CD

Design and Performance Analysis of OFDM based CDMA System for Frequency-Selective Channels

Submitted by

Tahir Abbas Khan

(109-FET/MSEE/F07)

Supervised by

Dr. Aqdas Naveed Malik

Department of Electronic Engineering Faculty of Engineering and Technology International Islamic University, Islamabad.

1. Frequency bridges - electric engineering

2.

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

In the name of Allah (SWT) the most benificient and the most merciful.

Dedicated...

To a person who is
"The Rehmat" for all the Universe,
and
To Our Parents,
and
To whom we love and respect.

Design and Performance Analysis of OFDM based CDMA System for Frequency-Selective Channels

Dated:14-07-2011

This verified thesis is submitted by **Tahir Abbas Khan Reg. No. 109-FET/MSEE/F07**.This thesis is of adequate standard to warrant its acceptance by the International Islamic University, Islamabad for Masters Degree in Electronic Engineering (MSEE).

Committee

External Examiner
Dr. Abdul Jalil,
Associate Professor,
PIEAS. Nilore,
Islamabad.

Internal Examiner
Dr. Nouman Ahmed Khan
DEE, FET, IIUI.
Islamabad.

Supervisor
Dr. Aqdas Naveed
Associate Professor
Department of Electrical Engineering.
ISRA University, Islamabad.

Declaration

I hereby declare that my thesis, I have not copied this thesis through any other source. It is further declared that I have completed this thesis entirely on the basis of my personal effort made under the sincere guidance of my supervisor (Dr. Aqdas Naveed Malik). I am sure that no portion of the work presented in this thesis has been submitted in support of any kind of communication application, or any other degree or any other university or institute of learning.

Tahir Abbas Khan

109-FET/MSEE/F07

Acknowledgement

I am very great full to Almighty Allah, who gave me the knowledge, understanding, courage and patience to complete this valuable work.

I express my appreciation to my kind supervisor **Dr. Aqdas Naveed Malik,** who provided me a great opportunity to seek, learn and enhance my knowledge. As being my research supervisor, he helped a lot and guided me throughout the research.

In the last but not the least; I would like to accept the fabulous support of my all family members, friends and many other who are well wisher to me. All my achievements have come true by the loving parents, brothers, sisters and friends whose prayers are a source of determination for me.

Tahir Abbas Khan

109-FET/MSEE/F07

Abstract

Recent wireless communications require more efficient systems and higher bandwidth, OFDM based CDMA is recently developed technique for the efficient multicarrier transmission supporting multiple access communication. This technique is combination of two techniques; It is very famous because of its advantage in the frequency diversity and multipath fading resilience etc.

OFDM is scheme used to combat Inter Symbol Interference (ISI). Using OFDM, the frequency selective channel, i.e., the channel with ISI becomes the flat fading. CDMA is another scheme exploiting the orthogonal codes for channel equalization and to remove ISI. In this work we are considering a Multiple Input Multiple Output (MIMO) based OFDM system. That is the number of transmitter-Receiver pairs based on OFDM, are allowed to share the same bandwidth hence MIMO. Each user in a pair of transmitter-Receiver is allowed a unique code based on CDMA scheme. On receiver side the signal orthogonal OFDM is used for signal separation from different transmitter followed by CDMA which is used to extract the data on each carrier within a transmitter-receiver pair.

The results of this system clearly show the good Bit Error Rate (BER) performance in both the uplink and downlink channels with frequency selective Gaussian fading channel as well as Rayleigh fading channel.

Table of Contents

Table of figures

LIST OF ABBREVIATIONS

3G	Third Generation Mobile
4G	Fourth Generation Mobile
BER	Bit-error Rate
SER	Symbol Error Rate
BPSK	Binary Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
BS	Base Station
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
DSSS	Direct sequence Spread Spectrum
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
FH-SS	Frequency Hopping Spread Spectrum

GSM	Global System for Mobile Communication
ICI	Inter channel interference
IP	Internet Protocol
IS-95	Interim Standard Number 95
ISI	Inter symbol interference
ISM	Industrial, Scientific and Medical band
MAI	Multiple Access Interference
MS	Mobile Station
MUD	Multi-user detector
OFDM	Orthogonal Frequency Division Multiplexing
PN	Pseudo-noise
SNR	Signal-to-noise Ratio
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
TD-SCDMA	Time-division synchronous CDMAADMF
DS CDMA	Direct Sequence CDMA
DS SS	Direct Sequence Spread Spectrum
ICI	Inter Carrier Interference
IFFT	Inverse Fast Fourier Transform
FFT	Fast Fourier Transform
MC CDMA	Multi Carrier CDMA
MC DS CDMA	Multi Carrier Direct Sequence CDMA
RF	Radio Frequency
S/P	Serial to Parallel
P/S	Parallel to Serial
MSE	Mean Square Error
MMSE	Minimum Mean Square Error
AWGN	Additive White Gaussian Noise

1 Chapter Introduction

1.1 Introduction

To support the almost real-time high quality multimedia streaming for the future broadband high data rate transmission in the mobile communication is the requirement the systems are envisioned to offer throughput of up to 1.5 G bit/s with the system bandwidths of a hundreds of MHz's. In view of the fact that the channel path resolution is inversely proportional to the system bandwidth [1, 2], computational complexity of time domain-equalization needs to fight out the inter-symbol interference (ISI).ISI is the limiting factor in the broadband single-carrier as well as for the multicarrier communications. If we try to reduce the complexity at receiver level by frequency domain equalization or by an iterative time domain equalization, then the decoding can be applied to reduced the complexity which remains high at receiver terminal.

In multicarrier (MC) systems, it is given that perfect subcarrier synchronization is assured; ISI can be avoided competently by using appropriate length of CP (cyclic prefix) and a simple baseband signal. The grouping of orthogonal frequency division multiplexing [3–5] and a code-division multiple-access [6], well-known as MC-CDMA [7–10].It has gained a considerable attention as a powerful transmission technique to a downlink broadband wireless communications. But if we see to the conventional single-carrier direct-sequence (DS) CDMA [11] systems (DS-CDMA), the received signal's energy can be composed in frequency-domain in OFDM based CDMA systems with a very low complexity when the bandwidth of the signal is large [9, 10]. The main deficiency of a Multi-Carrier transmission is Multiple Access Interference (MAI) which occurs by sharing of same carrier/channel between multi-users concurrently. In this system, one bandwidth is shared by the multiple users concurrently and the separation of data is done by applying the separate user exacting codes. In MC-CDMA, a different modulation scheme is applied for decrease of symbol error rate. Its effect reduces Inter Symbol Interference (ISI') for each sub carrier. The major complicatedness is to reduce the MAI. There are many detectors which are helpful to minimize the MAI but MSE detector is a good one to decrease the MAI in my work.

1.2 Contributions

The goal of my work is to construct the OFDM based CDMA system with the help of two previous schemes: CDMA and OFDM. Using OFDM, the frequency selective channel, i.e. the channel with ISI becomes the flat fading. Hence the effect of OFDM is to provide an easily symbols recovery sent on different orthogonal carriers in parallel.

Similarly, CDMA is another scheme exploiting the orthogonal codes for channel equalization and to remove ISI. In this work we are considering a Multiple Input Multiple Output (MIMO) based OFDM system. That is the number of transmitter-Receiver pairs based on OFDM, are allowed to share the same bandwidth hence MIMO. Each pair of transmitter-Receiver is assigned a unique code based on CDMA scheme. On receiver side the orthogonal codes are used for signal separation from different transmits followed by OFDM which is used to extract the data on each carrier within a transmit - receive pair.

1.3 Thesis layout

The thesis is planned as follows. In Chapter 1, there is introduction, goal and the work is divided. In Chapter 2, there are basic concepts related to wireless communication ('literature review') such as CDMA. In chapter3, there is basic idea as well as the structure of OFDM ('literature review). In chapter4, there is basic idea of my proposed system "OFDM based CDMA" and then mathematical model of OFDM based CDMA system. In chapter 5, there is a design of OFDM based CDMA system. In chapter 6, this system will be revisited and there is a simulations and codes of my proposed system. In last Chapter, there is the conclusion of my work and little bit detail of my future work.

Chapter 2

Introductory Literature on CDMA

2 Chapter CDMA

2.1 Introduction

The **Code Division Multiple Access (CDMA)** is a channel access technique utilized by different radio communication technologies. The main idea of this system in telecommunication is, to permits simultaneous usage of indistinguishable bandwidth with multiple users, each user transmits the data with the help of unique user signature. These signatures are assigned to each user and each signature is orthogonal to extra user signature. This method is called **Multiplexing**.

2.2 Code Division Multiple Access System

In CDMA system, it uses spread-spectrum technique and a distinguished coding scheme to permit multiple users to be multiplexed over the same physical channel. A number of users are acceptable (DS-SSS) in CDMA system [8].A code sequence or self generated signature which are separate to each other and these sequences are multiply to each user. Here, each user modulates the data signal with these code sequences along with the allocated user. For user's modulated signal is separated from mixed users' data by taking the **Cross Correlation** with each user code sequences. The CDMA system is given below.

CDMA System:

