[
S_{\text{QPSK}}(t) = \left\{ \sqrt{E_s} \cos \left( i \frac{\pi}{2} \right) \phi_1(t) - \sqrt{E_s} \sin \left( i \frac{\pi}{2} \right) \phi_2(t) \right\} \quad i=1,2,3,4
\]

![Figure 2.2: Constellation Diagram of a QPSK System](image)

Special characteristics of QPSK are twice data can be sent in the same bandwidth compared to Binary PSK (BPSK) and QPSK has identical bit error probability to that of BPSK. When QPSK is compared to that of BPSK, QPSK provides twice the spectral efficiency with the
same energy efficiency. Furthermore, similar to BPSK, QPSK can be differentially encoded to allow non-coherent detection.

Due to these advantages of QPSK, it has been employed as the modulation technique in UMTS 3G wireless cellular networks where the following data rate can be achieved depending on the channel quality.

a) 144 kbps for high mobility.

b) 384 kbps for low mobility.

c) 2 Mbps for indoor or static environment.

2.6 M-ary Quadrature Amplitude Modulation (QAM)

QAM is a modulation technique where its amplitude is allowed to vary with phase. QAM signalling can be viewed as a combination of Amplitude Shift Keying (ASK) as well as Phase Shift Keying (PSK). Also, it can be viewed as ASK in two dimension.

![Figure 2.3: Constellation diagram of a 16-QAM system](image)

Figure 2.2 shows the constellation diagram of 16-ary QAM (16-QAM). The constellation consists of a square lattice of signal points. The general form of an M-ary signal can be defined as

\[ S_i(t) = \sqrt{\frac{2E_{\min}}{T_s}}a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{\min}}{T_s}}b_i \sin(2\pi f_c t) \quad 0 \leq t \leq T \quad i=1,2,\ldots,M \]  

Where \( E_{\min} \) is the energy of the signal with the lowest amplitude and \( a_i \) and \( b_i \) are a pair of independent integers chosen according to the location of the particular signal point.
Theoretically, higher order of M-ary QAM enables data to be transmitted in a much smaller spectrum. However, the symbols are easily subjected to errors due to noise and interference because the symbols are located very closely together in the constellation diagram. Thus such signal has to transmit extra power so that the symbol can be spread out more and this reduces power efficiency as compared to simpler modulation scheme. Also the radio equipment is more complex.

2.7 Wideband-Code Division Multiple Access (W-CDMA)

2.7.1 Direct Sequence Spread Spectrum (DSSS)

A DSSS system spreads the baseband data by directly multiplying the baseband data pulses with a pseudo-noise sequence that is produced by a pseudo-noise (PN) code generator [5]. A PN sequence is a binary sequence with an autocorrelation that resembles, over a period, the autocorrelation of a binary sequence.

The PN sequence is usually generated using sequential logic circuits (i.e. feedback shift register). A single pulse or symbol of the PN waveform is called chip. Spread spectrum signals are demodulated at receiver through cross-correlation with locally generated version of the pseudo random carrier. Cross-correlation with the correct PN sequence de-spreads the spread spectrum signal and restores the modulated message in the same narrow band as the original data, whereas cross-correlating the signal from an undesired user results in a very small amount of wideband noise at the receiver output.

Unlike modulation and demodulation techniques that have primary objective to achieve power and bandwidth efficiency in AWGN channel, the transmission bandwidth of DSSS has several orders of magnitude greater than the minimum required signal bandwidth. In other words, DSSS modulation transforms an information signal into a transmission signal with a larger bandwidth. It is achieved by encoding the information signal with a code signal that is independent of the data and has a much larger spectral width than that of information signal. In DSSS, many users can simultaneously use the same bandwidth without significantly interfering one another.
DSSS is normally used in Code Division Multiple Access (CDMA) scheme. The received DSSS signal for a single user can be represented as

\[ S_{ss}(t) = \sqrt{\frac{2E_s}{T_s}}m(t)p(t)\cos(2\pi f_c t + \theta) \]  

(10)

Where \( m(t) \) is the data sequence, \( p(t) \) is the PN spreading sequence, \( f_c \) is the carrier frequency and \( \theta \) is the carrier phase angle at \( t = 0 \).

There are numerous advantages of DSSS for cellular radio system which can describe as follows:

1. DSSS has interference rejection capability since each user is assigned with a unique PN code that is approximately orthogonal to the codes of other users.

2. Capable to resist radio jamming by a narrowband interferer.

3. DSSS eliminates the need of frequency planning since all cells can use the same channels.

4. It has high resistance to multipath fading. Since DSSS signals have uniform energy over large bandwidth, only a small portion of the spectrum will undergo fading. The delayed version of PN sequence arrived at W-CDMA receiver will have poor correlation with the original PN sequence and the receiver will ignore it. This situation will occur even if the delay is only one chip form the intended signal. In other words, the multipath signal would appear invincible to the receiver.

5. Apart from resistance to multipath fading, DSSS can exploit the delayed multipath components to improve the performance of the system. This can be done by using RAKE receiver where it consists of a bank of correlators. Each correlator will correlate to a particular multipath component of the desired signal. The correlated outputs are weighted according to their strengths and summed to obtain the final signal estimate.

Two conditions have to be satisfied for a technique to be classified as a spread spectrum technique.

1. The transmission bandwidth must be larger than the information bandwidth.

2. The resulting radio-frequency bandwidth must be determined by a function other than the information being sent. This excludes such modulation techniques such as frequency modulation (FM) and (PM).
2.7.2 Code Division Multiple Access (CDMA)

CDMA is a multiple access scheme employed normally with DSSS. Each user has a unique code that is orthogonal to one another. In CDMA, the power of multiple users at a receiver determines the noise floor after decorrelation.

Unlike the other digital systems that divide the spectrum into different time slots, CDMA’s spread spectrum technique overlaps every transmission on the same carrier frequency by assigning a unique code to each conversation.

After the speech codec converts voice to digital, CDMA spreads the voice stream over the full 1.25MHz bandwidth of the CDMA channel, coding each stream separately so it can be decoded at the receiving end. The rate of the spreading signal is known as the “chip rate”, as each bit in spreading signal is called “chip”. All voice conversations use the full bandwidth at the same time. One bit from each conversation is multiplied into 128 coded bits by the spreading techniques; giving the receiving side an enormous amount of data it can average just to determine the value of one bit.

2.8 DSSS-CDMA Bit-Error Probability Calculations

There are two approaches to calculate BER for DSSS-CDMA operating under AWGN channel [12]-[14]. The first approach uses accurate BER approximations because it is presumed that BER evaluation is numerically cumbersome.

