ANALYSIS OF THE PERFORMANCE OF CDMA CORRELATION RECEPTION UNDER THE INFLUENCE OF INTERFERENCE

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If it was not for all these mentioned, this project would have never been conducted.
TO MY MOTHER, MY FATHER, MY BELOVED BROTHERS.

OMAR
Abstract

Communications in general and especially wireless communications is a rapidly changing and developing field. Code Division Multiple Access represented a mile stone in communication industry; since it overcame the bandwidth limitations of prior system such as FDMA and TDMA.

The basic idea behind CDMA is the use of orthogonal codes to discriminate among users accessing the system. The problem arises when the number of users in the system begins to increase, which leads to reduction in the orthogonality of these codes and as a consequence the system performance is lowered.

This project aims to analyze the CDMA correlation reception under the influence of interference caused by multiple users accessing the system using non- perfectly orthogonal codes. The IS-95 CDMA system was modeled using MATLAB, and the number of users and the corresponding bit error rate BER were tested against the signal to noise ratio SNR. The results obtained were analyzed and discussed, and the optimum number of users for the designed model was stated.
تشمل الاتصالات بصورة عامة وخصوصا الاتصالات اللاسلكية مجالًا يتطور بصورة متطردة. يمثل الولوج المتعدد بالشفرة المرمزية حجر الزاوية في هذا المجال حيث تغلب على محدودية عرض النطاق في الأنظمة السابقة مثل الولوج المتعدد بتقسيم التردد والزمن.

تتلخص الفكرة الأساسية في الولوج المتعدد بالشفرة المررمزية في استخدام المرموزات المعتمدة للتفريق بين المستخدمين عند الاستقبال، تكمن المشكلة في ان زيادة عدد المستخدمين في النظام يؤثر على تعامد هذه المرموزات مما يقلل من أداء النظام.

يهدف هذا المشروع إلى دراسةاستفادة الترابط في نظام الولوج المتعدد بتقسيم المرمزية ومدى تأثره بالداخل الناتج عن تعدد المستخدمين وتشخيصهم لمزدوجات غير معتمدة بصورة مثلى. صمم نموذج نظام الولوج المتعدد بتقسيم المررمزية باستخدام تطبيق الحاسوب (ماتلاب)، ودُرست علاقة عدد المستخدمين و معدل الخطأ في مقابل نسبة الإشارة إلى الضجيج. دُرست النتائج المتحصل عليها وحُللت، ومن ثم جُد عدد المستخدمين الأمثل لهذا النظام.
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<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<td>FDMA</td>
<td>Frequency Division Multiple Access</td>
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<td>TDMA</td>
<td>Time Division Multiple Access</td>
</tr>
<tr>
<td>BS</td>
<td>Base Station</td>
</tr>
<tr>
<td>MS</td>
<td>Mobile Station</td>
</tr>
<tr>
<td>AWGN</td>
<td>Additive White Gaussian Noise</td>
</tr>
<tr>
<td>BER</td>
<td>Bit Error Rate</td>
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<tr>
<td>SNR</td>
<td>Signal to Noise Ration</td>
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<tr>
<td>DS</td>
<td>Direct Spreading</td>
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<tr>
<td>FH</td>
<td>Frequency Hopping</td>
</tr>
<tr>
<td>SS</td>
<td>Spread Spectrum</td>
</tr>
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<td>MC</td>
<td>Multi Carrier</td>
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<tr>
<td>MT</td>
<td>Multi Tone</td>
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<tr>
<td>AM</td>
<td>Amplitude Modulation</td>
</tr>
<tr>
<td>FM</td>
<td>Frequency Modulation</td>
</tr>
<tr>
<td>TH</td>
<td>Time Hopping</td>
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<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
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<td>PN</td>
<td>Pseudo Noise</td>
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<td>MI</td>
<td>Multipath Interference</td>
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<td>MAI</td>
<td>Multiple Access Interference</td>
</tr>
<tr>
<td>ACF</td>
<td>Auto Correlation Function</td>
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<tr>
<td>CCF</td>
<td>Cross Correlation Function</td>
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<td>ISI</td>
<td>Inter Symbol Interference</td>
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$AGC$  automatic gain control

$QPSK$  quadrature phase shift keying

$OQPSK$  offset quadrature phase shift keying

$ESN$  electronic serial number

$MIN$  mobile identification number


Chapter 1

Introduction

1.1 History of the CDMA

CDMA is a military technology first used during World War II by English allies to foil German attempts at jamming transmissions. The allies decided to transmit over several frequencies, instead of one, making it difficult for the Germans to pick up the complete signal. Because Qualcomm created communications chips for CDMA technology, it was privy to the classified information. Once the information became public, Qualcomm claimed patents on the technology and became the first to commercialize it.

In recent years, spread spectrum has moved from military to commercial Communications. Service providers, both cellular and PCS\(^1\) carriers, have deployed commercial CDMA systems in major metropolitan areas.

1.2 Concept of the CDMA

One of the basic concepts in data communication is the idea of allowing several transmitters to send information simultaneously over a single communication channel. This allows several users to share the bandwidth. This concept is called multiplexing. CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code) to allow multiple users to be multiplexed over the same physical channel. In contrast, time division multiple access (TDMA) divides access by time, while frequency-division multiple access (FDMA) divides it by frequency. CDMA is a form of "spread-spectrum" signalling, since the modulated coded signal has a much higher data bandwidth than the data being communicated.

An analogy to the problem of multiple access is a room (channel) in which people wish to communicate with each other. To avoid confusion, people could take turns speaking (time division), speak at different pitches (frequency division), or speak in different languages (code division). CDMA is analogous to this example where people speaking the same language can understand each other, but not other people. Similarly, in radio CDMA, each group of users is given a shared code. Many codes occupy the same channel, but only users associated with a particular code can understand each other.

CDMA is a multiple-access scheme based on spread-spectrum communication techniques. It spreads the message signal to a relatively wide bandwidth by using a unique code that reduces interference, enhances system processing, and differentiates users. CDMA does not require

\(^1\) personal communication system
frequency or time-division for multiple access; thus, it improves the capacity of the communication system.

1.3 Problem definition
Communication systems in general are characterized either by the capacity or power. CDMA is a capacity limited system; because capacity is limited by the interference that is mainly related to the orthogonality of the CDMA codes. Increasing the system capacity for a fixed set of codes, reduces the orthogonality of these codes and thus reduces the system performance.