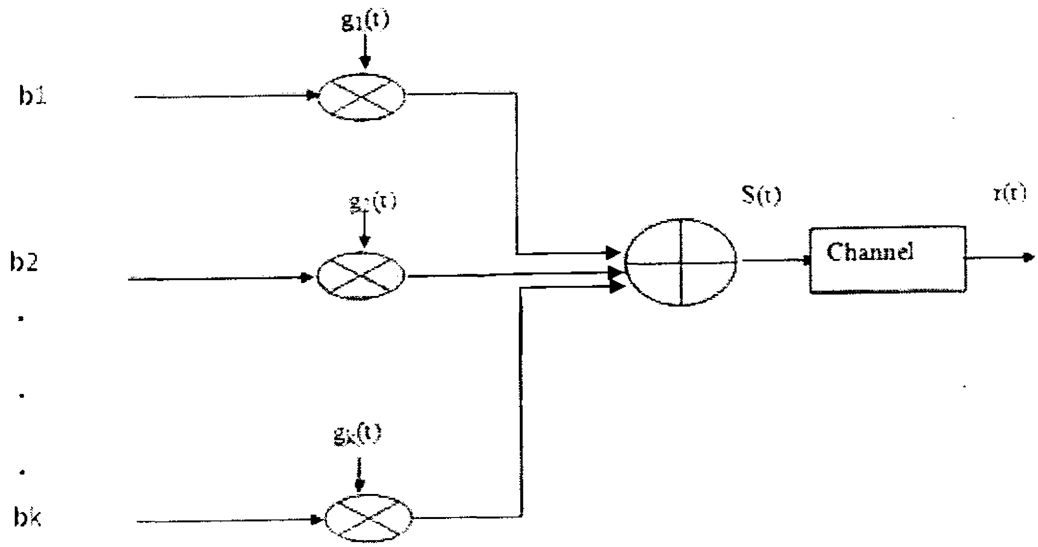


Figure 2. 1 **CDMA System**

And the receiver side is

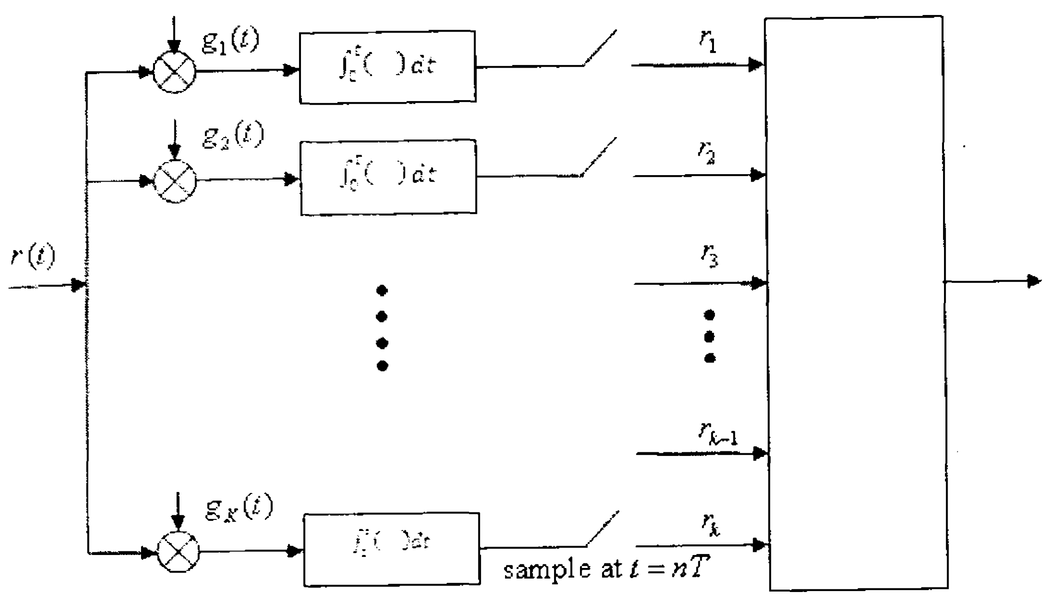


Figure 2. 2 **CDMA Receiver**

There is very minute cross correlation along with the above mention code sequences. The crosstalk arises at that point due to multiple users' signal that is mitigated.

In this system, the users use the channel randomly. These consequences more than one user in sum superimpose on signal broadcast of frequent users together in (TD) time domain as well as (FD) frequency domain. The demodulation of signals and separation at receiver end is done by code sequence /signature that used for each user signal modulation.

2.3 CDMA Signal Representation & Channel Model

Let suppose we have a K users parallel sharing CDMA system. Here each user has a unique spreading code waveform $g_k(t)$ of time period T and here T is the duration of symbol. Therefore the code waveform is

$$g_k(t) = \sum_{n=0}^{L-1} a_k(n)\, p(t - nT_c), 0 \le n \le L-1 \qquad (2.1)$$

And the code sequences $\{a_k(n), 0 \le n \le L-1\}$ consists of entirety L chips with significances ± 1. Pseudo Noise (PN), $p\ (t)$ is pulse and the pulse interval is T_c, and the interval of chip is T_c. It represents that each symbol has L chips and the T_c is the pulse interval, So the total time after spreading will be as

$$T = LTc$$

And with the assumption that K code waveforms have energy equivalent to unity, i.e.

$$\int_0^T g_k^2(t)\, dt = 1 \qquad (2.2)$$

The $\rho_{ij}(0)$ is the cross correlation, it is very important to satisfy for synchronous transmission which is represented as follow

$$\rho_{ij}(0) = \int_0^T g_i(t)\, g_j(t)dt \tag{2.3}$$

For acceptance, the source information is transmitted with the help of binary antipodal signal. The k[th] user information is presented as $\{b_k(m)\}$ and here each bit has values of +1 or -1.The information bits block is of total N duration. Therefore, the k[th] user data block is represented by

$$b_k = [b_k(1)\ldots\ldots\ldots\ldots b_k(N)]^t \tag{2.4}$$

The waveform of low pass correspondent presented by

$$s_k(t) = \sqrt{\varepsilon k} \sum_{i=1}^{N} b_k(i) g_k(t - iT - \tau k) \tag{2.5}$$

And the energy of signal bit is ε_k. The cumulative signal strength of K users are shown in mathematically as

$$s(t) = \sum_{k=1}^{K} \sqrt{\varepsilon_k} \sum_{i=1}^{N} b_k(i) g_k(t - iT - \tau_k) \tag{2.6}$$

Here, the transmission holdup is τ_k and the values of transmission will be in the range of $0 \le \tau_k < T$. For synchronous transmission $\tau_k = 0$ for $1 \le k \le K$.

The sending/transmitting signal is supposed to be physically abused by AWGN. After corrupting by AWGN channel, the received signal is represented as

$$r(t) = s(t) + n(t) \tag{2.7}$$

In above equation, $s(t)$ is the transmitting signal and $n(t)$ is the AWGN noise, its power spectral density $\frac{1}{2}N_0$.

2.4 CDMA Receiver with Synchronous transmitting

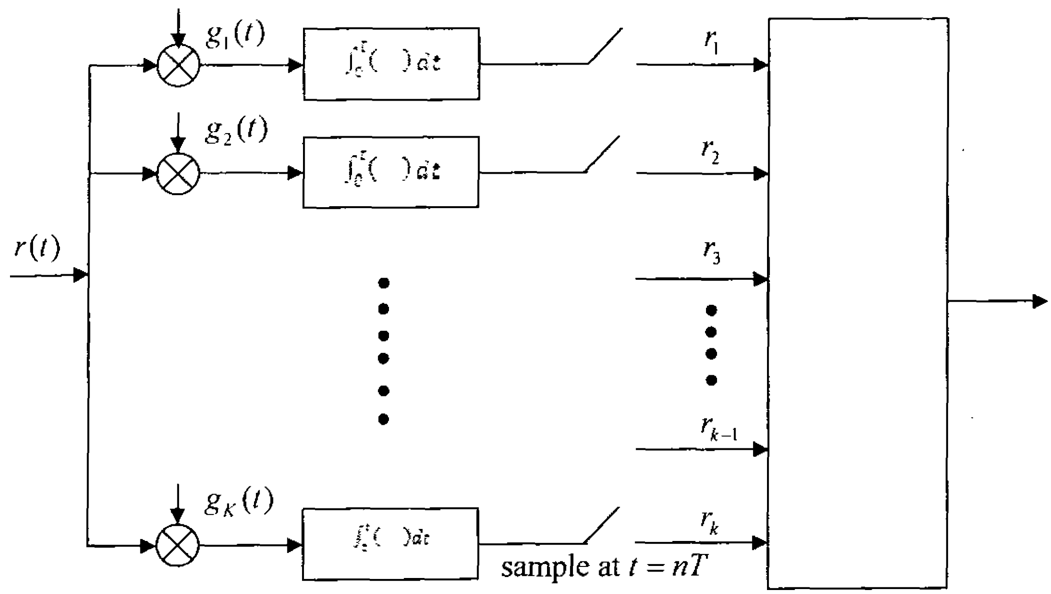


Figure 2. 2 CDMA Receiver with Synchronous transmitting

Here $r(t)$ is the receive signal and the information waveform of every user is $g_k(t)$. The matrix $r(t)$ is represented as follow

$$r(t) = \sum_{k=1}^{K} \sqrt{\varepsilon_k} b_k(t) + n(t), \qquad 0 \le t \le T \tag{2.8}$$

The received signal detection is made by probabilistic log detection function which is merged by a very popular function maximum-likelihood detector. This detector cab be shown in the form of correlation matrix

$$c(r_k; b_k) = 2b_k' r_k - b_k' R_s b_k$$

Here in R_s correlation matrix, the components $\rho_{jk}(0)$ and r_k is represented as

$$r_k = [r_1 r_2 \ldots. r_k]' \tag{2.9}$$

And b_k is represented as

$$b_k' = [\sqrt{\varepsilon_1} b_1(1) \ldots. \sqrt{\varepsilon_k} b_k(1)]' \tag{2.10}$$

The total available information sequence bits are equal to 2^k. The calculation of this correlation matrix is made with every matrix chosen.

Chapter 3
Introductory Literature on OFDM

3 Chapter OFDM

3.1 Introduction:

OFDM is a frequency-division multiplexing (FDM) method. A large number of closely-spaced orthogonal sub-carriers are made with the help of this technique and then we use these orthogonal sub carriers to carry data. The Orthogonal Frequency Division Multiplexing technique is a dominant agent in opposition to the Multi Path and it also guarantees good quality spectral effectiveness. These two very important communication schemes mutually forms the **OFDM based CDMA** system. Now we study the detailed OFDM systems before going to discuss the considerate of OFDM based CDMA system.

3.2 OFDM System

This technique is a combination of modulation and multiplexing. Modulation is a mapping technique of source information which changes the carrier frequency, phase & amplitude or both phase and amplitude. Multiplexing is the technique of sharing the BW to other individual carriers. A distinct frequency slot is owed to each user in OFDM.

The sequence of serial data is break up to a parallel number of carriers after moving from S/P converter. The N channels/carrier with having the frequencies $f_0, f_1 \ldots\ldots\ldots f_{n-1}$ has N modulators because each channel data is applied in such a way. The partition b/t the channels is Δf. The total modified bandwidth W of N carriers is $N\Delta f$. These adapted N carriers are compositely giving the OFDM signal

3.3 Basic structure of OFDM:

The blueprint of an OFDM system needs trade-off b/t different parameters as like in all communication system development. Generally, the input variables to the design are the available bandwidth, bit rate and the maximum delay spread introduced by a medium.

The implementation of this system involves calculation of different parameters such as number of sub-carriers, symbol duration, guard time, and coding schemes and the modulation among others.

3.4 Block Diagram of an OFDM System

The block diagram of an OFDM system deals with the important concepts of this system. The block diagram of an OFDM system is given below.