There are many researches on this approach and most widely used approximation is the so called Standard Gaussian Approximation (SGA) [12]-[14]. In the SGA, a central limit theorem (CLT) is employed to approximate the sum of the multiple-access interference (MAI) signals as an AWGN process additional to the background Gaussian noise process. To detect desired user signal, the receiver design consists of a conventional single-user matched filter (correlation receiver). The average variance of the MAI over all possible operating conditions is used to compute the SNR at the filter (correlator) output. SGA is widely used because it is easy to apply. However, it is known based on performance analysis that SGA often overestimate system performance especially for small number of users. Thus, Improved
Gaussian Approximation (IGA) is created to overcome the limitations in SGA. IGA is more accurate that SGA especially for small number of users but with exploiting numerical integration and multiple numerical convolutions.

Simplified IGA (SIGA) is created where neither the knowledge of the conditional variance distribution, nor numerical integration nor convolution is necessary to achieve acceptable BER estimation. This approach is chosen in this project to calculate BER in the channel of W-CDMA system.

The second approach is to perform the evaluation of the DS-CDMA system BER without knowledge of or assumptions about the MAI distribution. This approach is based on previous study on ISI. There are a number of ways to achieve this method. They include moment space technique, characteristic function method, method of moments, and an approximate Fourier series method [9], [10]. Generally, these techniques can achieve more accurate BER estimate than CLT-based approximations at the expense of much higher computational complexity. For BER of DSSS-CDMA systems operating in Rayleigh fading channels, an accurate method has been proposed by [8]. It gives in depth treatment on a generic DSSS-CDMA system with Rayleigh-distributed users under both synchronous and asynchronous operations for random sequences where the IGA and SIGA methods are extended to a Rayleigh fading channel system.

2.9 Theoretical DSSS-CDMA System and Channel Models

2.9.1 Transmitter Model

If BPSK modulation scheme is used in the W-CDMA system model, the transmitted signal of \( k \)th user in reverse link (mobile to base station) can be represented as [12].

\[
S_k = \sqrt{2P_k(t)}b_k a_k \cos(w_c t + \theta_k)
\]  

(11)

Where \( P_k \) represents transmitted signal power, \( b_k(t) \) is data signal, \( a_k(t) \) is spreading signal, \( w_c \) is carrier frequency and \( \theta_k \) is carrier phase. The \( k \)th user’s data signal is a random process that is a rectangular waveform, taking values from with service rate, and is expressed as

\[
b_k(t) = \sum_{j=\infty}^a b_j^{(k)} P_j(t - jT)
\]  

(12)
Where \( P_T (t) = 1 \), for \( 0 \leq t \leq T \), and \( PT = 0 \), otherwise. The \( j \)th data bit of \( k \)th user is denoted as \( b_j^{(k)} \). Data source are assumed uniform, i.e.

\[
P_r \{ b_j^{(k)} = +1 \} = P_r \{ b_j^{(k)} = -1 \} = \frac{1}{2}
\]

The spreading signal \( a_k (t) \) can be expressed as

\[
a_k (t) = \sum_{j=-\infty}^{\infty} a_j^{(k)} \psi (t - jT)
\]

(13)

Where \( \psi(t) \) is an arbitrary chip waveform that is time-limited to \([0, T_c]\) and \( T_c \) is chip duration. Chip waveform is assumed to be normalized according to \( \int_0^{T_c} \psi^2 (t) dt = T_c \). The \( l \)th chip of the \( k \)th user is denoted \( a_l^{(k)} \), which assumes values from \{-1, +1\}. All signature sequences \{\( a_l^{(k)} \}\} are assumed to be random in the following sense. Every chip polarity is determined by flipping an unbiased coin. Further justification for the random chip sequence assumption is provided in. There are \( N \) chips for one data symbol and the period of the signature sequence is \( N \). We normalize the chip duration so that \( T_c = 1 \) and, thus, \( T = N \). Note that if the chip waveform is rectangular, i.e. \( a_k (t) = \sum_{j=-\infty}^{\infty} a_j^{(k)} P_{T_k} (t - jT_k) \) the transmitted signal becomes the well known phased coded SS model [13].

For QPSK modulation scheme, the transmitted signal of \( k \)th user in the subsystem \( i \) is

\[
S_{ik} (t) = \sqrt{2P_k} b_{ik}^I (t)c_{ik}^I (t)\cos(\omega_k t + \theta_k) + \sqrt{2P_k} b_{ik}^Q (t)c_{ik}^Q (t)\cos(\omega_k t + \theta_k)
\]

(14)

Where \( b_{ik}^I (t) \) and \( b_{ik}^Q (t) \) are the In-phase and Quadrature-phase signal.

### 2.9.2 Receiver Model

The received signal \( r(t) \) at the input of the matched filter receiver is given by

\[
r(t) = \sum_{k=1}^{K} S_k * h_k (t) + n(t) = \sum_{k=1}^{K} \sqrt{2P_k} A_k b_k (t - \tau k) a_k (t - \tau k) \times \cos(\omega_k t + \phi_k) + n(t)
\]

(15)

Where * denotes convolution and \( \phi_k = \beta_k + \theta_k - \omega_k \tau_k \) is assumed a uniform random variable over \([0, 2 \pi]\). The average received power of the \( k \)th signal is \( E[P_r] = E[A^2 k] P_k \).
2.9.3 Channel Model

2.9.3.1 AWGN

The transmitted signal for BPSK modulation is subjected to AWGN process \( n(t) \), that has two-sided power spectral density \( \frac{N_0}{2} \) and \( A_k = 1, \ k=1, \ldots, K \). \( A_k \) is independent, Rayleigh-distributed and account for the fading channel attenuation of all signal. The first order of probability density function (pdf) is given by

\[
P_{A_k}(a) = a e^{-\frac{a^2}{2}} I_{[0,\infty]}(a)
\]  

Due to the fact that SGA considers an average variance value for Multi Access Interference (MAI) or in other words, the first moment of \( \zeta \), the IGA exploits knowledge of all moments of \( \zeta \). It was shown in [15] that the BER for an AWGN channel obtained from IGA is significantly more accurate than the BER obtained from the SGA especially for small number of user, \( k \). Thus by applying SIGA, overall BER can be represented as [16].

\[
P_{\zeta}^{\text{SIGA}} \approx \frac{1}{3} \left[ 1 - \frac{N}{\sqrt{\mu_\zeta + N^2}} \right] + \frac{1}{12} \left[ 1 - \frac{N}{\sqrt{\mu_\zeta + 3\sigma_\zeta + N^2}} \right] + \frac{1}{12} \left[ 1 - \frac{N}{\sqrt{\mu_\zeta - 3\sigma_\zeta + N^2}} \right]
\]  