1.4 Project Objectives
This project is aimed to:
- Analyze CDMA system as a multiple access technique and its correlation reception.
- Simulate the links structure of the CDMA.
- Discuss the performance of the reception in accordance to the simulation results.
- Find the acceptable limit of number of users that keeps the bit error rate as small as possible to make the original signal retrievable nearly error free.

1.5 Methodology
The methodology used in this project was first to study the CDMA systems, then follow up with both a conceptual and a detailed designs for the system and giving an insight analysis to the obtained results; this to make it possible to reach objectives of the project. The system was designed using MATLAB.

1.6 Thesis layout
The thesis is organized as follows

Chapter 2: gives the theoretical background of the project.

Chapter 3: describes the design and implementation of the project.

Chapter 4: shows the results obtained from the tests carried on MATLAB.

Chapter 5: goes through the conclusion and recommendations for future work.

Appendix A: will contain the whole M-file listing of the developed system.
Chapter 2

Theoretical Background

2.1 Code Division Multiple Access

CDMA protocols constitute a class of protocols in which multiple access capability is achieved by means of coding. In CDMA, each user is assigned a unique code sequence that is used to encode the user’s data. The receiver knowing the code sequence of the user decodes the received signal and recovers the original data as shown in Figure (2-1). Because the bandwidth of the code signal is much larger than the bandwidth of the information signal, the encoding process enlarges (spreads) the spectrum of the signal and is therefore also known as spread spectrum modulation. The resulting encoded signal is also called an SS signal, and CDMA protocols are often denoted as SS multiple access (SSMA) protocols. The available spectrum is divided into a number of channels, each with a much higher bandwidth than the TDMA systems. However, the same carrier can now be used in all cells.

![Figure 2-1: CDMA structure](image)

2.2 Spreading techniques:

There are three primarily different types of spreading techniques used in CDMA systems, direct sequence (DS), frequency hopping (FH), and time hopping (TH).
2.2.1 Direct Spreading

Each user in a DS-CDMA system uses a code to spread its information bit stream directly by multiplication or modulo-two addition operation. Since multiplication in the time domain corresponds to convolution in the frequency domain, a narrow band signal multiplied by a wide band signal ends up being wide band. One way of doing this is through the use of binary waveform as a spreading function, at a higher rate than the data signal. For one user:

![Diagram of Original and Spread Signals](image)

(a)

![Diagram of Signal Processing](image)

(b)
Figure 2-2: (DS) modulation (a) The message and the spreading signals in the frequency domain (b) Spreading done on the data signal \( x(t) \) by the spreading signal \( c(t) \) resulting in the message signal to be transmitted, \( m(t) \) (c) Waveforms.

The first two signals are multiplied together to give the third waveform. Bits of the spreading signal are called \textit{chips}. On the above figure, \( T_b \) represents the period of one data bit and \( T_c \) represents the period of one chip. The chip rate, \( 1/T_c \), is often used to characterize a spread spectrum transmission system.

The \textit{Processing Gain} or sometimes called the \textit{Spreading Factor} is defined as the ratio of the information bit duration over the chip duration:

\[
PG = SF = \frac{T_b}{T_c} \quad (2-1)
\]

Hence, it represents the number of chips contained in one data bit. Higher Processing Gain (PG) means more spreading. High PG also means that more codes can be allocated on the same frequency channel (more on that later).

Since the direct sequence allows multiple users to share the radio interface, the received waveform becomes the sum of \( k \) user signals and noise:

\[
r(t) = \sum_{n=1}^{k} c_n(t)x_n(t) + n(t) \quad (2-2)
\]

Where:

\( r(\ t) \) : the received signal.

\( n(\ t) \) : the noise signal.
The receiver retrieves the message signal by despreading the received signal. It does that by synchronizing its correlator to a specific spreading sequence, \( c(t) \) that is unique to the user and different from those of other users. As a result, the other user’s signals appear noise-like.

### 2.2.2 Frequency and Time Hoping

FH-CDMA uses a multi-tone oscillator to generate multiple discrete carrier frequency and each user in the system will be assigned a particular hopping pattern among those carrier frequencies. Each pattern has a specific sequence which must be orthogonal to other sequences.

The third type or the TH-CDMA is much less used in communication systems due to its implementation difficulty and hardware cost associated with the transmitter which must have an extremely high switching speed.

Finally it should be mentioned that there are also different types of hybrid CDMA schemes, which can be formed by combination of DS, FH, and TH, together with MC\(^1\) and MT\(^2\) techniques as shown in figure (2-3).

---

\(^1\) Multi Carrier

\(^2\) Multi Tone
2.3 CDMA Codes

Codes used in CDMA systems play an essential role in the system architecture because their characteristics will govern the performance and limit the performance of these systems. Although there are different ways to characterize the CDMA codes, the auto-correlation and cross-correlation functions are used; because they are more effective and intuitive than others.

The cross-correlation function defined as:

$$R_{xy}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t)y(t + \tau) \, dt$$  \hspace{1cm} (2-3)

Similarly, the autocorrelation for a sequence of M discrete values is written as:

$$R_{xx}(\tau) = \frac{\sum_{M} R_{x}(t)R_{x}(t+\tau)}{M}$$  \hspace{1cm} (2-4)
2.3.1 Pseudo Noise (PN) Sequences

Pseudorandom or pseudo Noise (PN) sequences are used in data scrambling as well as for spread-spectrum modulation. Data scrambling is achieved by changing the data sequence "randomly" or in a noise-like fashion before transmission. At the receiver, the scrambled sequence is "changed back" to the original data sequence. The two concepts of randomness and changing back are the key ideas involved in understanding the CDMA system.

The most important method of generating such binary sequences is by means of a linear feedback shift register (LFSR). For an LFSR sequence generator with n stages, the output sequence will always be periodic, because, whatever the initial conditions of the shift register, after a finite number of clock pulses, the initial conditions must eventually be reproduced. Because the maximum number of different combinations of n binary digits is $2^n$, the period cannot exceed $2^n$. It must be noticed that the all-zero condition, if reached, the register will remain in the same state forever, it cannot appear in the shift register if the initial condition (initial loading or state) is not all zeros. Therefore, the maximum number of possible states is $2^n - 1$.

A shift register output sequence with the period $2^n - 1$ is called a "maximal length sequence" or "m-sequence" for short. M-sequences are also referred to as "pseudorandom sequences" or PN sequences. When the PN sequences are clocked at very high rates and modulated (multiplied) with data sequences in a communications system, such as the IS-95 system, the resulting system is called a spread spectrum system.