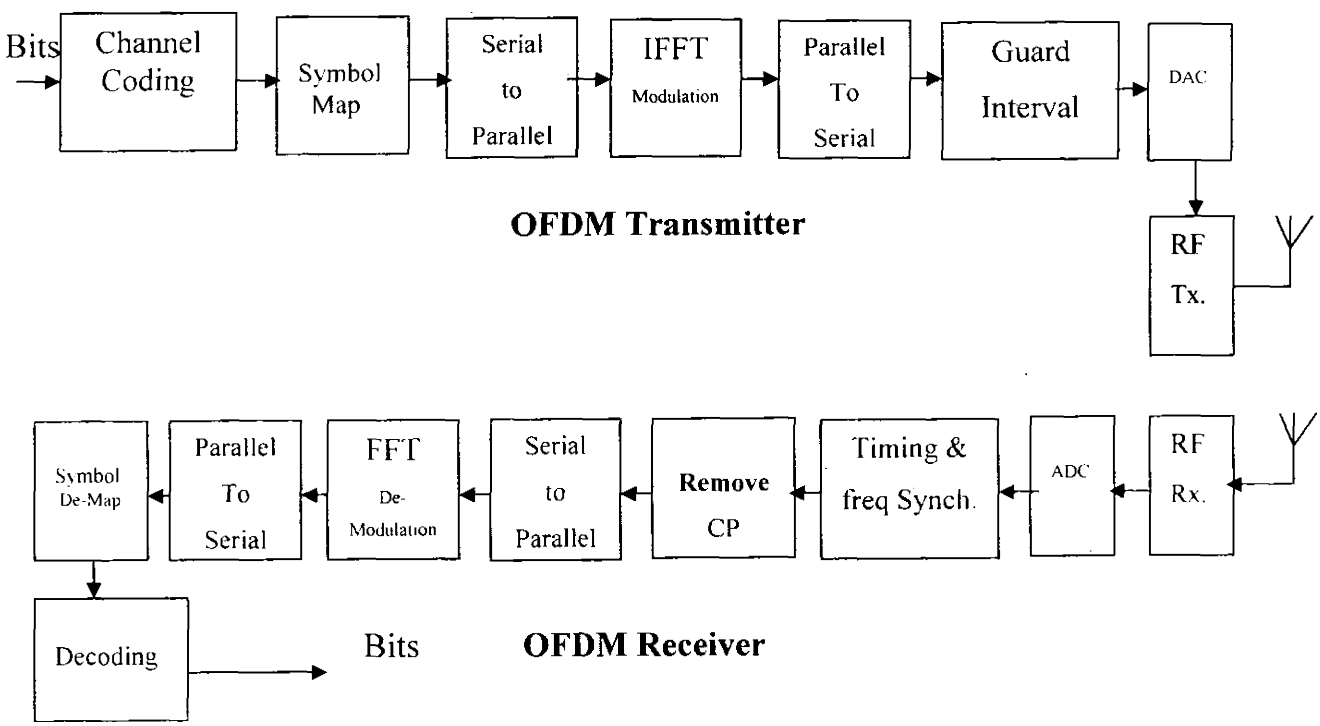


Figure 3. 1 *Block Diagram of OFDM*

Now we briefly describe the system components. At transmitter side, the information bit sequence of each user is first subjected to channel encoding to minimize the probability of error at the receiver side due to the noisy channel effects. There are many coding schemes are proposed. but convolution encoding scheme is preferred. First of all the bits of specific user are mapped to symbols. Usually, the information bits are mapped into the symbols of any modulation scheme such as Quadrature Phase Shifting Key (QPSK), or Quadrature Amplitude Modulation (QAM) 16-QAM. Then we convert the symbol sequence from serial to parallel format and then we apply the technique Inverse Fast Fourier Transform (IFFT) and after that the parallel sequence is once again converted to the serial format. Then we apply the Guard time interval, which is normally provided between the OFDM symbols and the guard time interval is filled with the cyclic extension of the OFDM symbol. After doing this process, the new sequence of information is converted to n analog signal using a function Digital to Analog Conversion (DAC) and after that passed it on to the Radio Frequency (RF) modulation stage. The RF modulated signal is, then, transmitted by using the transmit antennas to receiver end.

At the receiver side, first of all, RF demodulation is applied. After that, the signal is digitized with the help of anti function of DAC, which is done by using the ADC technique and after that timing of symbols and frequency synchronization are performed. Synchronization is very important aspect to both timing and frequency, and it is perform with full effort to get the maximum synchronization. Then we remove the guard time interval from each OFDM symbol and after that the sequences are converted to parallel format from serial format and Fast Fourier Transform (FFT) technique is applied for OFDM demodulations. The output sequence is then serialized and then we convert the symbols to bits by de-mapping function to get back the coded bit sequences.

3.5 OFDM Signal and Channel Model

Let we suppose, a good communication system that is modulated on the multi-carrier. Multi-carrier mean a large space of transmission medium/carrier is divided into number of slots or number of carriers where we can transmit the information on each slot. The given multi-carrier system transmits the N_c complex values information symbols $S_n, n = 0, \ldots\ldots N_c - 1$ [9]. All the symbols are made parallel after transmitting on N_c sub-carriers which can be done by both codes. The interval of source symbol is T_d. After converting from S/P, the transfer of OFDM symbol interval becomes

$$T_s = N_c T_d \tag{3.1}$$

The separation between subcarriers is $F_s = \frac{1}{T_s}$ and that is only for attaining the Orthogonality b/t the signals on the subcarriers by using the pulse shape rectangular. These contiguously transmitted symbols are called OFDM symbol.

The frequencies of total sub carrier N_c are placed in such a way on

$$f_n = \frac{n}{T_s}, \quad n = 0,1,\ldots\ldots, N_c - 1$$

We used the technique IFFT / IDFT for applying on multi-carrier transmission in OFDM system. Then the sampling of complex envelope $x(t)$ of a single OFDM symbol is made at $\frac{1}{T_d}$. Then the equation of sampled complex envelope can write as

$$x_v = \frac{1}{N_c} \sum_{n=0}^{N_c - 1} S_n e^{j2\pi nv/N_c}, \tag{3.2}$$

The sampled sequence x_v is become or resulted due to the IDFT of the symbols S_n.

If we increase the length of sub-carriers, it results that the interval time of symbol T_s grows larger as comparing with the period of τ_{max} .the benefit of doing this, it resulted reduces the ISI. For total deterrence of the ISI, Guard Interval (GI) period is.

$$T_g \geq \gamma_{max}$$

And it is placed b/t OFDM symbols close to each other. The inveterate addition of every OFDM symbol of GI is gotten growing OFDM interval to

$$T_s' = T_g + T_s \tag{3.3}$$

OFDM model succession together with guard interval

$$x_v = \frac{1}{N_c} \sum_{n=0}^{N_c - 1} S_n e^{j2\pi nv/N_c}, \quad v = -L_g, \ldots\ldots N_c - 1 \tag{3.4}$$

The succession of this model needs to pass alongside a converter, and that is Digital to Analog (D/A) converter. Finally the waveform x(k) is with increased interval T_s'. After the conversion RF. the transmission of signal to a channel is finally done.

After passing through the channel, the RF conversion is made to get back data. The waveform $x(k)$ is convolve with channel $h(\tau,t)$, the final $y(t)$ is written as

$$y(t) = \int_{-\infty}^{\infty} x(t-\tau)h(\tau,t)d\tau + n(t) \quad (3.5)$$

And the frequency domain R_x can be written as

$$R_n = H_n S_n + N_n, \quad n = 0,.....,N_c - 1 \quad (3.6)$$

3.6 Modulation

It is a process by which signals information that may be in analog or digital format, are transformed into waveforms which is only suitable way for transmission across channel. By taking digital modulation, digital information is transformed into digital waveforms. For a base band modulation. the waveforms are the pulses; but in band-pass modulation, the signals information are modulated over the radio frequency (RF). which have embed digital information. But the RF carriers are sinusoids; and these sinusoids have three salient features. which are its amplitude, phase and frequency. In pass band modulation, this sinusoid wave can be defined as the process in which amplitude, phase or frequency of an RF carrier, or any combination of these three salient features, is varied with respect to the digital information which is to be transmitted. The general form of RF carrier is represented as

$$s(t) = A(t) \exp\left(W_c t + \theta(t)\right)$$

Where,

The parameter W_c, is the frequency of the carrier. and $\theta(t)$ is the time varying phase.

On the receiver end, the transmitted signal information embedded in the RF carrier must be recovered back to original format. If the receiver knows the correct phase of the carrier where the signal is to detected. this process is called **coherent detection;** else the process is known as **non-coherent detection.** The main advantage of non-coherent detection over the coherent detection is reduced complexity at the price of increased probability of error. Almost we can achieve 3 dB gain while using coherent detection as compared to the non-coherent detection. The receiver uses any detection technique; it must decide which one of the possible symbol is most closely resemble the received signal, taking into account the effect of channel.

3.7 Number of Sub-carriers

When the symbol duration of signal information sequence is fixed, then we can create the spacing between the sub-carriers as the inverse of the symbol duration and also minus the guard time. The total number of the sub-carriers can be calculated with the ratio of the given bandwidth to the carrier spacing.

3.8 Quadrature Phase Shift keying

The general figure of QPSK modulation scheme is mention below. In the input of QPSK, binary digits stream can be transmitted and the data rate of this binary stream is $R = 1/T_b$, and where T_b is the size of each bit. The given stream is changed into two separate bit streams and size of each stream will be $R/2$ bps, by taking alternating bits for the two streams. These two data streams can be represented as I & Q, where I (in-phase) and Q (Quadrature phase) streams. These streams can be modulated on a carrier of frequency f_c by multiplying the sending bit stream by the carrier, and the behavior of carrier shifted by 90°. After this these two modulated signals are added together and transmitted through the medium / carrier, and the symbol error rate of combined signals is become half of the input bit rate.

This diagram also shows the different variation of QPSK and is known as a stream of orthogonal QPSK or offset QPSK (OQPSK). The main difference is that a delay of one bit is introduced in the Q stream. OQPSK differs from QPSK only by creating the delay in the Q stream; but the spectral characteristics and bit error performance are the same.

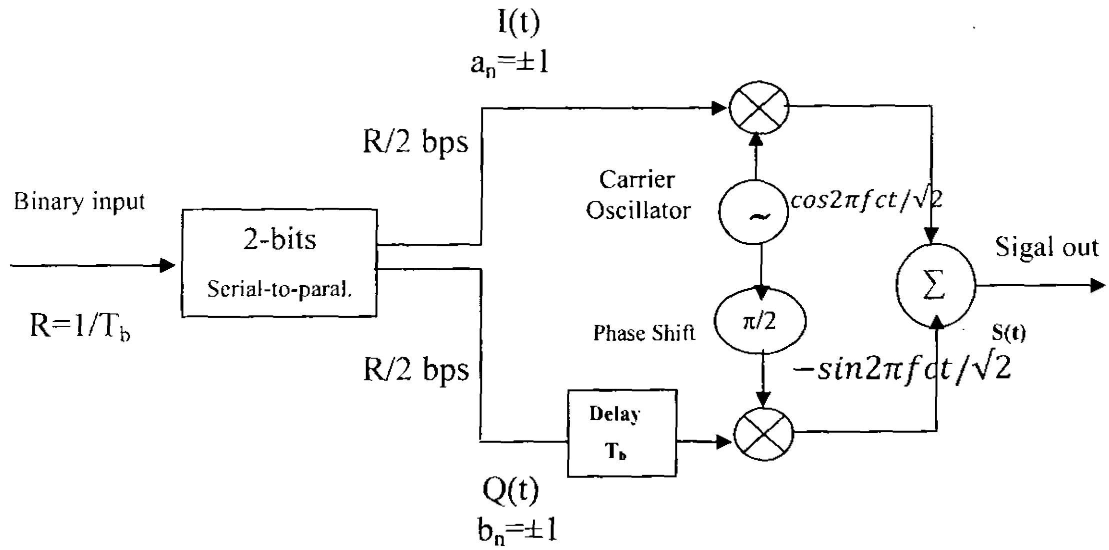


Figure 3. 2 QPSK Modulator

3.9 OFDM Modulation Using the IFFT

The OFDM transmitter operates on sets of M bits at a time where groups of nk bits modulate sub-carrier k; $k = 0 \ldots N-1$. In general, the number of bits assigned each subcarrier varies among the subcarriers. We must choose each nk such that if the transmitter uses 4-QAM on each channel, then $nk = 2$, $k \in 0 \ldots N-1$ and $M = 2N$ since each transmitted symbol carries two bits worth of information. Similarly, if 128-QAM is substituted for 4-QAM, then $nk = 7$, $k \in 0 \ldots N-1$ and $M = 7N$. When using a two-dimensional signal format, the transmitted point in the signal constellation for subcarrier k (which codes nk bits) is written

$$d[k] = x[k] + j\,y[k],$$

where

$$x[k] \in R$$

It represents the in-phase component and $y[k] \in R$ is the quadrature component. The subcarriers are spaced in frequency at the symbol rate to keep them orthogonal. Hence, an OFDM symbol duration of T seconds results in a subcarrier spacing of $1/T$ Hz. Longer symbol durations allow us to pack the subcarriers closer together in frequency. We can describe the band pass continuous time transmitted waveform D(t) during one symbol interval as:

$$D(t) = \sum_{k=0}^{N-1}(x[k]\cos\cos(2\pi f_k t) + y[k]\sin(2\pi f_k t)) \quad (3.7)$$

Here f_0 is a base frequency,

Δt is the serial symbol duration,

$\Delta f = 1/N\Delta t$ is the subcarrier spacing,

$fk = f_0 + k\Delta f$ is the kth user subcarrier frequency.