Where \( \mu_\zeta \) and \( \sigma_\zeta^2 \) are given by

\[
\mu_\zeta = \frac{2N}{3}(K-1)
\]  

and

\[
\sigma_\zeta^2 = (K-1) \left[ \frac{1}{45} \left( 43N^2 + 18N - 18 \right) + (k-2) \frac{N-1}{9} \right]
\]  

Where this method is extended by applying first and second moment for the received power.
2.9.3.2 Rayleigh Fading

The output of a low pass filter (LPF) of a synchronous system i.e. \( \tau_1 = \tau_2 = \ldots = \tau_k \) for user 1 can be represented as

\[
y_i = \int_{0}^{T} r(t) a_i \cos(\omega_c t) dt = S_i + I_i + n_i
\]  

(20)

Where \( n_i \) is a zero-mean Gaussian random variable with variance \( \sigma^2_{n_i} = N_0 \frac{N}{4} \), \( S_i \) is the signal component \( S_1 = \pm A_1 N \), and the interference term \( I_i \) is given by

\[
I_i = \sum_{k=2}^{K} A_k b^{(k)} \cos(\phi_k) \int_{0}^{T} a_k(t) a_i(t) dt
\]  

(21)

Since a sum of independent Gaussian random variable has Gaussian distribution, it follows that \( I_i \) is a Gaussian random variable with zero-mean and variance, by symmetry and using the independence \( I_1 \) and \( n_1 \), one has

\[
P_{e}^{SYNC} = \frac{1}{2} \left[ 1 - \frac{1}{\sqrt{1 + N_0 / 4 N + \sum_{k=2}^{K} \rho^2_{k_1}}} \right]
\]  

(22)

and averaging over the pdf of \( A_1 \), BER for a Rayleigh-faded user is

\[
P_{e}^{SYNC} = \frac{1}{2} \left[ 1 - \frac{1}{\sqrt{1 + N_0 / 4 N + \sum_{k=2}^{K} \rho^2_{k_1}}} \right]
\]  

(23)

From the equation above, one sees that the interferers act like additional independent Gaussian background noise. This is because the MAI on the flat Rayleigh fading channel has a Gaussian first-order distribution assuming synchronous transmission. This implies that the optimum receiver that does not perform user-interference cancellation is a correlator detector. However, this is not the case of asynchronous transmission. For uniformity, uniform random signature sequences \( E[\rho^2_{k_1}] = \frac{1}{N} \) and
In asynchronous transmission subjected to flat Rayleigh fading, average BER is computed by using characteristic function, $\Phi$. The proof for the following characteristic function can be found in [12]. Average characteristic function of MAI $I_k$, given $B$, is

$$
\Phi_{I_k|B}(\omega) = \int \Phi|S_kB(\omega)dS_k
$$

$$
= \frac{2^{-(N-1)}}{4} \sum_{i,A} \sum_{i,B} \left[ \Phi \left( \frac{\omega}{2} \right) \right] \times \left[ J(i+1, j) + J(i, j-1) + J(i, j+1) + J(i-1, j) \right]
$$

Using the fact that the $I_k$s given $B$ are independent, the characteristic function for total interference term $I$, given $B$, is

$$
\Phi_{I|B}(\omega) = \prod_{k=2}^{K} \Phi_{I_k|B}(\omega)
$$

The conditional BER for target user, after averaging over pdf of $A1$, can be expressed by symmetry as

$$
P_{d|B} = \frac{1}{2} \left[ 1 - \frac{1}{\sqrt{\sigma_n^2 + N^2}} \right] + \frac{N}{\sqrt{2\pi}} \int \left[ 1 - \Phi_{I|B}(\omega) \right] \Phi_{A1}(\omega) \times \exp \left( -\frac{1}{2} \omega^2 N^2 \right) d\omega
$$

When effect of the background noise is negligible that is $\sigma_n^2 \approx 0$ and $\Phi_{A1} \approx 1$, then the equation (27) becomes

$$
P_{d|B} = \frac{N}{\sqrt{2\pi}} \int_0^\infty \left[ 1 - \Phi_{I|B}(\omega) \right] \Phi_{A1}(\omega) \times \exp \left( -\frac{1}{2} \omega^2 N^2 \right) d\omega
$$

$$
= \frac{1}{2} \left[ \Phi_{I|B}(\omega) \right] \exp \left( -\frac{1}{2} \omega^2 N^2 \right) d\omega
$$

Equation no. (25), (26), (27) and (28) for noise and noiseless case gives the average BER experience by a target user with a name sequence that has a given value of $B$. The average BER for all users of for one target user averaged over all signature sequences randomly assigned by a base station for each request is

$$
P_e = 2^{-(N-1)} \sum_{B=0}^{B=N-1} \left[ \frac{N-1}{B} \right] P_{d|B}
$$

(29)
Chapter 3

CONFIGURATIONS ON W-CDMA SYSTEM

We begin our research thesis on first reviewing the high speed data rate modulation schemes, DSSS W-CDMA and fading effects on the channels. Then, we develop a generic model of DSSS W-CDMA as it is shown in figure 3.1 and is being simulated by MatLab modulation schemes 16-QAM and QPSK. Both modulation techniques are chosen in this thesis because there are the most important candidates to deliver higher data rate for High Speed Downlink Packet Access (HSDPA), an extension of 3G networks [1]-[3]. The simulation is done under AWGN noise and multipath fading channel using MATLAB 7.4.

As it is shown in figure 3.1, the user data is assumed to be Bernoulli distributed and can be represented as $b_n(t)$. 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 $s_n(t)$ after the signal is modulated by either 16-QAM or QPSK. Each signal is added before it is subjected to the channel. At the receiver, the signal $s_d(t)$ 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, observations and results will be scaled on plots based on the simulation results.

Rayleigh fading and AWGN noise (LOS) are selected to symbolize fading effect in the channel because we want to make a comparison of W-CDMA 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 with respect to time that is Doppler Effect. On the other hand, AWGN represents the thermal noise generated by electrical instruments.
3.1 Simulation Methodology

As computer based simulations are the most fitting, powerful and proficient means to stand for the actual or real time scenarios of mobile radio system. Thus, MATLAB 7.4 has been used to simulate W-CDMA model based on associated parameters, theories and formulae. So we use the MatLab 7.4 for simulation using m files. Throughout this project, we set the bit rate of 384Kbps for the signal generator.