An example PN sequence generation with $n = 5$ (5-stage) is given in Figure 2-4 for the case of an initial state (or loading sequence) of 1 0 0 0 0. One period of the sequence $S$ generated by the LFSR is

![PN generator using 5 stages FSR with period of 31 bit.](image)

PN Properties have many properties:

- Unpredictability
- Randomness
• Uniform distribution.
• Independence
• Balance property:
  In a complete period P = \(2^n - 1\) of a PN sequence, the number of 1s differs from the number of 0s by at most 1. This property is observed in the example sequence, as there are (16) 1s and (15) 0s.
• The run property:
  There are \((2^n - 1 + 1)/2 = 2^n - 1\) runs of consecutive
  1s or 0s, and half of the runs are of length 1, \(1/2^2\) of the runs are of length 2, \(1/2^3\) of the runs are of length 3, etc. There is one run (of zeros) is of length \(n - 1\), and 1 run (of 1s) is of length \(n\). Total number of runs in the above example is 16.
• Correlation property
  If a complete sequence is compared bit-by-bit with any shift of the sequence, the number of agreements minus the number of disagreements is always -1; that is, there is one more disagreement position than the number of agreement positions.

2.3.2 Gold Sequences
These are constructed by EXOR-ing two \(m\)-sequences of the same length with each other. Thus, for a Gold sequence of length \(m = 2^k - 1\), one uses two LFSR, each of length \(2^k - 1\).

2.3.3 Hadamard (Walsh) Codes
Walsh codes are commonly used orthogonal codes. They are based on the rows of a square (\(n\) by \(n\)) matrix known as the Hadamard matrix. In this matrix, the first row consists of all 0s, while the remaining rows contain equal occurrences of 0s and 1s. Furthermore, each code differs from every other code in \(n/2\) places.
Starting at \(H_1 = [0]\), the Hadamard matrix is formed by

\[
H_{2^n} = \begin{bmatrix} H_n & H_n \\ H_n & H_n \end{bmatrix}
\]

\[
H_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}
\]

\[
H_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}
\]

The Walsh codes are given by the rows. Usually map the binary data to polar form so we can use real numbers arithmetic when computing the correlations. So 0's are mapped to 1's and 1's are mapped to -1. All the Walsh codes are orthogonal.
\[ W_0 = 1\quad 1\quad 1\quad 1 \]
\[ W_3 = 1\quad -1\quad -1\quad 1 \]

2.3.4 Kasami Codes
Kasami sequences are binary sequences of length \(2^N\) where \(N\) is an even integer. Kasami sequences have good cross-correlation values approaching the Welch lower bound.

2.4 Interference in CDMA
There are two major sources of interference in any CDMA system; one is multiple access interference (MAI) and the other is multipath interference (MI).

2.4.1 MAI
MAI is caused by the un-matched synchronization of CCF (cross-correlation function) of all CDMA codes in the system. However due to multipath propagation, the MAI will consist of two parts, one the CCFs between the code of and all other unwanted active codes as well as their multipath returns, and the other part being the out-of-phase ACFs (auto-correlation function) of the code of interest at the receiver due to the fact that the receiver will receive several replicas of the code with different delays. Clearly the MAI changes accordingly to the number of users in the system and the performance of the spreading codes used.

In order to overcome the MAI problem, multi user joint detection MUD technique is used. The basic idea was motivated by the fact that a single-user based receiver always treats other transmissions as unwanted interference that should be suppressed. On the other hand, MUD algorithm takes the correlation among the users into account in a positive manner.

2.4.2 Multipath Interference
The multipath effect can be expressed or illustrated in terms of both time and frequency domain. In time domain, if the inter-path delay\(^\text{3}\) is smaller than one chip width a correlator at the reception or even a Rake will not be able to distinguish between multipath returns. Here there will be no great threat unless there is a large number of a multipath returns and that will cause ISI. On the other hand, if the inter-path delay is larger than the chip width, all multipath returns will be considered and can be handled by a RAKE receiver. In frequency domain, the channel can be modeled by a delayed tap-filter with the coefficient on each tap represents the path gain of one

\(^{3}\) Time between two consecutive paths
multipath return and a delay element to represent the inter path delay. And so, the transfer function of the impulse response of the channel can be obtained.

![Two path channel model](image_url)

**Figure 2-5:** (a) two path channel model  
(b) delayed tap-line filter

### 2.4.2.1 Small scale fading

The fading phenomena occur when the received signal is made up of a group of reflections from objects. The different reflected signal paths arrive at slightly different times, with different amplitudes, and with different phases. Small scale fading has three important effects which are:

- Rapid changes in signal strength over a small travel distance or time interval.
- Random frequency modulation due to varying Doppler shifts on different multipath signals.
- Time dispersion (echoes) caused by multipath propagation delays

![Amplitude vs Distance](image_url)

**Figure 2-6:** for illustration, as the mobile travels it will experience fades once every half wave length.

The time it takes a mobile user to travel from one fade to the next fade
\[ \Delta t = \frac{\lambda/2}{v} \]  

\( v \): Wave velocity

There are factors, other than multi path returns, that influence fading such as the speed of the mobile, the speed of the surrounding objects, and the transmission bandwidth of the signal. For the first and the second factors, the relative motion between the receiver and the base station results in random frequency modulation due to the different Doppler shift on each of the multipath components. This Doppler shift will be positive or negative depending on the movement direction of the mobile receiver towards or away from the base station. The signal power in the direct path decreases relatively slowly as the receiver moves away from the transmitter. However, as a receiver moves away, obstacles that partially block the signal path (such as trees and building) cause occasional drops in received power. This decrease in power occurs over many wavelengths of the carrier and is fading and can be either slow or fast depending on the Doppler spread. For the last factor, the bandwidth of the channel can be quantified by the coherence bandwidth\(^4\) which is related to the multi path structure of the channel. Depending on the bandwidth of the signal compared to the coherence bandwidth, there will be flat of frequency selective fading. Figure (2-7)

---

Small Scale Fading

- Flat Fading  
  (based on multipath time delay spread)
- Fast Fading  
  (based on Doppler spread)
- Frequency Selective Fading  
  (based on multipath time delay spread)
- Slow Fading  
  (based on Doppler spread)

Figure 2-7: types of small scale fading

---

\(^4\) coherence bandwidth is a measure of the maximum frequency difference for which signals are still strongly correlated in amplitude
It should be noted that the nature of the transmission mode in the uplink and the downlink can further complicate their impact to the performance of a CDMA system.