Here, one thing keeps in mind that the individual subcarrier is separated by

$$\Delta f = 1/N\Delta t = 1/T,$$

And it is the correct amount of space to keep them orthogonal.

By Using Euler's identity, we can rewrite equation as follows:

$$D(t) = \mathrm{Re}\left\{\sum_{k=0}^{N-1} d[k]e^{j2\pi f_k t}\right\} \quad (3.8)$$

A pass band signal can be represented in single real function. However, the other is used to represent complex part of signal, which is required for a baseband description. Therefore, we can transform D(t) into a baseband signal by taking sampling intervals of Δt and also maintaining the complex notation.

Remember, ***wk* = 2πfk**: and it can be represented as

$$D[n] = \sum_{k=0}^{N-1} d[k]e^{j(2\pi nk)/N} \quad (3.9)$$

The above equation is same as likewise the FFT analysis equation (IFFT) given in equation. In fact, here we can rewrite this equation in different way

$$\mathrm{D}[\mathrm{n}] = \mathrm{DFT}\{\mathrm{d}[\mathrm{n}]\}$$

By Modulating the D[n] with carrier signal, and effectively the signal with a rectangular base band shaping function h(t) ,and h(t) can be represented as,

$$h(t) = \left\{\begin{matrix} 1/T & 0 \le t < T \\ 0 & otherwise \end{matrix}\right\}$$

These rectangular pulses impose a sinc frequency response on each sub-channel. The sinc function $(\sin(\omega)/\omega T)$ has zeros at every multiples of $\Delta f = 1/T$, which satisfied the Nyquist condition for eliminate ISI and make ISI free transmission.

In the end of reviewing theory, we study that the receiver can recall all of the transmitted symbols. If we suppose, that the transmitted data is

$$U(-N/2),\ U(-N/2+1),\ldots\ldots U(N/2-1)$$

Here N is a total number of channels, the signal representation in discrete-time after taking IFFT is shown as

$$u(n)=\sum_{k=N/2}^{\frac{N}{2}-1} U(k)e^{j2\pi\left(\frac{nk}{N}\right)},\ n\hat{I}\{-\frac{N}{2},\frac{N}{2}\}$$

Now at the receiver end, the signal is recovered by taking the FFT operation on the received signal, it can be represented as

$$U(k)=\frac{1}{N}\sum_{k=N/2}^{\frac{N}{2}-1} u(n)e^{-j2\pi\frac{nk}{N}},\ k\ \grave{o}[-\frac{N}{2},\frac{N}{2}]$$

At the end, OFDM modulation and demodulation can be done by using the Computationally efficient operations - IFFT and FFT respectively.

Chapter 4
OFDM Based CDMA

4 Chapter OFDM based CDMA System

4.1 Introduction

By joining the OFDM transmissions with CDMA, it allows us to effort the wideband channel's inherent frequency diversity by spreading each data symbol across multiple subcarriers.

4.2 OFDM transmission system:

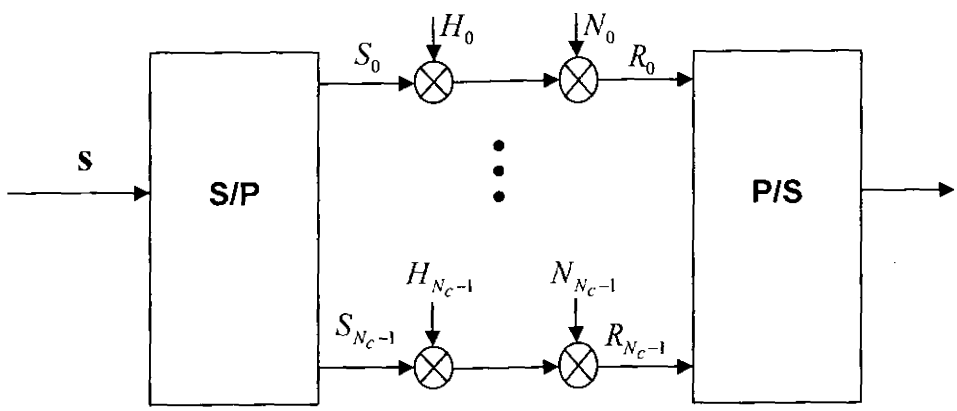


Figure 4. 1 OFDM transmission system

The Input symbol vector **s** is going to be transmitted on $N_c \times N_c$ channel matrix ***H*** and also channel additive noise is to be considering which is declaring with ***N***. The vector ***r*** is the receiving symbols which is the result, and the following equation can be mathematically represented as

$$\mathbf{r} = (R_0, R_1, ...R_{N_c-1})^T \tag{4.1}$$

And this vector **r** is gotten via

$$r = Hs + n \tag{4.2}$$

Therefore, the channel matrix H can be represented as

$$H = \begin{bmatrix} H_{0,0} & 0 & . & . & . & 0 \\ 0 & H_{1,1} & & & & 0 \\ . & & . & & & . \\ . & & & . & & . \\ 0 & 0 & . & . & . & H_{N_c-1,N_c-1} \end{bmatrix}$$

And so on ,the source vector S is represented by

$$s = \left(S_0, S_1, ..., S_{N_c-1}\right)^T \tag{4.3}$$

Moreover, the the channel noise **n** is

$$n = \left(N_0, N_1, ..., N_{N_c-1}\right)^T \tag{4.4}$$

4.3 OFDM based CDMA System

Our main focus is on the detail of OFDM based CDMA system, and it is going to discussed after completing the basic idea and the main sub systems of this system. Signal structure of this system is described first [9].

4.4 Signal Structure of OFDM based CDMA

By following the above discussion in this chapter, this system is basically a combination of sub systems and that are the CDMA with OFDM. Each data symbol is modulated with direct sequence chip and then these modulated symbols are drawn on a distinct subcarrier. That way, the spread sequence data chips are sent equally on different subcarriers of this system. The simultaneous active users K in OFDM based CDMA transmission can be graphically represented as,

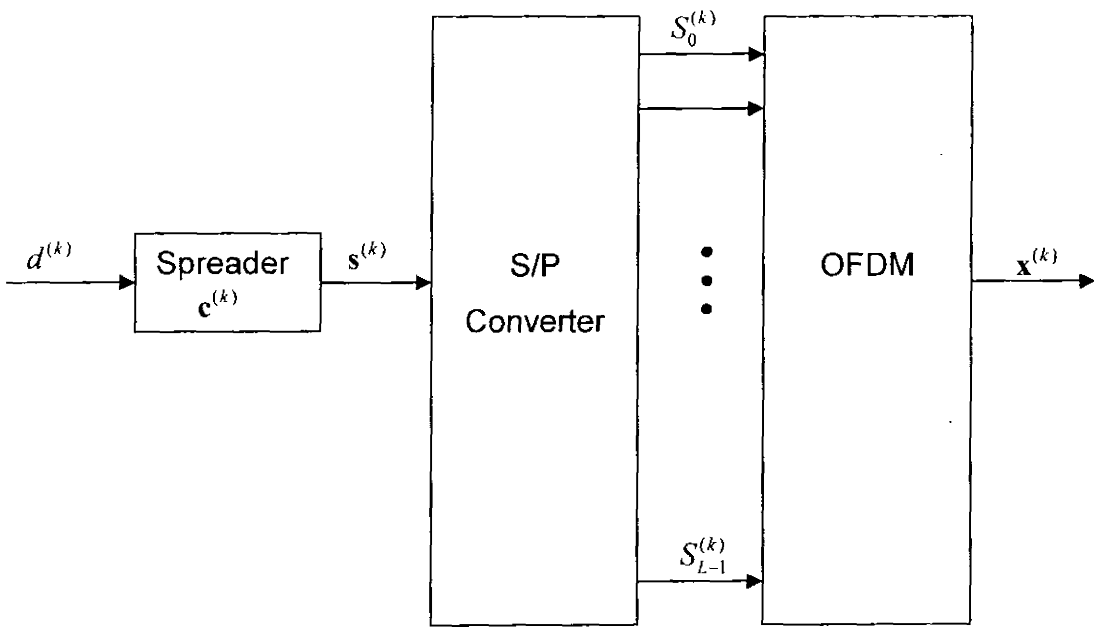


Figure 4. 2 Signal generation through MC-SS

The source symbols vector $d^{(k)}$ is allocated to k users which are spreader by multi-carrier spectrum, and the symbol rate of this serial source data is *1/Td.*

For generalization. the creation of OFDM based CDMA signal is paying attention pro one data symbol of each user. and then the data symbol $d^{(k)}$ is multiply with user precise specific spreading code, and this can be represented in equation format as

$$c^{(k)} = (c_0^k, c_1^k, ..., c_{L-1}^{(k)})^T \qquad (4.5)$$

Then the spreading code length is $L = P_g$. Before transforming to S/P alteration, the chip rate of $\mathbf{c}^{(k)}$ serial spreading code can be shown by

$$\frac{1}{T_c} = \frac{L}{T_d}$$

The chip rate is" L " times greater as compare to the data rate symbol $1/T_d$. The resulting vector form of this complex valued spreading is

$$s^{(k)} = d^{(k)}c^{(k)} = (S_0^{(k)}, S_1^{(k)}, ..., S_{L-1}^{(k)})^T \tag{4.6}$$

The different components of $s_l^{(k)}$ modulation is applied on adjacently subcarriers which resulted from MC-SS. Let we suppose, the subcarriers N_c of OFDM symbol that is the same to length 'L' of spreading code, the guard interval which is added to the OFDM symbol with MC-SS, it can be mathematically shown as

$$T_s^{'} = T_g + LT_c$$

Each user sends one data symbol on each subcarrier of the OFDM in above discussion.