There will be three W-CDMA wireless cellular system models that will be used in this research. The models are
1. W-CDMA system in AWGN channel
2. W-CDMA system in AWGN and Multipath Rayleigh Fading.
3.2 Simulation Using M file

The simulation is done in this project by 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 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.
3.2.1 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.

The first and second requirements are important with respect to the multipath propagation effects that occur in mobile outdoor and indoor radio environments.

However, the third requirement is important with respect to the multiple access capability of communication systems. Thus, to ensure a distinction level of codes for requirements 1 and 2, an autocorrelation function and a cross-correlation function are used respectively.

The argument of this function is the number of periods of the code for which the autocorrelation function is to be obtained. Autocorrelation function is used to measure the distinction level and it is defined as follows:

\[ R_{XX}(t) = \frac{1}{T_0} \int_0^T X(t)Y(t + \tau) d\tau \]

For instance, to obtain an autocorrelation function of a code, the following command can be typed in the command window.

\[ X(t)=[1, 1, 1, -1, -1, 1, -1] \]
\[ >> X=[1, 1, 1, -1, -1, 1, -1]; \]
\[ >> RXX=autocorr(X); \]

The polynomial rings generated using maximal linear feedback shift registers and are so called MLS(maximum length sequence) because they are periodic and reproduce every binary sequence that can be reproduced by the shift registers (i.e., for length-\( m \) registers they produce a sequence of length \( 2^m - 1 \)). A MLS is also sometimes called a n-sequence or a m-sequence.
In this case, three-stage M-sequence with a code length of 7 is used. The value of correlation function \( R \) can be obtained by typing \( RXX \).

On the other hand, \texttt{cross-corr.m} is used to calculate the value of cross-correlation function between two distinct codes \( X(t) \) and \( Y(t) \).

\[
R_{XX}(\tau) = \frac{1}{T} \int_{0}^{T} X(t)Y(t + \tau) \, d\tau
\]

The arguments of this function are the name of the sequence and the number of periods of the code for which the autocorrelation function is to be obtained. The following function will be typed to calculate the cross-correlation function of codes \( X(t) \) and \( Y(t) \).

\[
\begin{align*}
&>> \text{X}=[1, 1, 1, -1, -1, 1, -1]; \\
&>> \text{Y}=[1, -1, 1, -1, 1, 1, -1, 1]; \\
&>> \text{RXY}=\text{crosscorr(X,Y)};
\end{align*}
\]

Also, in this case, three-stage M-sequence and a random sequence with a code length of 7 will be used. To calculate the cross-correlation function, \( \text{RXY} \) is typed. Thus, the spreading code can be calculated by using these autocorrelation and cross-correlation functions.

### 3.2.2 Code Generation by LSFR (Linear Feedback Shift Register)

In this task Linear feedback shift register will be used to generate code sequences in W-CDMA. A shift register contains a number of cells identified by numbers 1 to \( r \), and each cell is a storage unit that, under the control of a clock pulse, moves the contents to its output while reading its new contents from the input. In a standard configuration of a feedback register, the input of cell \( m \) will be a function of the output of cell \( m-1 \) and the output of cell \( r \) (the last cell of the shift register) forms the desired code sequence.

In linear feedback shift registers (linear FSRs), the function combining the outputs of cell \( m-1 \) and cell \( r \) with the input of cell \( m \) is linear. Figure 3.2 shows a single linear binary shift register, which can generate a sequence from generation polynomial \( h(x) = x^5 + x^2 + 1 \). In general, the configuration of a linear binary shift register of \( n \) sections is described by a
generator polynomial, which is a binary polynomial of degree \( n \). \( n \), in this case, is the number of register of the shift register.

\[
h(x) = h_n x^n + h_{n-1} x^{n-1} + \ldots + h_1 x^1 + 1 \quad (h_i \in \{0,1\})
\]

### 3.2.3 Generation of M-Sequence

M-sequence is a sequence generated by a single LFSR where a sequence of possible period, \( (N_c = 2^n - 1) \), is generated by an \( n \)-stage binary shift register with linear feedback. To generate an M-sequence, the generator polynomial must be of degree \( n \). Thus, the periodic autocorrelation function of an M-sequence is given by

\[
r_{xx}(t) = \begin{cases} 
1 & t \equiv \text{mod } N_c \\
-1/N_c & \text{otherwise}
\end{cases}
\]

If \( n \neq 0 \mod 4 \), there exist pairs of maximum-length sequence with a three-valued cross-correlation function, where the two values are \( \{-t(n), t(n)-2\} \) with

\[
t(n) = \begin{cases} 
1 + 2^{(n+1)/2} & n: \text{odd} \\
1 + 2^{(n+2)/2} & n: \text{even}
\end{cases}
\]

The m file is given as mseq.m. The number of registers, the initial values of the registers and the position of the feedback taps are given as argument in mseq.m. For instance, suppose the 3rd number register, the initial values of the registers are [1, 1, 1] and the position of the feedback tap is in the first and third taps. The generation polynomial can be expressed as

\[
h(x) = x^3 + x + 1.
\]

This configuration can be visualized using shift register as it is shown in figure. M-sequence can be generated by using the following command.

\[
>> m1=mseq(3, [1,3], [1,1,1])
\]

As a result, a three-stage M-sequence [1, 1, 1, 0, 1, 0, 0] is generated as a vector. A fourth argument, which denotes the number of output, is available in mesq.m. For a given number of \( N \) output, \( N \) one-chip shifted M-sequence. For example, another three stage M-sequence is generated by the following command:

\[
>> m2=mseq(3, [2, 3], [1, 1, 1], 3)
\]

This command yields and output of

\[
\text{Ans} = \\
1 1 1 0 1 0 1 0 \\
0 1 1 1 0 1 0 1
\]
The shifting of the number of chips given by the users for the vector or matrix is performed by the function in file shift.m.

The characteristics of the M-sequences can be evaluated by using functions autocorr.m and crosscorr.m. The following commands are used to convert the generated code sequences consisting 0 and 1 to code sequences consisting -1 and 1.

```plaintext
>> m1=m2*2-1;
>> m2=m2*2-1;
```

The correlation function of three-stage M-sequence m1 can be calculated by typing the following command.

```plaintext
>> autocorr(m1);
```

The autocorrelation value obtained is [7, -1, -1, -1, -1, -1, -1]. Thus it satisfies the above equation. Next, the following command is used to find the cross-correlation function between m1 and m2(1,:).

```plaintext
>> crosscorr(m1,m2(1,:));
```

[3, -1, 3, -1, -1, -5, 3] is the cross-correlation value obtained from this command. This result takes three values namely [-1, -t(n), t(n)-2] where t(n)=5 taken from equation. Thus, m1 and m2(1,:) have the characteristics of a preferred pair.