2.4.2.2 RAKE Receiver against MI

RAKE receiver architecture allows an optimal combining of energy received over paths with different. It avoids wave cancellation (fades) if delayed paths arrive with phase differences and appropriately weighs signals coming in with different signal-to-noise ratios.

The rake receiver consists of multiple correlators, in which the received signal is multiplied by time-shifted versions of a locally generated code sequence. The intention is to separate signals such that each finger only sees signals coming in over a single (resolvable) path. The spreading code is chosen to have a very small autocorrelation value for any nonzero time offset.

The rake receiver is designed to optimally detect a DS-CDMA signal transmitted over a dispersive multipath channel. It is an extension of the concept of the matched filter.

![RAKE Receiver Diagram]

Figure 2-8: Rake receiver

2.5 Interim Standard 95 (IS-95)\(^6\)

It is a 2G Mobile Telecommunications Standard that uses CDMA to send voice, data and signaling data (such as a dialed telephone number) between mobile telephones and cell sites. The

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\(^5\) The brand name for IS-95 is CDMA One

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link between the mobile station (MS) transmitter and base station (BS) receiver is called the uplink or the reverse link, while the downlink or the forward link is defined as the link between the base station transmitter and the mobile station receiver.

The IS-95 CDMA system is unique in that its forward and reverse links have different link structures. Also the user data rate (but not the channel chip rate) changes in real time according to the voice activity.

The base station (BS) transmits radio signals to the mobile station (MS) in the forward link, or downlink. And the link between the MS to the BS is called the reverse link, or the uplink.

The forward link consists of four types of logical channels: pilot, sync, paging, and traffic channels. There is one pilot channel, one sync channel, up to seven paging channels, and several traffic channels. Each of these forward-link channels is first spread orthogonally by its Walsh function, and then it is spread by a Quadrature pair of short PN sequences. All channels are added together to form the composite SS signal to be transmitted on the forward link.

The reverse link consists of two types of logical channels: access and traffic channels. Each of these reverse-link channels is spread orthogonally by a unique long PN sequence; hence, each channel is identified using the distinct long PN code. The reason that a pilot channel is not used on the reverse link is that it is impractical for each mobile to broadcast its own pilot sequence.
2.5.1 Forward Link

The IS-95 CDMA system uses a 64 by 64 Hadamard matrix to generate 64 Walsh functions that are orthogonal to each other, and each of the logic channels on the forward link is identified by its assigned Walsh function.

2.5.1.1 The forward channels

2.5.1.1.1 The Pilot channel

This channel is continuously transmitted by each CDMA carrier and it is used by the MS to identify the BS, also it is used to assess the suitability of the cell for handoff and to give coherence demodulation for other transmitted signals in the same carrier.

In this channel the bit stream is all zeroes (using WALSH code zero), and these zeroes are XORed with the short in phase pseudo-random noise and the Quadrature pseudo-random noise.
[PNI,PNQ], in other words we can say that the pilot channel sends the PNI,PNQ codes only. The resulted is then modulated using QPSK modulation scheme.

![QPSK Modulation](image)

Figure 2-10: (a) illustration of QPSK modulation. (b) for illustration of PN offset associated with each BS

2.5.1.1.2 The synchronization channel

Another channel is a continuously transmitted synchronization channel (Walsh code 32) that is used to convey system information to all users in the cell. This information includes the pilot PN offset of the cell, the system time, and the content of the long code generator (used for data scrambling).
2.5.1.1.3 The paging channels
The paging channels (Walsh codes 1 up to 7) perform a number of functions in addition to carrying paging messages between the network and a MS. It conveys general system information like handover threshold, access information, and a list of surrounding cells and channel assignment messages.

2.5.1.1.4 The traffic channels
The traffic channels are used to carry out users data and 

They are assigned the remaining Walsh codes (8 up to 31 and from 33 up to 63). Signaling messages are also sent over the traffic channel.

2.5.1.2 Convolution encoder
Convolution encoding is used to encode data prior to transmission over a channel. The received data is decoded by the classic Viterbi decoder. In a basic convolution encoder, 2 or 3 bits (depending on the encoder output rate) are transmitted over the channel for every input bit. The basic architecture of the encoder is shown below. The incoming data is brought into the constraint register a bit at a time and the output bits are generated by modulo-2 addition of the required bits from the constraint register. The bits to be XORed are selected by the convolution codes.

2.5.1.3 Block Interleaver
The interleaving process scatters the bit order of each frame so that if a segment of data is lost during fading, its bits are dispersed throughout the reorganized frame. After repetition, symbols are sent in blocks to the interleaving array.

2.5.1.4 Long PN Sequence
The encoded and interleaved paging channel symbols are scrambled with a 42-stage long-code PN sequence running at 1.2288 Mcps\(^6\) that is decimated to a 19.2-kbps\(^7\) rate by sampling every 64th PN code chip. The long PN code is generated by a 42-stage shift Symbol repetition with the following characteristic polynomial with a period of \(2^{42} - 1\)

\[
PN(X) = X^{12} + X^{35} + X^{33} + X^{13} + X^{27} + X^{26} + X^{25} + X^{22} + X^{21} + X^{19} + X^{18} + X^{17} + X^{16} + X^{10} + X^{7} + X^{6} + X^{5} + X^{3} + X^{2} + X^{1} + 1
\]
Each PN chip is generated by the modulo-2 product of 42 bit mask and 42 bit state vector of the sequence generator. Two types of masks are used, a public mask for the MS’s electronic serial number (ESN) to initiate the call, and a private mask for the MS identification number (MIN) to proceed with the call once authentication is performed.

2.5.1.5 Data Scrambler
This step is performed after the block Interleaver. The high rate PN sequence is first decimated so that the symbol rate of the decimator is the same as the data rate. A modulo-2 addition is then performed between the data and the decimated PN code.

2.5.1.6 Base Band Filtering
Another way to increase capacity in a communication system is to limit the transmit energy outside the channel bandwidth. The base station transmitter includes a bandwidth-shaping filter for that purpose.

_Pulse shaping_ is used to shape the baseband digital pulses in the I and Q output channels and is determined by a FIR filter that is designed to control the spectrum of the radiated power for minimal adjacent-frequency interference.

2.5.2 The IS-95 Uplink
The IS-95 reverse link channel structure consists of two types of channels: access and traffic channels. To reduce interference and save mobile power, a pilot channel is not transmitted on the reverse link. A mobile transmits on either an access or a traffic channel but never both at the same time. Thus, as far as the mobile is concerned, the reverse link "channel" is an operating mode.