4.5 Downlink Signal

In downlink signaling, the synchronous transmission of an OFDM operation is performed after the addition of spread signals of total 'K' users. These 'K' sequences of $s^{(k)}$ vector is the assignment result in the sequence, and it is given by

$$\begin{aligned} s &= \sum_{k=0}^{K-1} s^{(k)} \\ &= (S_0, S_1, ..., S_{L-1})^T \end{aligned} \tag{4.7}$$

A new downlink presentation for the vector **s** is

$$s = Cd \tag{4.8}$$

Where,

$$d = (d^{(0)}, d^{(1)} ...., d^{(k-1)})^T$$

The total 'K' user's transmitted symbols with $\boldsymbol{d}$ vector. Then C is the spreading matrix, and it can be represented as

$$C = (c^{(0)}, c^{(1)}, ..., c^{(k-1)})$$

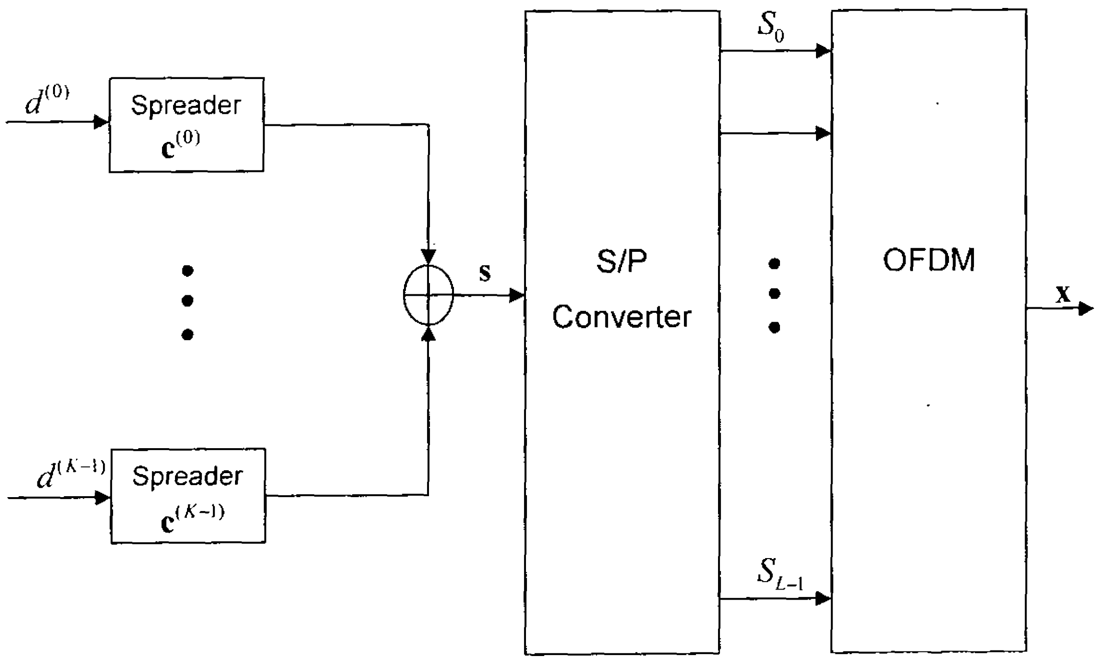


Figure 4. 1 OFDM based CDMA Downlink transmitter

The signal of this system for downlink transmitter attained after the sequence s giving out in OFDM block by (2.9)

$$x(t) = \frac{1}{N_c} \sum_{n=0}^{N_c - 1} S_n e^{j2\pi f_n t}, \quad 0 \le t \le T_s \tag{4.9}$$

Here we consider, all the noise is absorbed because there is a long enough guard interval for absorbing the all the echoes. Therefore, the inverse of an OFDM and inverse or de-interleaving of received vector sequence **s** can be retrieving by the help of this equation, given below

$$r = Hs + n = (R_0, R_1, \ldots, R_{L-1})^T \qquad (4.10)$$

The channel matrix H is of dimension L x L and vector S is the source symbol vector, and noise vector n of length L, and the received vector **r** is set of data detector for receiving the spread data. In case of multiuser detection, the eq. (2.23) also be represented as given by

$$r = Ad + n = (R_0, R_1, \ldots, R_{L-1})^T \qquad (4.11)$$

The system matrix A is made with channel matrix H and C, and it is represented as

$$A = HC$$

4.6 Uplink Signal

Then the output of the following processing of sequence $s^{(k)}$ in an OFDM block which is mention in equation (2.9)

$$x(t) = \frac{1}{N_c} \sum_{n=0}^{N_c - 1} S_n e^{j2\pi f_n t}, \quad 0 \le t \le T_s$$

in uplink. Then de-interleaving the frequency and Inverse OFDM or IOFDM of recognized vector of broadcasted successions vector $s^{(k)}$ .then the received vector **r** can be represented as

$$r = \sum_{k=0}^{K-1} H^{(k)} s^{(k)} + n = (R_0, R_1, \ldots, R_{L-1})^T \qquad (4.12)$$

In above equation, the channel matrix $H^{(k)}$ consists of the channels coefficients which are allocated to the preferred user. The requirement we supposes to uplink signal synchronous for attaining an OFDM. Then the matrix A can be represented as

$$A = (a^{(0)}, a^{(1)}, \ldots, a^{(k-1)})$$

Which comprises of K user each has distinct vectors

$$a^{(k)} = H^{(k)}c^{(k)} = (H_{0,0}^{(k)}c_0^{(k)}, H_{1,1}^{(k)}c_1^{(k)}, \ldots, H_{L-1,L-1}^{(k)}c_{L-1}^{(k)})^T \qquad (4.13)$$

4.7 Spreading Codes

There are many spreading codes which are proficient for the both transmitting schemes, the uplink signals & downlink signaling transmission. For synchronized and a synchronized Transmission, there we use different spreading codes. Generally, the Walsh codes are the most favorite codes utilized in OFDM Based CDMA system.

4.8 Multiple User Detection Techniques

The main types of multiuser detection are

- Optimum detection
- Sub-optimum detection

The short explanation is as following:

4.8.1 Optimum detection method:

In this method, the most likely sequence bits of data such that

$$[\, b[k](n), 1 <= k <= K, 1 <= n <= N]$$

On $r(t)$ is detected with the time duration of $0 <= t <= NT + 2T$ **[8]**.This method utilizes the MAP law or it can be ML law. The main very important detection or most likelihood optimum detecting techniques are

i: Maximum Likelihood Sequence Estimate (MLSE)

i i: Maximum Likelihood Symbol-by-Symbol Estimation (MLSSE).

Maximum Likelihood (ML) Detection is a very good optimum multiuser detection method. Both the ML methods are shortly described here.

In [8], The MLSE is, that guesses

$$d = (d^{(0)}, d^{(1)}, \ldots, d^{(k-1)})^T$$

And the second is MLSSE which guesses $d^{(k)}$ detail given in [10]. The possible are

$$d_{\mu},\ \mu = 0,\ldots,M^{K}\text{ -1}$$

Here M^{K} is the no. of possible transmitted data samples sequences and the M is a possible no. of iterations of the data sequence $d^{(k)}$.

4.8.2 Sub-optimum Detectors

The complexity of the optimum detection gives the rising in power of integers as by increasing users [9]-[10].

Chapter 5
Design of Proposed System

5 Chapter Design

5.1 Introduction Proposed System

In my thesis, OFDM based CDMA system has been studied and implemented. We developed this system with the help of two famous techniques CDMA and OFDM. In this system, we have applied two approaches to investigate the result of this system,

In, 1st approach, I have fixed the number of carriers to transmit the signals of multiple users. I have accommodated multiple users and passed the signals of different users like a 4-user, 8-user, 16-users and so on up to 64-users to those fixed carriers. After passing the signals of multiple users on these fixed carriers, I have tried to find out the enhanced result with the comparison of two different channels: AWGN channel and Rayleigh channel.

In, 2st approach, I have fixed the number of users and passed these fixed users to a different carriers. These fixed user can pass through different carrier like a 4-carrier, 8-carrier and so on up to 64-carrier.After passing through different carriers, I have tried to investigate the improved results.

The ordered of detail, in this thesis is: "Firstly, a short introduction. After completing introduction, a special concentration is paid to a OFDM based CDMA model. After that, the MSE detector is described".

5.2 OFDM based CDMA System representation

Suppose an 'L' samples are going to transmit in multi carrier'. In this model, For Uplink transmission, the samples of uplink signals are taking place to the ending sample. Hence fig. 5.1 illustrates th transmition of this model.

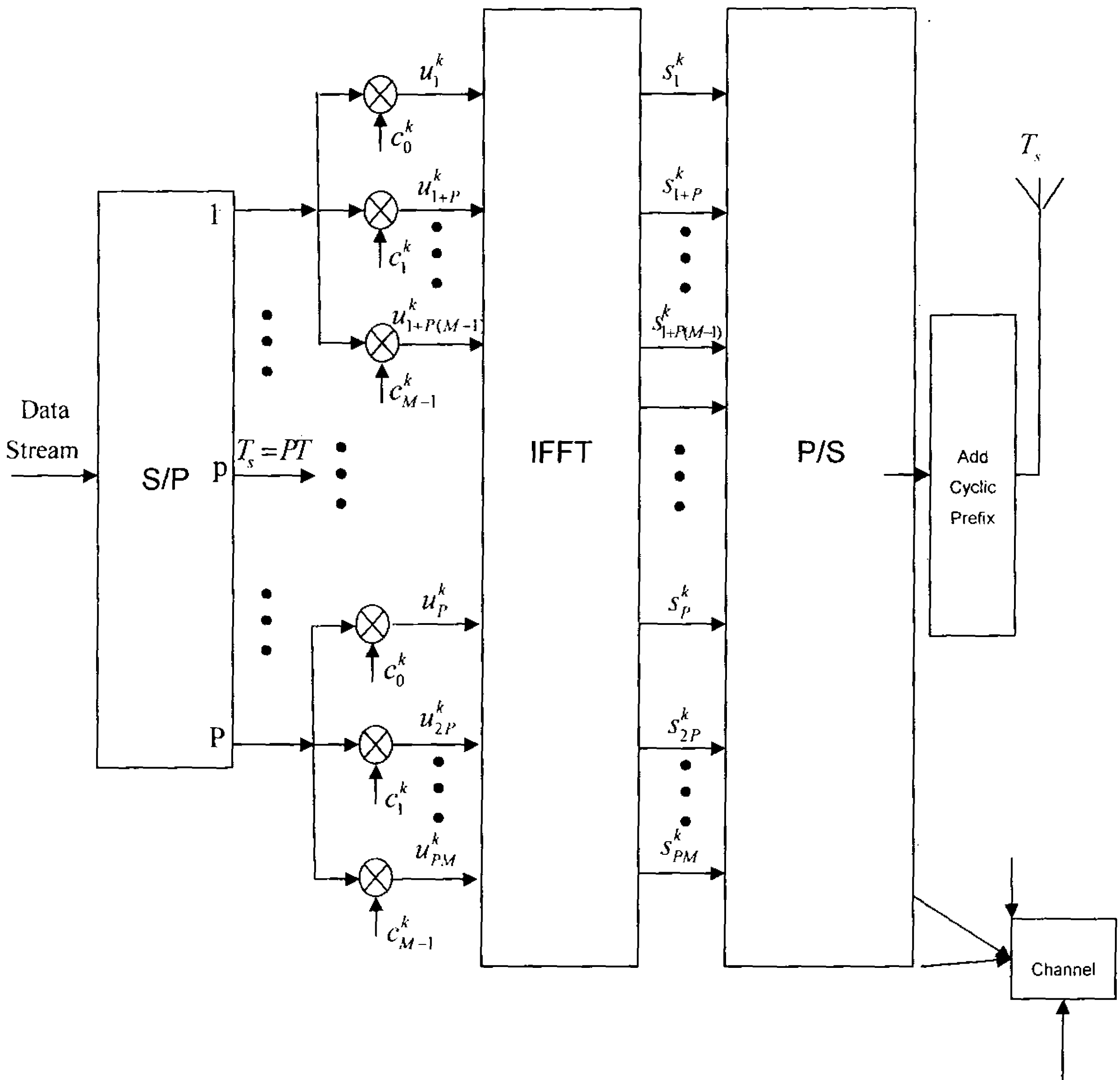


Figure 5. 1 Transmission of OFDM based CDMA

From another OFDM based CDMA User

All the data streams given below are for the i^{th} time interval. The 1st user data stream is represented by a vector $\mathbf{b}^1$ with time interval **i,**

$$b^1(i) = [b_0^1(i), b_1^1(i), b_2^1(i), ..., b_{p-1}^1(i)] \quad (5.1)$$

The 2^{nd} user data stream is

$$b^2(i) = [b_0^2(i), b_1^2(i), b_2^2(i), ..., b_{p-1}^2(i)] \quad (5.2)$$

Correspondingly, the P^{th} user data stream is

$$b^P(i) = [b_0^P(i), b_1^P(i), b_2^P(i), ..., b_{p-1}^P(i)] \quad (5.3)$$

Total K users data stream is

$$b(i) = [b^1(i), b^2(i), b^3(i), ..., b^K(i)] \quad (5.4)$$

The K^{th} user data stream is changed to P similar bit order $\mathbf{b}(i)$ for the i^{th} interval. Let t and t_s be the symbols period prior to and later than the one path to multiple transmission path conversion. However, $t_s = Pt_s$. If symbol period t_s on mid path is longer as compare to medium has more then one path holdup expand, the every path almost practice equal effect .