![Figure 3.2: Three-stage M-sequence](image)

### 3.2.4 Configuration of Transmitter and Receiver

In this section, the system is configured based on synchronous W-CDMA system. Each user employs their own sequence to spread the information data. In this downlink transmission, the information data are modulated by the modulation scheme. After, the modulated data are spread by code that is M-sequence. The spreaded data of all users in the system are
transmitted to the mobile users at the same time. The mobile user detects the information data of each user by correlating the received signal with a code sequence allocated to each user.

The performance of the W-CDMA system is studied based on QPSK and 16-QAM modulation techniques that will be used in this simulation.

The main simulation file is dscdma.m. The parameters used in the simulation are defined as follows.

\[
\begin{align*}
\text{sr} &= 192000; \quad \% \text{Symbol rate} \\
\text{m1} &= 2; \quad \% \text{Number of modulation levels} \\
\text{br} &= \text{sr} \times \text{m1}; \quad \% \text{Bit rate} \\
\text{nd} &= 100; \quad \% \text{Number of symbols} \\
\text{ebn0} &= 10; \quad \% \text{Eb}/\text{No} \\
\text{irfn} &= 21; \quad \% \text{Number of filter taps} \\
\text{IPOINT} &= 8; \quad \% \text{Number of oversamples} \\
\text{alfs} &= 0.5 \quad \% \text{Roll-off factor}
\end{align*}
\]

The coefficients of the two (T and R) filters that evaluate the performance of QPSK and 16-QAM are defined as follows.

\[
\begin{align*}
[xh] &= \text{hrollfcoef}(\text{irfn}, \text{IPOINT}, \text{sr}, \text{alfs}, 1); \quad \% \text{T Filter Function} \\
[xh2] &= \text{hrollfcoef}(\text{irfn}, \text{IPOINT}, \text{sr}, \text{alfs}, 0); \quad \% \text{R Filter Function}
\end{align*}
\]

In synchronous W-CDMA, the number of code sequences that can be allocated to different users is equal to the number of code lengths. Therefore, the length of the code sequence must be larger than the number of users. To generate a code, the number of registers, the position of the feedback tap and the initial value of the registers has to be specified. Thus, the following parameters are used.

\[
\begin{align*}
\text{user} &= 1; \quad \% \text{Number of users} \\
\text{seq} &= 1; \quad \% \text{M-sequence} \\
\text{stage} &= 3; \quad \% \text{Number of stage} \\
\text{ptap1} &= [1 \ 3]; \quad \% \text{Position of taps for 1st} \\
\text{ptap2} &= [2 \ 3]; \quad \% \text{Position of taps for 2nd}
\end{align*}
\]
regi1 = [1 1 1];  % Initial value of register for 1st
regi2 = [1 1 1];  % Initial value of register for 2nd

By using these parameters, a spread code is generated and the generated code is stored as variable code. Code is a matrix with a sequence of the number of users multiplied by the length of the code sequence. The following commands are used to convert generated code sequence consisting 0 and 1 into a sequence of -1 and 1.

Code = code * 2 – 1;
Clen = length(code);

Subsequently, the parameters for the fading simulator are defined. When rfade is declared as 0 (LOS), the file that evaluates the BER performance in the AWGN channel. On the other hand, when rfade is 1(NLOS), the simulation evaluates the BER performance in a multipath Rayleigh fading environment.

rfade = 0; % Rayleigh fading
% 0:nothing, 1:consider
itau = [0,8];  % Delay time
dlvll = [0.0,40.0];  % Attenuation level
n0 = [6,7];  % Number of wave to generate fading
th1 = [0.0, 0.0]  % Initial phase of delayed wave
itnd1 = [3001,4004];  % Set fading counter
now1 = 2;  % Number of direct waves +delayed waves
tstp = 1/sr/IPOINT/clen;  % Frequency resolution
fd = 160;  % Doppler frequency (HZ)
flat = 1;  % Flat Rayleigh environment
intndel = itndel=nd*IPOINT*clen*30;

Consequently, the number of simulation loops is set. The variables that count the number of transmitted data bits and the number of errors are initiated.

nloop = 100;  % Simulation number of times
noe = 0;  % Number of errors
nod = 0;  % Number of data

The transmitted data in the In-phase channel and Quadrature phase modulated by QPSK or 16-QAM are multiplied by the code sequence used to spread the transmitted data. The spread
Data are then oversampled and filtered by a roll-off filter and transmitted to a communication channel. The format used to input these new functions does not depend on the vector or matrix. The files that perform these simulations are compoversamp2.m and compconv2.m.

```matlab
Data = rand(user,nd*m1) 0.5;
[ich, qch] = qpskmod(data,user,nd,m1); % QPSK modulation
[ich1,qch1] = spread(ich,qch,code); % Spreading
[ich2,qch2] = compoversamp2(ich1,qch1,IPOINT); % Oversampling
[ich3,qch3] = compconv2(ich2,qch2,xh); % T filter
```

It follows with the synthesis of transmitted signals from users.

```matlab
If user == 1 % Number of users is 1
    ich4 = ich3;
    qch4 = qch3;
else % Number of user is plural
    ich4 = sum(ich3);
    qch4 = sum(qch3);
end
```

Then, the synthesized signal is contaminated in a Rayleigh fading channel.

```matlab
If rfade == 0 % in AWGN
    Ich5 = ich4;
    qch5 = qch4;
else % Rayleigh fading channel
    [ich5,qch5]=sefade(ich4,qch4,itau,dlvl1,th1,n0,itnd1,now1,length(ich4),tstp,fd,flat);
    itnd1 = itnd1 + itndel; % fading counter
end
```

At the receiver, AWGN is added to the received data as it is represented in a simulation file comb2.m. Next, the contaminated signal is filtered by using root cosine roll-off filter.

```matlab
spow = sum(rot90(ich3.^2 + qch3.^2)) / nd; % attenuation Calculation
attn = sqrt(0.5 * spow * sr / br * 10^(-ebn0/10));
```
\[ \text{ich6}, \text{qch6} = \text{comb2(ich5,qch5,attn)}; \quad \% \text{Add AWGN} \]
\[ \text{ich7}, \text{qch7} = \text{compconv2(ich6,qch6,xh2)}; \quad \% \text{filter} \]
\[ \text{sampl} = \text{irfn} \times \text{IPOINT} + 1; \]
\[ \text{ich8} = \text{ich7(:,sampl:}\text{IPOINT:}\text{IPOINT*nd*clen+sampl-1}); \quad \% \text{Resampling} \]
\[ \text{qch8} = \text{qch7(:,sampl:}\text{IPOINT:}\text{IPOINT*nd*clen+sampl-1}); \]