Unlike the forward link, it is nearly impossible to establish truly orthogonal traffic channels on the reverse link. That is because the mobile radios are located randomly in the cell area, at different distances to the base station, and with different propagation delays. As such, synchronization breaks down and spreading codes become less effective. Mobile radios are further constrained by portable operation and other consumer form-factor requirements. Consequently, the reverse-link modulator is comparatively simple, and the performance burden of the reverse link is shouldered by the base station.

Because of the non-coherent nature of the reverse link, Walsh functions are not used for channelization. Instead, long PN sequences are used to distinguish the users from one another.
The access channel is used by the mobile to communicate with the base station when the mobile doesn’t have a traffic channel assigned. The mobile uses this channel to make call originations and respond to pages and orders.

![Diagram](image)

**Figure 2-11: uplink traffic channel**

### 2.5.2.1 Convolution encoder and symbol repetition

The encoder used in the reverse link has a rate of 1/3 and a constraint length 9. The three vector generators $G_0$, $G_1$, and $G_2$ are 557, 663, and 771 respectively all in octal.

The coded bits are then repeated if needed as mentioned in the downlink.

The symbols are then block interleaved.

### 2.5.2.2 Orthogonal modulation

Walsh modulation is a 64-ary modulation method that translates 6 bit symbols to one of 64 modulation states. Each modulation state is a 64-bit entry from the 64-by-64 Hadamard matrix used by the forward-link modulator. The difference is that here the Hadamard matrix is used to define the distinct points (or modulation states) of the constellation and is not used for spreading or multiple access.

The selection is performed by computing the index $i$ according to the rule

$$i = C_0 + 2C_1 + 4C_2 + 8C_3 + 16C_4 + 32C_5$$
where \( i \) is the row of the 64 x 64 Hadamard matrix, and the \( \{ C_j \} \) are encoded binary (0, 1) symbols. The symbol rate is therefore increased by 64/6.

The orthogonally modulated data is fed into the data burst randomizer. The function of the data burst randomizer is to take advantage of the voice activity factor on the reverse link by generating a masking pattern that randomly masks the redundant data generated by the code repetition process.

### 2.5.2.3 Direct Sequence Spreading

The reverse traffic channel is spread by the long PN sequence which operate at a higher rate than the orthogonally modulated data.

### 2.5.2.4 Quadrature Modulation

The data is further scrambled in the \( I \) and the \( Q \) paths by the short PN sequences (also running at 1.2288 Mcps) defined in the IS-95 standard. Because the reverse link uses OQPSK modulation, the data in the \( Q \) path is delayed by one-half a PN chip. The primary purpose of this chip delay is to make sure that the QPSK signal envelope will not collapse to zero. This property is important because the power amplifier of the mobile is typically small and limited in performance. If we can ensure that the signal envelope never reaches zero and always stays above a certain level, then the amplifier would only have to remain linear over a smaller dynamic range.

The rest of the modulation and filtering operations are the same as in the downlink.

### 2.6 Power Control

It is very important to force each user to provide the same power level at the base station regardless of his/her position with in the cell. This is important in order to combat the near far\(^8\) problem which arises because of received power imbalance. The receiver includes an automatic gain control (AGC) loop to track the received power level, which varies because of large-scale path loss and small-scale fading. To compensate for those effects, CDMA 1S95 employs two power control methods.

The open-loop method uses the power level at the mobile radio receiver to estimate the forward-link path loss. It then specifies the transmit power of the mobile radio. Adding a feedback signal completes the AGC loop and improves the accuracy of the open-loop method. Since both signal and interference are continually varying, power control updates are sent by the BS every 1.25ms. These control commands (feedback) are sent in the forward control sub channel to each subscriber.

---

\(^8\)The near far problem arises when the unwanted data of a near user overcomes a wanted data of a far user
instructing the MS to increase or decrease its transmitted power in 1dBsteps depending on the control signal.

2.7 Handoff

2.7.1 The Soft Handoff

As the mobile moves from its current cell (source cell) to the next cell (target cell), a traffic channel connection is simultaneously maintained with both cells. On the forward link (see Figure 4.16(a)), the mobile uses the rake receiver to combine the two signals to yield a composite signal of better quality. On the reverse link, the mobile’s transmit signal is received by both base stations. The two cells demodulate the signal separately and send the demodulated frames back to the mobile switching center (MSC). The MSC contains a selector that selects the best frame out of the two that are sent back.

2.7.2 The Softer Handoff.

Occurs when the mobile transits between two different sectors of the same cell. On the forward link, the mobile performs the same kind of combining process as that of soft handoff. On the reverse link, the signals are demodulated and combined inside the cell, and only one frame is sent back to the MSC.

2.7.3 The Hard Handoff

The CDMA system uses two types of hard handoffs. CDMA-to-CDMA handoff occurs when the mobile is transitioning between two CDMA carriers. Sometimes called D-to-D handoff.

On the other hand, CDMA-to-analog handoff occurs when a CDMA call is handed down to an analog network. This can occur when the mobile is traveling into an area where there is analog service but no CDMA service. CDMA-to-analog handoff is sometimes called D-to-A handoff.
Chapter 4

Results and Comments

These results were taken for 100000 bit.

4.1 The effect of AWGN on the QPSK

Figure (4-1): The effect of the SNR on the constellation plot for one user in the system for one frame of data (Program 6.7). Constellation for (a) Perfect SNR (no AWGN) (b) SNR=5dB (c) SNR=0dB (d)SNR= -5dB.
Figure (4-2): The effect of the number of users on the constellation plot for the received user’s data in the system for one frame of data for fixed SNR=5 (a) 5 users (b) 10 user (c) 15 user (d) 20 user.
4.2 BER vs. Total Number of Users in the system for different values of SNR:

- SNR = -5 dB

Table 4-1:

<table>
<thead>
<tr>
<th>No. of users in the system</th>
<th>BER1 synchronous</th>
<th>BER2 asynchronous</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.0020</td>
</tr>
<tr>
<td>7</td>
<td>0.0060</td>
<td>0.0090</td>
</tr>
<tr>
<td>10</td>
<td>0.0010</td>
<td>0.0080</td>
</tr>
<tr>
<td>13</td>
<td>0.0190</td>
<td>0.0190</td>
</tr>
<tr>
<td>16</td>
<td>0.2070</td>
<td>0.2090</td>
</tr>
<tr>
<td>19</td>
<td>0.3020</td>
<td>0.3140</td>
</tr>
<tr>
<td>22</td>
<td>0.3130</td>
<td>0.3520</td>
</tr>
<tr>
<td>25</td>
<td>0.3580</td>
<td>0.3560</td>
</tr>
<tr>
<td>28</td>
<td>0.3630</td>
<td>0.3650</td>
</tr>
<tr>
<td>31</td>
<td>0.3800</td>
<td>0.3940</td>
</tr>
<tr>
<td>34</td>
<td>0.4920</td>
<td>0.4920</td>
</tr>
</tbody>
</table>

(a) ![Graph](image1.png)
(b) ![Graph](image2.png)

Table (4-1): describes the variations in values of the BER due to different number of users with synchronous and asynchronous spreading codes for SNR of -5dB.