Suppose the user spreading code is $c_k = [c_0^k, c_1^k, ..., c_{M-1}^k]^T, k = 0, ..., K-1$. These are for spreading output of each user after the S/P changing. The bits changed to N different path after S/P.

The 1[st] user output modulated with c_k is

$$b_0^1(i)[c_0^1, c_1^1, ..., c_{M-1}^1]^T = [b_0^1 c_0^1, b_0^1 c_1^1, ..., b_0^1 c_{M-1}^1]^T$$
$$b_1^1(i)[c_0^1, c_1^1, ..., c_{M-1}^1]^T = [b_1^1 c_0^1, b_1^1 c_1^1, ..., b_1^1 c_{M-1}^1]^T$$

.

.

.

$$b_{p-1}^k(i)[c_0^1, c_1^1, ..., c_{M-1}^1]^T = [b_{p-1}^k c_0^1, b_{p-1}^k c_1^1, ..., b_{p-1}^k c_{M-1}^1]^T$$

The k^{th} user output modulated with c_k is

$$b_0^k(i)[c_0^k, c_1^k, ..., c_{M-1}^k]^T = [b_0^k c_0^k, b_0^k c_1^k, ..., b_0^k c_{M-1}^k]^T$$
$$b_1^k(i)[c_0^k, c_1^k, ..., c_{M-1}^k]^T = [b_1^k c_0^k, b_1^k c_1^k, ..., b_1^k c_{M-1}^k]^T$$

.

.

.

$$b_{p-1}^k(i)[c_0^k, c_1^k, ..., c_{M-1}^k]^T = [b_{p-1}^k c_0^k, b_{p-1}^k c_1^k, ..., b_{p-1}^k c_{M-1}^k]^T$$

The separation among consecutive subcarriers is $\Delta f = 1/T_s$. The upper limit of frequency diversity is achieved by sending the sample h[l][y] for the different path . For resultant chips are $N = PM$. These are

$$u_k(i) = [b_0^k(i)c_0^k, b_0^k(i)c_1^k, ..., b_0^k(i)c_{M-1}^k, b_1^k(i)c_0^k, b_1^k(i)c_1^k, ..., b_1^k(i)c_{M-1}^k, ..., b_{P-1}^k(i)c_0^k, b_{P-1}^k(i)c_1^k, ..., b_{p-1}^k(i)c_{M-1}^k]^T_{N\times 1}$$

Suppose $u_0^1 = b_0^1 c_0^1$. Equally, $u_{k+Pk}^1 = b_k^1 c_k^1$. So that

$$u_0^1 = [u_0^1, u_{0+p}^1, ..., u_{0+p(M-1)}^1]^T$$
$$u_1^1 = [u_1^1, u_{1+p}^1, ..., u_{1+p(M-1)}^1]^T$$

.

.

.

$$u_{p-1}^1 = [u_{p-1}^1, u_{2p+1}^1, ... u_{p(M-1)}^1]^T$$

Correspondingly,

$$u_0^P = [u_0^P, u_{0+p}^P, ..., u_{0+p(M-1)}^P]^T$$
$$u_1^P = [u_1^P, u_{1+p}^P, ..., u_{1+p(M-1)}^P]^T$$

.

.

.

$$u_{p-1}^P = [u_{p-1}^P, u_{2p+1}^P, ..., u_{p(M-1)}^P]^T$$

And **u** with dimensions $N \times 1$ writes below

$$u^k = \begin{bmatrix} u_0^k \\ u_1^k \\ M \\ u_{P-1}^k \end{bmatrix} = \begin{bmatrix} u_0^k, u_{0+P}^k, L, u_{0+P(M-1)}^k, L, u_1^k, u_{1+P}^k, L \\ , u_{1+P(M-1)}^k, L, u_{P-1}^k, u_{2P-1}^k, L, u_{PM-1}^k \end{bmatrix}_{N\times 1}^T \tag{5.5}$$

The above vector is convolved with carrier signal and take. Then result of the desire users results in data samples at i^{th} time are

$$s_k(i) = F_1 u_k(i) \tag{5.6}$$

$F_1 \in C^{N\times N}$ is Fourier matrix utilized for IDFT. Then $(a,b)^{th}$ component is exponantional of [2abi*3.1415/total number of users] divided by total number of users. The 1^{st} component of K^{th} user at the I^{th} time is

$$\begin{aligned} s_0^K(i) &= \frac{1}{2\pi}\int_{-\infty}^{\infty} u_0^k e^{jwi} di \\ &= \frac{1}{2\pi}\int_{-\infty}^{\infty} b_0^k(i) c_0^k e^{jwi} di \\ &= \frac{c_0^k}{2\pi}\int_{-\infty}^{\infty} b_0^k(i) e^{jwi} di \\ &= \frac{c_0^k}{2\pi} \end{aligned}$$

Correspondingly, s could compute. The **s** is given by

$$s^k(i) = \begin{bmatrix} s_0^K(i), s_{0+P}^K(i), \ldots, s_{P(M-1)}^K(i), \\ s_1^K(i), s_{1+P}^K(i), \ldots, s_{1+p(M-1)}^K(i), \\ \ldots, s_{P-1}^K(i), s_{2P-1}^K(i), \ldots, s_{PM-1}^K(i) \end{bmatrix}_{N\times 1} \tag{5.7}$$

Hence, the explanation given above can be used to derive (3.7).

This user signal has been transmit with specific slot in k lines. The medium represent as $(Q-1)^{th}$ Impulse Response finite filter [18]. Then medium has h of the system

$$h_k(t) = \sum_{l=0}^{L-1} g_{k,l}(t)\delta(t-\tau_{k,l})$$

Where k user indicator and $g_{k,l}(t)$ is jth line take-up. The $g_{k,l}(t)$ is autonomous 0 MCGRP that has value $\sigma^2_{k,l}$. Then delay spread of *specific line* is τ of k and l. Then power wait profile of follower $\sigma^2_{k,l}$ $(l = 0,..., L-1)$.

At the same time the Inter Symbol Interference (ISI) also occurs. So, the elimination of ISI is essential at the same time. To get rid of samples further every, then. Then multi carrier transmit ion in the medium after that.

The picture (5.2) shows receiver for multi carrier system.

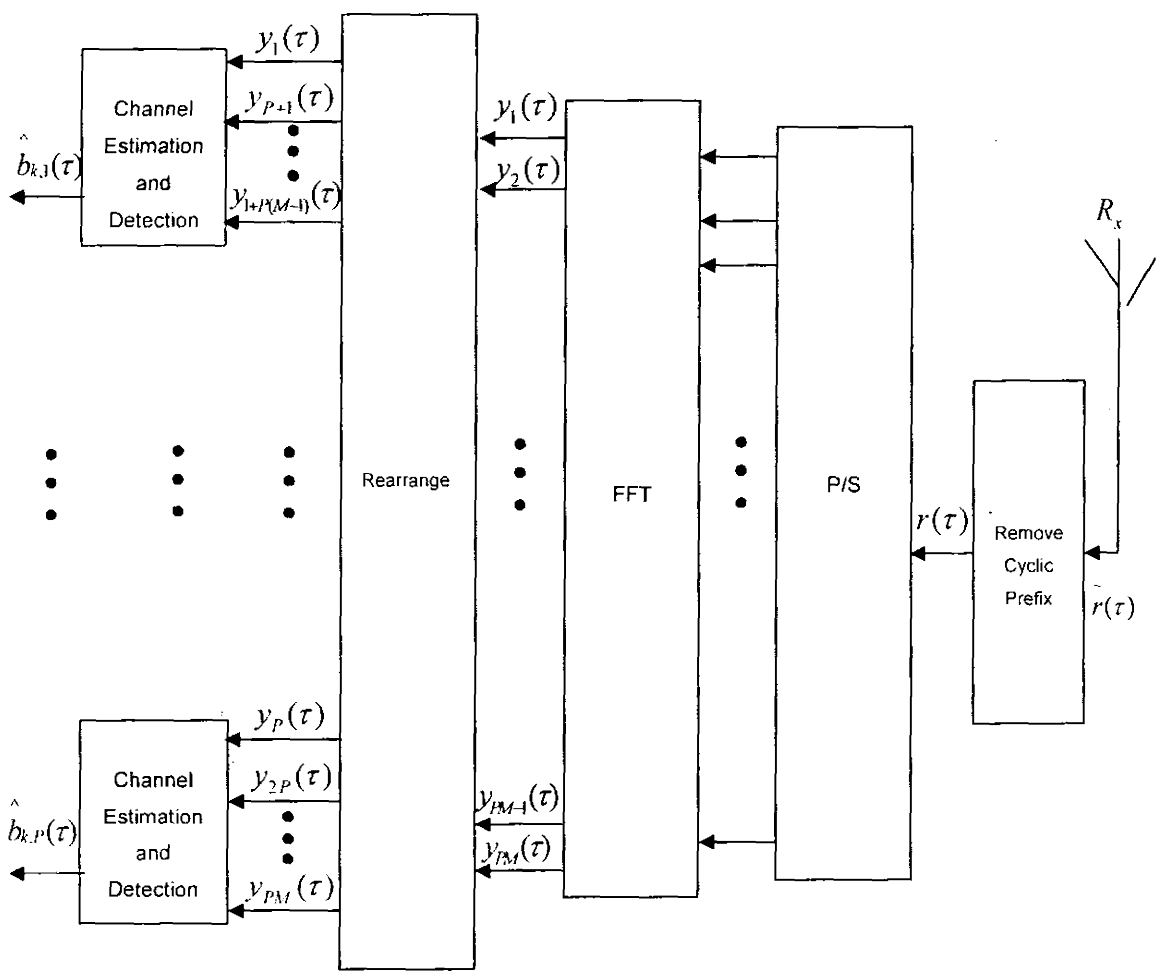


Figure 5. 2 **Receiver for OFDM based CDMA' system**

We supposed the channel is constant while multi-carrier sampling. At receiver side, the sampling is taken at time interval $n+ng/t$. Then receiver side samples for a specific user on any level value as

$$\begin{aligned}\hat{r}_k(\tau) &= \int h_k(t)\hat{s}_k(t-l)dt+\eta \\ &= \int\sum_{l=0}^{L-1} g_{k,l}(t)\delta(t-\tau_{k,l})\hat{s}_k(t-l)dt+\eta\end{aligned} \tag{5.8}$$

So, the original samples received for l^{th} user on τ is.

$$\hat{r}_k(\tau)=\sum_{l=0}^{L-1}\sqrt{P_k}g_{k,l}(\tau)s_k(\tau-l)dt+\eta_k \tag{5.9}$$

$\tau_{k,l}=t$ and $\int\delta(t-\tau_{k,l})dt=1$. Then

$$\begin{aligned}\hat{r}(\tau) &= \sum_{k=0}^{K-1}\hat{r}_k(\tau) \\ &= \sum_{k=0}^{K-1}\sum_{l=0}^{L-1}\sqrt{P_k}g_{k,l}(\tau)\hat{s}_k(\tau-l)dt+\hat{\eta}(\tau)\end{aligned} \tag{5.10}$$

$\hat{\eta}(\tau)=\left[\eta_1 \quad \eta_2 \quad L \quad \eta_k\right]^T$ Refers to WGN that has 0 E[x] and E[x*x]-E[x]^{2}on i^{th} line, $\hat{s}_k(\tau)\hat{I}C^{N_{tot}\times 1}$. $N_{tot}=N+N_g$ for broadcasted s, then p at k time is taken equal to k for implemented.