Now the resample data are the synthesized data of all the users. By correlating the synthesized data with the spread code used at the transmitter, the transmitted data of all the users are detected. The correlation is done by despread.m.

\[ \text{ich9 qch9} = \text{despread(ich8,qch8,code)}; \quad \% \text{disspreading} \]

Then, the correlated data is demodulated by a modulation technique. The total number of errors for all the users is calculated. Eventually, the BER is calculated.

\[ \text{noe2} = \text{sum(sum(abs(data-demodata))}); \quad \% \text{QPSK demodulation} \]
\[ \text{nod2} = \text{user} \times \text{nd} \times \text{ml}; \]
\[ \text{noe} = \text{noe} + \text{noe2}; \]
\[ \text{nod} = \text{nod} + \text{nod2}; \]

To simulate W-CDMA system in multipath fading channel with Doppler shift, similar procedures are used. The Doppler shifts (Hz) are based on mobile terminal velocity of 60kmph, 120kmph respectively.

### 3.2.5 Steps to Realize the Simulation in dscdma.m file

The simulations for QPSK and 16-QAM modulation techniques are done by simulating the value of Eb/No at a fixed interval. For example, if the range of Eb/No is from 0 to 10 with interval of 1, the value of BER will be obtained for Eb/No at 1 interval.

This means the simulation to get the value of BERs has to be done 11 times. The range of Eb/No is determined by the behavior of the BER at that Eb/No’s range. To realize the simulation of W-CDMA in LOS scenario, the value of rfade is initialize to 0. Otherwise, it
can be assigned to 1. When rfade=1, the channel of W-CDMA system is subjected to AWGN and multipath fading channel. The Doppler shift, on the other hand, is defined in fd. It represents the value of Doppler shift in Hertz (Hz).

Furthermore, the simulation of 16-QAM can be achieved by swapping the functions of modulator and demodulator from qpskmod and qpskdemod to qammod and qamdemod respectively.

### 3.2.6 Limitation and Assumption

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 noise and Rayleigh fading only.

Furthermore, the BER in LOS 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, Φ, is used in asynchronous transmission to determine the total MAI, I, and therefore the BER can be computed based on these variables.
Chapter 4

PERFORMANCE ANALYSIS ON W-CDMA SYSTEM

Based on data generated by computer simulation of W-CDMA models, relationship for ray-tracing model using QPSK and QAM modulation techniques between BER as a function of the following parameters are obtained for NLOS. 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 channel for 16-QAM modulation scheme.
3. BER versus SNR in AWGN and multipath Rayleigh fading channel with Doppler shift (60kmph and 120kmph) for QPSK modulation technique.
4. BER versus SNR in AWGN and multipath Rayleigh fading channel with Doppler shift (60kmph and 120kmph) for 16-QAM modulation scheme.
5. BER versus SNR to compare between AWGN channel and multipath Raleigh fading channel for different number of user for QPSK modulation technique.
6. BER versus SNR to compare between AWGN channel and multipath Raleigh fading channel for different number of user for 16-QAM modulation technique.

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 and 120kmph. However, the simulation does not yield the desired outcome when 16-QAM is employed as the modulation technique in the W-CDMA system. The results of these two approaches are discussed in this chapter.
4.1 SIMULATION USING M FILES

4.1.1 Performance Analysis of QPSK modulation technique of W-CDMA in AWGN

Table 4.1: Simulation result for evaluation on BER vs. SNR for ray tracing (also called 2-ray, one is LOS and other is reflected or NLOS) AWGN channel for 1 user when the number of data is 200,000.

<table>
<thead>
<tr>
<th>Signal-to-Noise Ratio (EbNo)</th>
<th>Number of Error</th>
<th>Bit Error rate (BER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15615</td>
<td>7.807500e-002</td>
</tr>
<tr>
<td>1</td>
<td>11334</td>
<td>5.667000e-002</td>
</tr>
<tr>
<td>2</td>
<td>7520</td>
<td>3.760000e-002</td>
</tr>
<tr>
<td>3</td>
<td>4484</td>
<td>2.242000e-002</td>
</tr>
<tr>
<td>4</td>
<td>2489</td>
<td>1.244500e-002</td>
</tr>
<tr>
<td>5</td>
<td>1205</td>
<td>6.025000e-003</td>
</tr>
<tr>
<td>6</td>
<td>462</td>
<td>2.310000e-003</td>
</tr>
<tr>
<td>7</td>
<td>165</td>
<td>8.250000e-004</td>
</tr>
<tr>
<td>8</td>
<td>39</td>
<td>1.950000e-004</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>1.000000e-005</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>5.000000e-006</td>
</tr>
</tbody>
</table>

In this simulation, the BERs are obtained by varying the values of Eb/No in the range of 0 to 10. The iteration is done 1000 times where the total number of data transmitted is 200,000.
4.1.2 Performance Analysis of QPSK modulation technique of W-CDMA in AWGN and Multipath Fading Channel

The simulation of BER is done in the range of 0 to 20 of Eb/No. The BER graphs of various Doppler shifts are simulated on the same graph as it is shown in figure 4.2. The y axis of BER is blown up to depict the behavior in Doppler shift environment.

Figure 4.1: Performance of W-CDMA in ray-tracing model AWGN Channels for 1 user
**Table 4.2:** 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 kmph.