Figure (4-3): (a) synchronized code (b) not synchronized code; the bit error rate was plotted in a logarithmic scale. (Program6.9)
SNR 5dB

Table 4-2:

<table>
<thead>
<tr>
<th>No. of users in the system</th>
<th>BER1</th>
<th>BER2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>0.1000</td>
<td>0.1130</td>
</tr>
<tr>
<td>19</td>
<td>0.1380</td>
<td>0.1430</td>
</tr>
<tr>
<td>22</td>
<td>0.1750</td>
<td>0.2035</td>
</tr>
<tr>
<td>25</td>
<td>0.2410</td>
<td>0.2460</td>
</tr>
<tr>
<td>28</td>
<td>0.2560</td>
<td>0.2730</td>
</tr>
<tr>
<td>31</td>
<td>0.3400</td>
<td>0.3600</td>
</tr>
<tr>
<td>34</td>
<td>0.4300</td>
<td>0.4800</td>
</tr>
</tbody>
</table>

Table (4-2): describes the variations in values of the BER due to different number of users with synchronous and asynchronous spreading codes for SNR of 5dB.

Figure (4-4): (a) synchronized code (b) not synchronized code. The bit error rate was plotted in a logarithmic scale. (Program6.9)
Table 4-3:

<table>
<thead>
<tr>
<th>No. of users in the system</th>
<th>BER1</th>
<th>BER2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>0.0580</td>
<td>0.0730</td>
</tr>
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<td>19</td>
<td>0.0790</td>
<td>0.0840</td>
</tr>
<tr>
<td>22</td>
<td>0.1620</td>
<td>0.1700</td>
</tr>
<tr>
<td>25</td>
<td>0.2020</td>
<td>0.2330</td>
</tr>
<tr>
<td>28</td>
<td>0.2520</td>
<td>0.2340</td>
</tr>
<tr>
<td>31</td>
<td>0.2710</td>
<td>0.2800</td>
</tr>
<tr>
<td>34</td>
<td>0.3200</td>
<td>0.3980</td>
</tr>
</tbody>
</table>

Table (4-3): describes the variations in values of the BER due to different number of users with synchronous and asynchronous spreading codes for SNR of 10dB.

Figure (4-5): (a) synchronized code (b) not synchronized code. The bit error rate was plotted in a logarithmic scale. (Program6.9)
4.3 Comments and discussion

In Figure (4-1) the results described the performance of the system when there was one user and for different values of SNR. It was found that for one user the BER is zero until the SNR =-5dB where we have a negligible error.

Figure (4-2) described the effect of the number of users on the constellation plot for the received user’s data in the system for one frame of data and for fixed SNR=5. From the plots it is clear that the error is also negligible.

In order for us to determine the performance of the CDMA system under the influence of multiple access interference (MAI), the following results were obtained for different signal to noise ratios (SNR), and for each result the performance was measured under synchronous and asynchronous condition between the received data and the orthogonal codes used for despreading (Walsh codes). The bit error rate was plotted in a logarithmic scale. (Program6.9)

Firstly and beginning with SNR of -5 figure (4-3) and table (4-2), if the acceptable value of BER ≤ .25 then the last BER with an acceptable value was 0.207 for synchronous spreading codes and 0.209 for asynchronous spreading codes while the number of users was 16 users.

From figure (4-4) and table (4-2) SNR =5 the acceptable number of users is 25 user.

From figure (4-5) and table (4-2) SNR =10 the acceptable number of users is 28 user.

It is clear that number of acceptable users increases with the increase of SNR which is affected by the AWGN of the communication channel.

As was seen the BER has a zero value at small values of number of users and this is due to the small number of bits that was set as an input to the system (100000 bit), the required number of bits that is enough to make the BER occur at the small number of users must be in millions and this requires a high computational power which was not available.

Also it clear that the BER for the asynchronous spreading codes is greater than the BER for the synchronous codes and this is due to the reduced orthogonality in the former case.
Chapter 5

Conclusion and Future Work recommendations

5.1 Conclusion

By the end of the project a CDMA system was successfully implemented and fairly satisfying results were obtained.

The problem of the capacity of CDMA systems of CDMA systems was analysed and the maximum number of users that can access the system within an acceptable BER was determined for different SNRs and it was noticed that as SNR increases the BER decreases.

5.2 Future work

After the implementation of the project there are many notifications that must be mentioned for the further development that may be done in the future:

✓ The system was implemented using the Walsh codes for spreading; further development should consider the rest of CDMA codes.

✓ The simulation was performed for the forward link (traffic channels), other channels of the forward link and reverse link could be developed in the future.

✓ Limitations of the communication channel were designed to be AWGN only; neglecting the effects of other factors like the multi-path fading. Future designs will have to consider this type of interference in order to enhance the design reliability.

✓ This design included one base station transmitting for many mobile stations (one cell), future designs may consider more than one cell to get more practical and realistic results.
Future designs are to consider power control algorithms application, opening the door for the application of handoff algorithms.