Suppose frequency and time harmonization is achieved on receiver and ISI is eliminated with condition $N_g \geq L-1$. All values relevant are removed. Therefore, then harmonized τth MC-CDMA symbol after eliminating cyclic prefix is

$$r(\tau)=\sum_{k=0}^{K-1}\sqrt{P_k}G_k(\tau)s_k(\tau)+\eta(\tau) \tag{5.11}$$

With

$$s_k(\tau)=\left[\hat{s}_k(\tau N_{tot}+N_g),\ldots,\hat{s}_k(\tau N_{tot}+N_{tot}-1)\right]^T,$$

$\eta(\tau)=\left[\hat{\eta}(\tau N_{tot}+N_g),\ldots,\hat{\eta}(\tau N_{tot}+N_{tot}-1)\right]^T$. $G_k(\tau)$ defines the Toeplitz matrix like

$$\mathbf{G}_k=\begin{bmatrix} g_{k,0} & 0 & 0 & \cdots & g_{k,l} \\ g_{k,l} & g_{k,0} & 0 & \cdots & g_{k,2} \\ g_{k,2} & g_{k,l} & g_{k,0} & \cdots & g_{k,3} \\ . & . & . & & . \\ . & . & . & . & . \\ . & . & . & & . \\ 0 & 0 & 0 & . & g_{k,0} \end{bmatrix}$$

(If entire elements on main diagonal of the matrix are same and the values of whichever diagonal similar major values on diagonals also like.

In last, the FFT with size N is executed on receiver. Let $F\in C^{N\times N}$ is Fourier matrix. $\exp(-j2\pi uv/N)$ is (u, v)th component of F . Then in frequency domain in matrix form

$$\begin{aligned} y(\tau) &= Fr(\tau) \\ &= F\left[\sum_{k=0}^{K-1}\sqrt{P_k}G_k(\tau)s_k(\tau)+\eta(\tau)\right] \end{aligned} \tag{5.12}$$

$$s_k(\tau)\underset{F}{\overset{F^{-1}}{\rightleftarrows}}u_k(\tau)\ and\ \eta(\tau)\underset{F^{-1}}{\overset{F}{\rightleftarrows}}n(\tau),$$

$G_k(\tau)$ is Toeplitz matrix described previously.

$$H_k(\tau)=diag\left[h_{k,0}(\tau),\ldots,h_{k,N-1}(\tau)\right] \tag{5.13}$$

$$h_{k,n}(\tau)=\sum_{l=0}^{L-1}g_{k,l}(\tau)\exp(-j2\pi(nl)/N),\ n=0,\ldots,N-1 \tag{5.14}$$

It also

$$h_n^k(\tau)=\sum_{l=0}^{L-1}g_l^k(\tau)\exp(-j2\pi(nl)/N),\ n=0,\ldots,N-1 \tag{5.15}$$

$h_0^k(\tau), h_1^k(\tau), \ldots, h_{N-1}^k$ can be computed to (5.16)

$$h_0^k(\tau) = \sum_{l=0}^{L-1} g_l^k(\tau)\exp(-j2\pi((0)l)/N) = \sum_{l=0}^{L-1} g_l^k(\tau)$$

$$h_1^k(\tau) = \sum_{l=0}^{L-1} g_l^k(\tau)\exp(-j2\pi l/N)$$

.

.

.

$$h_{N-1}^k(\tau) = \sum_{l=0}^{L-1} g_l^k(\tau)\exp(-j2\pi(N-1)l/N)$$

Because $G_k(\tau) \xrightarrow{FFT} H_k(\tau)$. Therefore, the equation (5.15) also given as

$$y(\tau) = \sum_{k=0}^{k-1} \sqrt{P_k} H_k(\tau) u_k(\tau) + n(\tau) \tag{5.16}$$

Number of torque is white noise having no changing σ_n^2.

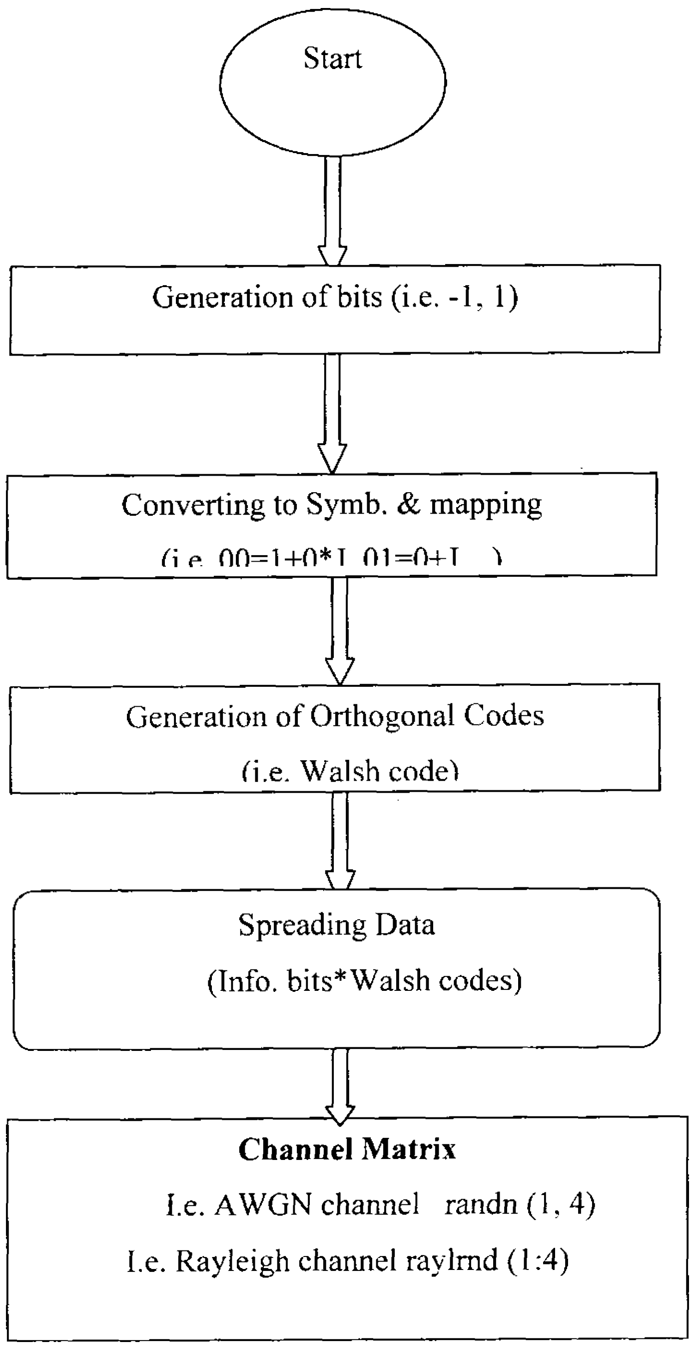
Consider, every user transmits the p[th] data stream. The $M \times 1$ data vector $y_p(\tau) = \left[y_p(\tau), y_{P+p}(\tau), \ldots, y_{P(M-1)+p}(\tau) \right]^T$ corresponding to b_p^k is

$$\begin{aligned} y_p(\tau) &= \sum_{k=0}^{K-1} \sqrt{P_k} C_k h_p^k(\tau) b_p^k(\tau) + n_p(\tau) \\ &= \sum_{k=0}^{K-1} \sqrt{P_k} d_p^k(\tau) b_p^k(\tau) + n_p(\tau) \end{aligned} \tag{5.17}$$

$h_p^k(\tau) = [h_p^k(\tau), h_{P+p}^k(\tau), \ldots, h_{P(M-1)+p}^k(\tau)]^T$ *is channel coefficient on subcarriers*

$C_k = diag\{c_0^k, c_1^k, \ldots, c_{M-1}^k\}$ *is code matrix*, $d_p^k(\tau) = C_k h_p^k(\tau)$ *is the effective signature* of user k and $n_p(\tau)$ is the white Gaussian noise with zero mean and variance .