<table>
<thead>
<tr>
<th>Signal-to-Noise Ratio (Eb/No)</th>
<th>Number of Error</th>
<th>Bit Error rate (BER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27889</td>
<td>1.394450e-001</td>
</tr>
<tr>
<td>2</td>
<td>20441</td>
<td>1.022050e-001</td>
</tr>
<tr>
<td>4</td>
<td>14529</td>
<td>7.264500e-002</td>
</tr>
<tr>
<td>6</td>
<td>9742</td>
<td>4.871000e-002</td>
</tr>
<tr>
<td>8</td>
<td>6494</td>
<td>3.247000e-002</td>
</tr>
<tr>
<td>10</td>
<td>4197</td>
<td>2.098500e-002</td>
</tr>
<tr>
<td>12</td>
<td>2926</td>
<td>1.463000e-002</td>
</tr>
<tr>
<td>14</td>
<td>1888</td>
<td>9.440000e-003</td>
</tr>
<tr>
<td>16</td>
<td>1261</td>
<td>6.305000e-003</td>
</tr>
<tr>
<td>18</td>
<td>916</td>
<td>4.580000e-003</td>
</tr>
<tr>
<td>20</td>
<td>614</td>
<td>3.070000e-003</td>
</tr>
</tbody>
</table>

**Table 4.3:** 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 120 kmph.

<table>
<thead>
<tr>
<th>Signal-to-Noise Ratio (Eb/No)</th>
<th>Number of Error</th>
<th>Bit Error rate (BER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27920</td>
<td>1.396000e-001</td>
</tr>
<tr>
<td>2</td>
<td>20820</td>
<td>1.041000e-001</td>
</tr>
<tr>
<td>4</td>
<td>14570</td>
<td>7.285000e-002</td>
</tr>
<tr>
<td>6</td>
<td>9998</td>
<td>4.999000e-002</td>
</tr>
<tr>
<td>8</td>
<td>6708</td>
<td>3.354000e-002</td>
</tr>
<tr>
<td>10</td>
<td>4436</td>
<td>2.218000e-002</td>
</tr>
<tr>
<td>12</td>
<td>2889</td>
<td>1.444500e-002</td>
</tr>
<tr>
<td>14</td>
<td>1878</td>
<td>9.390000e-003</td>
</tr>
<tr>
<td>16</td>
<td>1240</td>
<td>6.200000e-003</td>
</tr>
<tr>
<td>18</td>
<td>794</td>
<td>4.580000e-003</td>
</tr>
<tr>
<td>20</td>
<td>543</td>
<td>3.070000e-003</td>
</tr>
</tbody>
</table>
Figure 4.2: Performance of W-CDMA in 2-Rays Multipath Rayleigh Fading Channels for 1 user
4.1.3 Performance Analysis Comparison of QPSK modulation technique of W-CDMA between AWGN and Rayleigh Fading Channel

Table 4.4: Simulation result for evaluation on BER vs. SNR for 2-ray AWGN channel for 1 user when the number of data is 200,000.

<table>
<thead>
<tr>
<th>Signal-to-Noise Ratio (Eb/No)</th>
<th>Number of Error</th>
<th>Bit Error rate (BER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15615</td>
<td>7.807500e-002</td>
</tr>
<tr>
<td>1</td>
<td>11334</td>
<td>5.667000e-002</td>
</tr>
<tr>
<td>2</td>
<td>7520</td>
<td>3.760000e-002</td>
</tr>
<tr>
<td>3</td>
<td>4484</td>
<td>2.242000e-002</td>
</tr>
<tr>
<td>4</td>
<td>2489</td>
<td>1.244500e-002</td>
</tr>
<tr>
<td>5</td>
<td>1205</td>
<td>6.025000e-003</td>
</tr>
<tr>
<td>6</td>
<td>462</td>
<td>2.310000e-003</td>
</tr>
<tr>
<td>7</td>
<td>165</td>
<td>8.250000e-004</td>
</tr>
<tr>
<td>8</td>
<td>39</td>
<td>1.950000e-004</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>1.000000e-005</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>5.000000e-006</td>
</tr>
</tbody>
</table>
**Table 4.5:** Simulation result for evaluation on BER vs. SNR for 2-ray Multipath Rayleigh channel for 1 user when the number of data is 200,000

<table>
<thead>
<tr>
<th>Signal-to-Noise Ratio (Eb/No)</th>
<th>Number of Error</th>
<th>Bit Error rate (BER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28979</td>
<td>1.448950e-001</td>
</tr>
<tr>
<td>1</td>
<td>24809</td>
<td>1.240450e-001</td>
</tr>
<tr>
<td>2</td>
<td>21465</td>
<td>1.073250e-001</td>
</tr>
<tr>
<td>3</td>
<td>18128</td>
<td>9.064000e-002</td>
</tr>
<tr>
<td>4</td>
<td>15283</td>
<td>7.641500e-002</td>
</tr>
<tr>
<td>5</td>
<td>12601</td>
<td>6.300500e-002</td>
</tr>
<tr>
<td>6</td>
<td>10143</td>
<td>5.071500e-002</td>
</tr>
<tr>
<td>7</td>
<td>8285</td>
<td>4.142500e-002</td>
</tr>
<tr>
<td>8</td>
<td>6503</td>
<td>3.251500e-002</td>
</tr>
<tr>
<td>9</td>
<td>5194</td>
<td>2.597000e-002</td>
</tr>
<tr>
<td>10</td>
<td>4119</td>
<td>2.059500e-002</td>
</tr>
</tbody>
</table>
Figure 4.3: Performance Comparison of W-CDMA in 2-Rays between AWGN and Multipath Rayleigh Fading Channels for 1 user
Table 4.6: Simulation result for evaluation on BER vs. SNR for 2-ray AWGN channel for 5 user when the number of data is 100,000

<table>
<thead>
<tr>
<th>Signal-to-Noise Ratio (Eb/No)</th>
<th>Number of Error</th>
<th>Bit Error rate (BER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>94680</td>
<td>9.468000e-002</td>
</tr>
<tr>
<td>2</td>
<td>56563</td>
<td>5.656300e-002</td>
</tr>
<tr>
<td>4</td>
<td>29383</td>
<td>2.938300e-002</td>
</tr>
<tr>
<td>6</td>
<td>13676</td>
<td>1.367600e-002</td>
</tr>
<tr>
<td>8</td>
<td>5393</td>
<td>5.393000e-003</td>
</tr>
<tr>
<td>10</td>
<td>1932</td>
<td>1.932000e-003</td>
</tr>
<tr>
<td>12</td>
<td>552</td>
<td>5.520000e-004</td>
</tr>
<tr>
<td>14</td>
<td>72</td>
<td>7.200000e-005</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>4.000000e-006</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 4.7: Simulation result for evaluation on BER vs. SNR for 2-ray Multipath Rayleigh channel for 5 user when the number of data is 100,000