Number of bits accessed by the system was limited to 100Kb due to the lack of computational power, which led to some impractical results as having a zero bit error rate in a system consisting of many users.
Appendix 1

%% Program 6.1

% mseq.m

% The generation function of M-sequence

% An example

% stg=3

% taps=[1,3]

% indata=[1,1,1]

% n=2

function [mout]=mseq(stg,taps,indata,n)

%******************************************************************************************************

% stg : Number of stages

% taps : Position of register feedback

% indata : Initial data

% n : Number of out sequence(it can be omitted)

% mout : Output M sequence

%******************************************************************************************************

if nargin<4

n=1;

end

mout=zeros(n,2^stg-1);

fpos=zeros(stg,1);

fpos(taps)=1;

for i=1:2^stg-1

mout(1,i)=indata(stg);  \%storage of the output data

num=mod(indata*fpos,2);  \%calculation of feedback data

indata(2:stg)=indata(1:stg-1);\%shift the register once

indata(1)=num;  \%place the output bit as the first
\%bit of the initial data

end

if n>1

for i=2:n

mout(:,i)=mshift(mout(:,i-1),1);\% output shifted sequences

end

end
Program 6.2

mshift.m

%Shifts the contents of a sequence

function [seq] = mshift(indata, shift)

%indata : The input sequence
%shift : The amount of shift to the right
%seq : The shifted sequence

for i=1:length(indata)
    j = mod((i+shift), (length(indata)+1))+floor((i+shift)/(length(indata)+1));
    seq(j) = indata(i);
end
end
function [out, phases] = qpskmod(dataI, dataQ)

%input  : The input inphase component of the data.
%dataQ  : The input quadrature component of the data.
%out    : The output qpsk modulated data.
%phases : Has the following output form for example if the phase is 3pi/4
%the output is 2.
%output Phase
%1 Pi/4
%2 3pi/4
%3 -pi/4
%4 -3pi/4

nsp = length(dataQ);

Isymbols = 1-2*dataI;    % Change the type to bi-polar
Qsymbols = 1-2*dataQ;  %Change the type to bi-polar

% The modulation procedure is made by checking the I and Q data bits and
% linking each possibility with a phase

for i=1:nsp

    if Isymbols(i)==1 & Qsymbols(i)==1

        ph(i)=pi/4;
        phases(i) = 1;
    elseif Isymbols(i)==-1 & Qsymbols(i)==1

        ph(i)=3*pi/4;
        phases(i) = 2;
    elseif Isymbols(i)==1 & Qsymbols(i)==-1

        ph(i)=-pi/4;
        phases(i) = 3;
    elseif Isymbols(i)==-1 & Qsymbols(i)==-1

        ph(i)=-3*pi/4;
        phases(i) = 4;

    end

end

ph=cos(ph)+j*sin(ph);

out=ph;
Program 6.4

% qpskdemod.m

% function [DATAI1,DATAQ1] = qpskdemod(qpdata)

%******************************************************************************

% qpdata : The input data to the function.
% DATAI1 : The inphase component of the data.
% DATAQ1 : The quadrature component of the data.
%******************************************************************************

r = real(qpdata);
i = imag(qpdata);
nsp = length(qpdata);

% This function perform the demodulation process
% by checking the quadrant of each complex point

for ii = 1:nsp
    if r(ii) >= 0 & i(ii) >= 0
        Isymbols2(ii) = 1; Qsymbols2(ii) = 1;
    end
end
if r(ii)<=0 & i(ii)>=0
    Isymbols2(ii)=-1 ; Qsymbols2(ii)=1;
end

if r(ii)>=0 & i(ii)<=0
    Isymbols2(ii)=1 ; Qsymbols2(ii)=-1;
end

if r(ii)<=0 & i(ii)<=0
    Isymbols2(ii)=-1 ; Qsymbols2(ii)=-1;
end

end

DATAI1=-Isymbols2/2+.5; %change data to uni-polar form

DATAQ1=-Qsymbols2/2+.5; %change data to uni-polar form
%Program 6.5

%walsh.m

%

%The generation of a WALSH CODE

%The output is in bi-polar form

%

function wal_code=walsh(wal_id)

%%%%%%%%%%%%%%%%%%%%%%%%

%wal_id : The Walsh code index.

%wal_code : The Walsh code.

%%%%%%%%%%%%%%%%%%%%%%%%

H=hadamard(64); % The Hadamard matrix 64 by 64

for i= 1:64

wal_code(1,i)=H(wal_id+1,i); % Take the a row from the hadamard matrix

% as the walsh code

end

%The one is added because the walsh index starts with zero

End
clear all;
clc;

%Program 6.7
%One_user.m

%Plotting
%

for snr=-5:5:15

[data,a,Intr,phases]=users(1),%for one user

%data is the sum of the spreaded data for the users
%a is the first user's data before spreading
%Intr is the interleaving code used in the transmitter

%%%%%%%%%%%%%%%%%%%%%%%%%

% AWGN Channel

ch_data=awgn(data,snr);

%%%%%%%%%%%%%%%%%%%%%%%%%
W=walsh(1);

for xx=1:1000 %frames

frame(1:64,1:128)= ch_data(1:64,(xx-1)*128+1:(xx-1)*128+128);

for i=1:128

f=xcorr(W.frame(:,i));%correlation reception

sg(i)=sum(f(20:108));
end

sp=length(sg);

% The constellation plots

%******************************************************************************

if xx==1 %for the first frame

% the next instructions are to place each phase angle in a separate
% matrix(posphase)using phases before AWGN channel

count = 1 ;

for in=1:sp

if(phases(in) == 1)

posphase1(count) = sg(in) ;% if the angle is pi/4

count = count + 1 ;
end
end

count = 1;
for in=1:sp
    if(phases(in) == 2)
        posphase2(count) = sg(in); % if the angle is 3pi/4
    end
end

end

count = 1;
for in=1:sp
    if(phases(in) == 3)
        posphase3(count) = sg(in); % if the angle is -pi/4
    end
end

end

count = 1;
for in=1:sp
    if(phases(in) == 4)
        posphase4(count) = sg(in); % if the angle is -3pi/4
    end
end

end
mys = scatterplot(posphase1,1,0,’r’);
hold on;
scatterplot(posphase2,1,0,’b’,mys);
scatterplot(posphase3,1,0,’g’,mys);
scatterplot(posphase4,1,0,’m’,mys);
title(’Customized Constellation for QPSK’);
hold off;
end
%

Data_des=sg;
%

%Demodulation
%

[DATAI1,DATAQ1]=qpskdemod(Data_des);
c=1;
s=1;

for ii=1:2*length(DATAI1)
if mod(ii,2)==0
DATA(ii)=DATAI1(c);
end
Appendix 1

c=c+1;
else
DATA(ii)=DATAQ1(s);
s=s+1;
end
end

DATAw(1:255)=DATA(1:255); % remove the extra bit

%Descrambling

%Descrambling

PNr=mseq(8,[2 3 4 5 8],[1,0,0,0,0,0,0,0]); % the same generator used in the transmitting part
Data1=xor(DATAw,PNr);
ncr=200; % no. of bits after convolution encoding in the transmitter
Data11=Data1(1:ncr); % remove padding