<table>
<thead>
<tr>
<th>Signal-to-Noise Ratio (Eb/No)</th>
<th>Number of Error</th>
<th>Bit Error rate (BER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>153437</td>
<td>1.534370e-001</td>
</tr>
<tr>
<td>2</td>
<td>118123</td>
<td>1.181230e-001</td>
</tr>
<tr>
<td>4</td>
<td>87273</td>
<td>8.727300e-002</td>
</tr>
<tr>
<td>6</td>
<td>61830</td>
<td>6.183000e-002</td>
</tr>
<tr>
<td>8</td>
<td>41875</td>
<td>4.187500e-002</td>
</tr>
<tr>
<td>10</td>
<td>27248</td>
<td>2.724800e-002</td>
</tr>
<tr>
<td>12</td>
<td>17799</td>
<td>1.779900e-002</td>
</tr>
<tr>
<td>14</td>
<td>11307</td>
<td>1.130700e-002</td>
</tr>
<tr>
<td>16</td>
<td>7314</td>
<td>7.314000e-003</td>
</tr>
<tr>
<td>18</td>
<td>4713</td>
<td>4.713000e-003</td>
</tr>
<tr>
<td>20</td>
<td>3210</td>
<td>3.210000e-003</td>
</tr>
</tbody>
</table>
Figure 4.4: Performance Comparison of W-CDMA in 2-Rays between AWGN and Multipath Rayleigh Fading Channels for 5 users
4.1.4 Performance Analysis of 16-QAM modulation technique of W-CDMA in AWGN

![Simulation of BER/SER for 16-QAM with Gray coding (Rayleigh multipath and AWGN)](image)

4.1.5 Performance Analysis of 16-QAM modulation technique of W-CDMA in AWGN and Multipath Fading Channel

We can not obtain any results in this scenario as the results are inconsistent and uncertain. Therefore, we can not investigate the performance of W-CDMA for this scenario.

4.2 Analysis and Discussion

Simulation using m files shows that each QPSK and 16-QAM modulation techniques in AWGN channel has good performance when it is compared to that of Multipath Rayleigh channel. Also, the performance of QPSK and 16-QAM degrades when the channel is subjected to Multipath fading with increasing value of Doppler shift (Hz). In other words, it
performs poorly as the speed of mobile terminal is increased. Moreover, the system performs badly as the number of users is increased. Comparison between QPSK and 16-QAM modulation schemes shows that 16-QAM performs very poorly in both AWGN (LOS channel) and AWGN with Multipath fading channel. The simulation of 16-QAM modulation technique using m files cannot be done because it is suspected that the variation of amplitude with phase causes errors in the constellation of 16-QAM signal.

The reason behind this poor performance of 16-QAM of W-CDMA system in multipath fading channel is basically due to the interference between adjacent carriers phase in the constellation of 16-ary QAM. A sound approach is needed to be used in 16-QAM of W-CDMA system to ensure zero or minimal interference between adjacent carriers phase in the constellation of 16-QAM. It is suggested that error correction coding such as convolution coding or turbo coding is used in this system to ensure better performance of 16-QAM modulation technique of W-CDMA system. Also, it is possible to consider the use of a RAKE receiver or a smart antenna (MIMO) in this system to exploit the delayed signals generated in multipath fading channel. It is discovered, as well, that the performance of multi-user in the m file is limited to a maximum of 7 users. Thus, this system needs to be improved to simulate more number of users so that the performance of multiple access in W-CDMA can be studied more dynamically.
Chapter 5

CONCLUSION

5.1 Conclusion

In telecommunication field the major challenges is to convey the information as efficiently as possible through limited bandwidth, though the some of 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 two modulation techniques, QPSK and 16-QAM to reduce the error performance of the signal and compare which technique is better 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 compared to that of 16-QAM. Furthermore, similar trend is found when the channel is subjected to multipath Rayleigh fading with Doppler shift. The performance of QPSK and 16-QAM modulation technique in W-CDMA system degrades as the mobility is increased from 60kmph to 120kmph for both QPSK and 16-QAM. However, QPSK shows better performance compared to that of 16-QAM in LOS channel and multipath Rayleigh fading channel. In other words, 16-QAM suffers signal degradation and error prone when the simulations are done in these channels. As the number of users is increased, the QPSK modulation technique performs poorly in W-CDMA system. Unfortunately, the simulation for 16-QAM has failed to show the expected results in both Simulink and m files. This is because the 16-QAM modulation scheme experiences adjacent carrier interference when the simulation is carried out. Therefore, it results in inconsistence of data or signal throughput causing abnormal values of BER and eventually affecting the performance of W-CDMA system. It is expected that 16-QAM will show performance degradation similar like QPSK as the number of users is increased but with lower performance compared to that of QPSK. 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. Many studies and researches have showed that 16-QAM modulation technique is a primary candidate for high speed data transmission in 3G mobile communication [5]-[8], [3],[9],[10],[15] and [17],[18]. High Speed Downlink Packet Access (HSDPA) is considered as a 3.5G where it has the capability to boost up the data rates of up to 10.7 Mbps using 16-QAM in a static environment. However, higher data rate modulation scheme (e.g.16-QAM) 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 in constellation of M-ary QAM. Larger value of M of M-ary QAM suffers more signal degradation. Thus, it is suggested that high data rate modulation technique such as 16-QAM needs an error correction coding such as convolutional coding or turbo coding so that the interference from the adjacent carrier phase in the constellation of 16-QAM can be eliminated if not minimized.

5.2 Suggestion for Future Work

A more complete W-CDMA system can be developed using the suggested method as they are explained as follows.
1. Generate binary data source for various data rates for various services that can be offered by W-CDMA system in 3G environment. For example 144 Kbps for suburban (indoor/outdoor), urban vehicular and pedestrian, and 2 Mbps for indoor office.
2. Implement error correction scheme such as convolution coding and turbo coding particularly with M-QAM modulation technique in W-CDMA system. Higher order QAM modulation schemes are vulnerable to error. Therefore, error correction coding ensures higher chances of signal survivability in AWGN and multipath Rayleigh channel and thus enhances the performance of the system.
3. It is proposed that Rician fading is included in the channel in addition of AWGN and multipath Rayleigh fading channel. Then, comparison can be made between these channels.
4. Also, it is proposed that other sequence generator is employed to generate unique chip code and spread the bandwidth of W-CDMA system such as Gold Sequence Generator, and Kasami Sequence Generator beside the PN Sequence Then, comparison can be made to determine which one is having a better performance and good BER characteristics.
5. A complete uplink and downlink W-CDMA system can be implemented in the W-CDMA system for a comprehensive study.
6. A RAKE receiver or a smart antenna (Multiple Input and Multiple Output) is suggested to be used in this system to exploit the delayed signals arrived at the antenna caused by Multipath Rayleigh fading.
7. Newer version of MATLAB should be considered. This is due to the limitation of blocks in communication toolbox and block set. Even though the numbers of block in communication block set are many, more designs of block set using CDMA, especially W-CDMA technologies are needed in this project. This is to produce high accuracy and precision simulation model of W-CDMA system.
REFERENCES