%Deinterleaving

%Deinterleaving

for bb=1:ncr
if Data1(bb)<=0
Datak(bb)=0;
else
\textbf{Appendix 1}

Data(k) = 1; 
end 
end 

\texttt{Data\_l = deintvlv(Data,\text{Intr});}

\%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

\%Convolution Decoding

\%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

\texttt{\texttt{tr = POLY2TRELLIS(9, [753 561]);} \%the same polynomial used in the transmitting part}

\texttt{Data\_l = vitdec(Data\_l, tr, 2, 'trunc', 'hard');}

\%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

\texttt{Data((xx-1) * 100 + 1: (xx-1) * 100 + 100) = Data\_l(1:100); %place the frame in the correct place}

end 
end
clear all;
clc;

%Program 6.8
%fìxed_snr.m

%Plotting
%

for User=5:5:20

[data,a,Intr,phases]=users(User);

%data is the sum of the spreaded data for the users
%a is the first user's data before spreading
%Intr is the interleaving code used in the transmitter

%******************************************

% AWGN Channel

snr=5; %fixed

ch_data=awgn(data,snr);

%******************************************

%Despreading

1- 15
W=walsh(1);

for xx=1:10 %frames
frame(1:64,1:128)= ch_data(1:64,(xx-1)*128+1:(xx-1)*128+128);

for i=1:128
f=xcorr(W,frame(:,i));%correlation reception
sg(i)=sum(f(20:108));
end

sp=length(sg);

% The constellation plots

%***************************************************************************

if xx==1 %for the first frame
% the next instructions are to place each phase angle in a separate % matrix(posphase)using phases before AWGN channel
count = 1;
for in=1:sp
if(phases(in) == 1)
posphase1(count) = sg(in); % if the angle is pi/4
count = count + 1 ;
end
end
count = 1 ;
for in=1:sp
    if (phases(in) == 2)
        posphase2(count) = sg(in) ; % if the angle is 3pi/4
        count = count + 1 ;
    end
end
count = 1 ;
for in=1:sp
    if (phases(in) == 3)
        posphase3(count) = sg(in) ; % if the angle is -pi/4
        count = count + 1 ;
    end
end
count = 1 ;
for in=1:sp
    if (phases(in) == 4)
        posphase4(count) = sg(in) ; % if the angle is -3pi/4
        count = count + 1 ;
    end
end
mys = scatterplot(posphase1,1,0,'r.'); 
hold on; 
scatterplot(posphase2,1,0,'b.',mys); 
scatterplot(posphase3,1,0,'g.',mys); 
scatterplot(posphase4,1,0,'m.',mys); 
title('Customized Constellation for QPSK'); 
hold off; 
end

Data_des=sg;

%Demodulation

[DATAI1,DATAQ1]=qpskdemod(Data_des);
c=1;
s=1;

for ii=1:2*length(DATAI1)
    if mod(ii,2)==0

DATA(ii)=DATA11(c);
c=c+1;
else
DATA(ii)=DATAQ1(s);
s=s+1;
end
data
end

DATAw(1:255)=DATA(1:255),% remove the extra bit

%******************************************************************************

%Descrambling
%******************************************************************************

PNr=mseq(8,[2 3 4 5 8],[1,0,0,0,0,0,0,0]),%the same generator used in the transmitting part
Data1=xor(DATAw,PNr);
ncr=200;%no. of bits after convolution encodind in the transmitter
Data1=Data1(1:ncr),%remove padding

%******************************************************************************

%Deinterleaving
%******************************************************************************

for bb=1:ncr
if Data1(bb)<=0
Datak(bb)=0;
end
else
Data(k)=1;
end
end

Data1 = deintrlv(Data, Inr);

%*******************************************************************************

%Convolution Decoding

%*******************************************************************************

tr = POLY2TRELLIS(9,[753 561]); % the same polynomial used in the transmitting part
Data1 = vitdec(Data1, tr, 2, 'trunc', 'hard');

%*******************************************************************************

Data((xx-1)*100+1:(xx-1)*100+100)=Data1(1:100); % place the frame in the correct place
end
end

% Program 6.9
%
% BER_vs_no_of_users.m

clear all;
clc;

count=1;
for User=1:5:35

[data,a,Intr,phases]=users(User);

%data is the sum of the spreaded data for the users
%a is the first user's data before spreading
%Intr is the interleaving code used in the transmitter

% AWGN Channel
snr=0;
ch_data=awgn(data,snr),% in dB

%Despreading

for xx=1:1000 %simulation frames
frame(1:64,1:128)= ch_data(1:64,(xx-1)*128+1:(xx-1)*128+128),%take one frame

%Insert Synch. Problem
synch=0; % No problem 2 for problem
KK=walsh(1);
h=mshift(KK,synch);
for tt=1:255
if tt==1
    h(1:synch)=1;
else
    h(1:synch)=KK(65-synch:64);
end
W=h; % Output is the asynchronized code
end

for i=1:128
    f=xcorr(W,frame(:,i));
    sg(i)=sum(f(20:108));
end

Data_des=sg;

% Demodulation

% QPSK Demodulation

[DATA11,DATAQ1]=qpskdemod(Data_des);
c=1;
s=1;

for ii=1:2*length(DATA11)
    if mod(ii,2)==0
        DATA(ii)=DATA11(c);
        c=c+1;
    else
        DATA(ii)=DATAQ1(s);
        s=s+1;
    end
end

DATAw(1:255)=DATA(1:255);% remove the extra bit

%Descrambling

PNr=mseq(8,[2 3 4 5 8],[1,0,0,0,0,0,0,0]);%the same generator used in the transmitting part
Data1=xor(DATAw,PNr);
ncr=200;% no. of bits after convolution encodind in the transmitter
Data1=Data1(1:ncr);% remove padding

%Deinterleaving
for bb=1:ncr
  if Data1(bb)<=0
    Datak(bb)=0;
  else
    Datak(bb)=1;
  end
end
Data1=deintrlv(Datak,Intr);

%Convelution Decoding

tr=POLY2TRELLIS(9,[753 561]),%the same polynomial used in the transmiting part
Data1 = vitdec(Data1,tr,2,'trunc','hard');

Data((xx-1)*100+1:(xx-1)*100+100)=Data1(1:100),%place the frame in the correct placeend

end %for frames

%BER
% calculate BER
[bit,ber]=biterr(Data,a)

U(count)=User;%place number of users in a matrix
BER(count)=(ber);%place number of users in a matrix

count=count+1;

end %for users
semilogy(U,BER,'r-*')
xlabel('Eb/No')
ylabel('BER')
hold on