5.3 Flow Chart of Proposed System



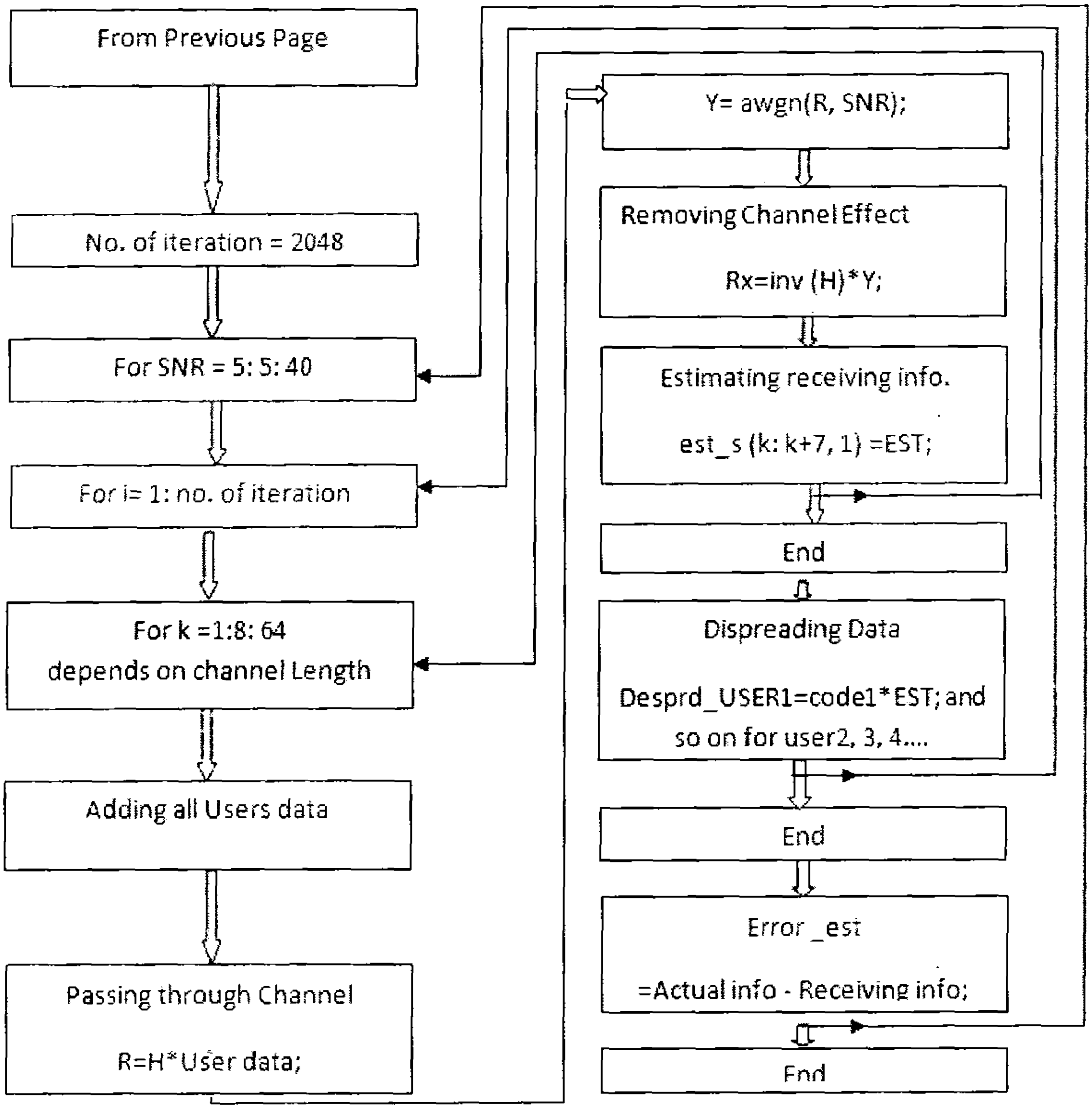


Figure 5. 3 Flow Chart of Proposed System

5.4 MSE Detector

The **Mean Square Error** is an estimator/detector which is one of different ways to calculate the difference b/t the estimated received values and the original values of the quantity being estimated. MSE measures the average of the square of the "error." The error is the amount by which the estimator differs from the amount to be estimated. This difference can occurs due to randomness or may be the estimator doesn't calculate the receive information that could generate a more exact estimate.

$$\varepsilon_x = I_x - \hat{I}_x$$

Where I_x is transmitted source information in x[th] signaling interval and $\hat{I}_x$ is the estimated symbol of that source symbol at the o/p of the equalizer. But if the source symbols I_x are complex valued, then the performance of MSE criterion can be mathematically define as

$$j = |\hat{I}_x|^2 = |I_x - \hat{I}_x|^2$$

Chapter 6
Simulation and Results

6 CHAPTER Simulation and Results

6.1 Introduction

It will explain the simulation & consequences of working which shown designed system in this lesson. Focused on OFDM based CDMA system design and the detection is MSE Based technique, and it is also implementing for comparison programmatically with different channels. This chapter also gives the specific algorithms/technique of this model/system. The simulated result has been implemented in Mat lab 7.3.

Then estimation the consequences give the final result like different arguments such as t, SNR, SER, BER etc.

6.2 Simulation

To check the efficiency of this system, I applied two approaches; one is to fix the users and transmits the information of these fixed users on different number of sub-carrier to check the SER se well as BER. On the other hand, I tried to fix the carriers and make the transmission of different number of users to see the effect of noise on different channels like AWGN channel as well as Rayleigh channel. As the users grow up, the probability of error also differ with the affect of noise.

The simulations help for the comparison among the both techniques. In 1st technique, there is fixed carrier, but we apply it on different user which is implemented on distinct SNR.

Below given figure shown the average SNR versus symbol error rate SER of different user on a specific carrier. The below figure shows the result of AWGN channel affect on different users.

SER Vs SNR at Fixed Carriers # 4 (AWGN Channel)

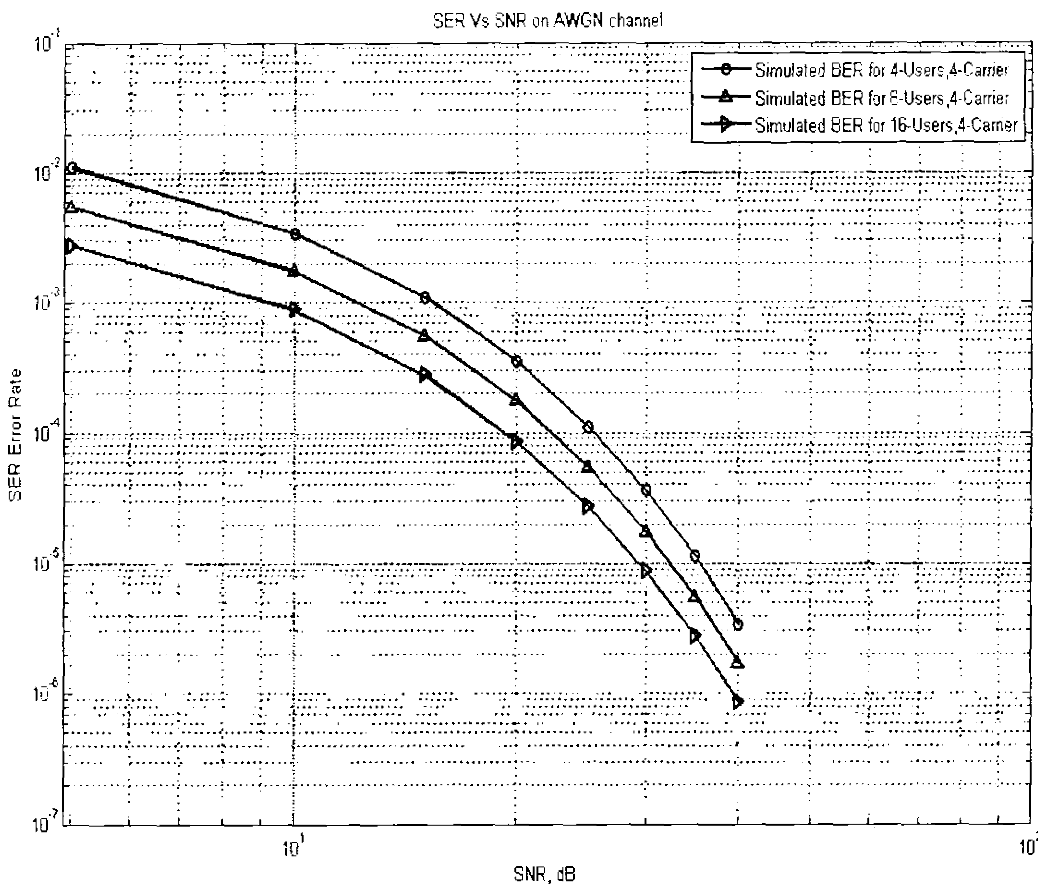


Figure 6. 1 BER Vs SNR at Fixed Carriers # 4

As the above figure clearly shows that I have accommodated the 4, 8 and 16-users at a time on AWGN Channel with length L = 4 and there is clear difference between 4-user and 8-user. and if we compare the result of 4-user with 16-user there is difference of error in log format is 10^{-6} to $10^{-6.7}$ at fixed SNR = $10^{1.6}$ or at 40db. Similarly, you can see at different SNR, the probability of error is going down and down with the increasing of users. There is the result of same procedure at Rayleigh channel. See the below figure.

SER Vs SNR at Fixed Carriers # 4 (Rayleigh Channel)

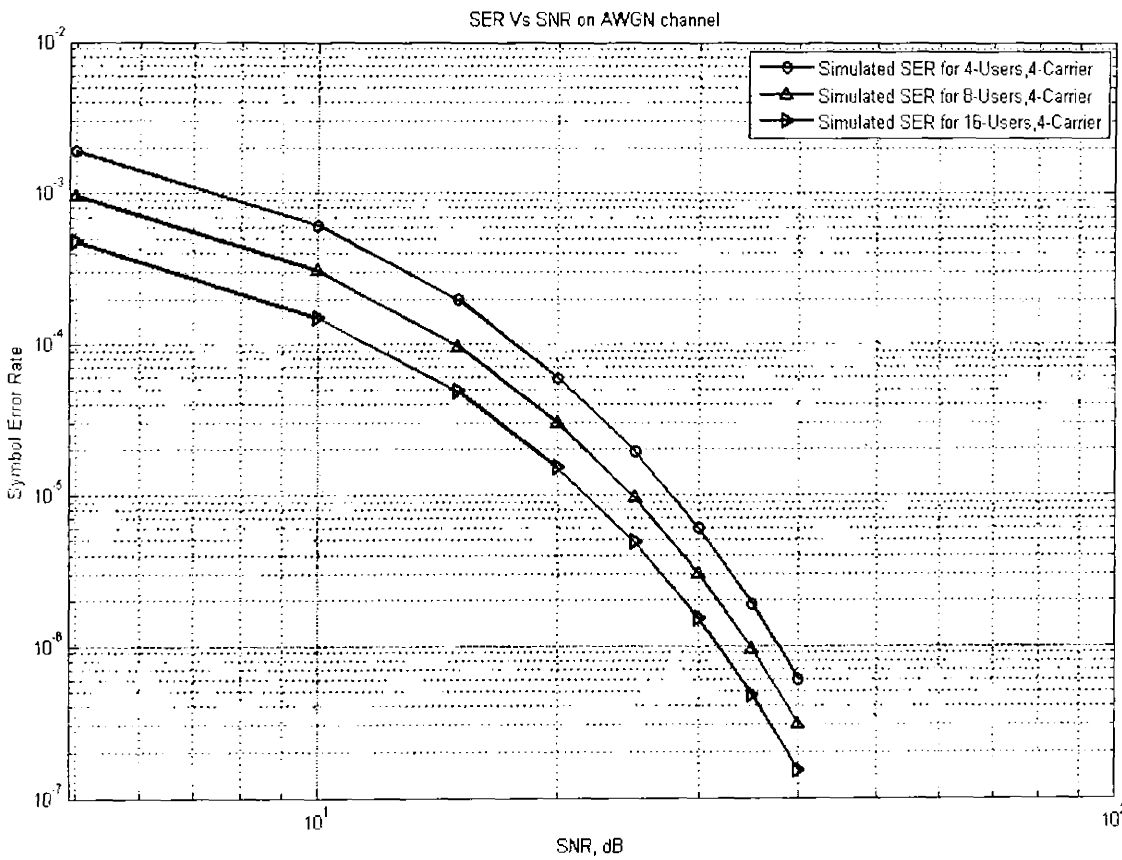


Figure 6. 2 SER Vs SNR at Fixed Carriers # 4

As the above figure shows, when the numbers of users are less or equal to number of carrier, it gives not fruitful result. But as I increased the number of users, it gives the better result. It is due to my proposed technique and algorithm. When the number of user increased as compare to number of carrier, the probability of error also decrease as shown in fig.

There is also a great difference when we compare the result of AWGN channel with Rayleigh Channel. Rayleigh Channel gives the better result with my proposed algorithm. The probability of error is very minute with Rayleigh Channel as compare to AWGN channel and the difference between these two channels is clearly showed in graphs.

Now we see the simulated result of 2nd experiment. Here we fixed 8 carriers/sub channels for transmission, and try to pass the signal/information of 4-user, 8-user, 16-user, 32-user and 64-user. The figure is given below

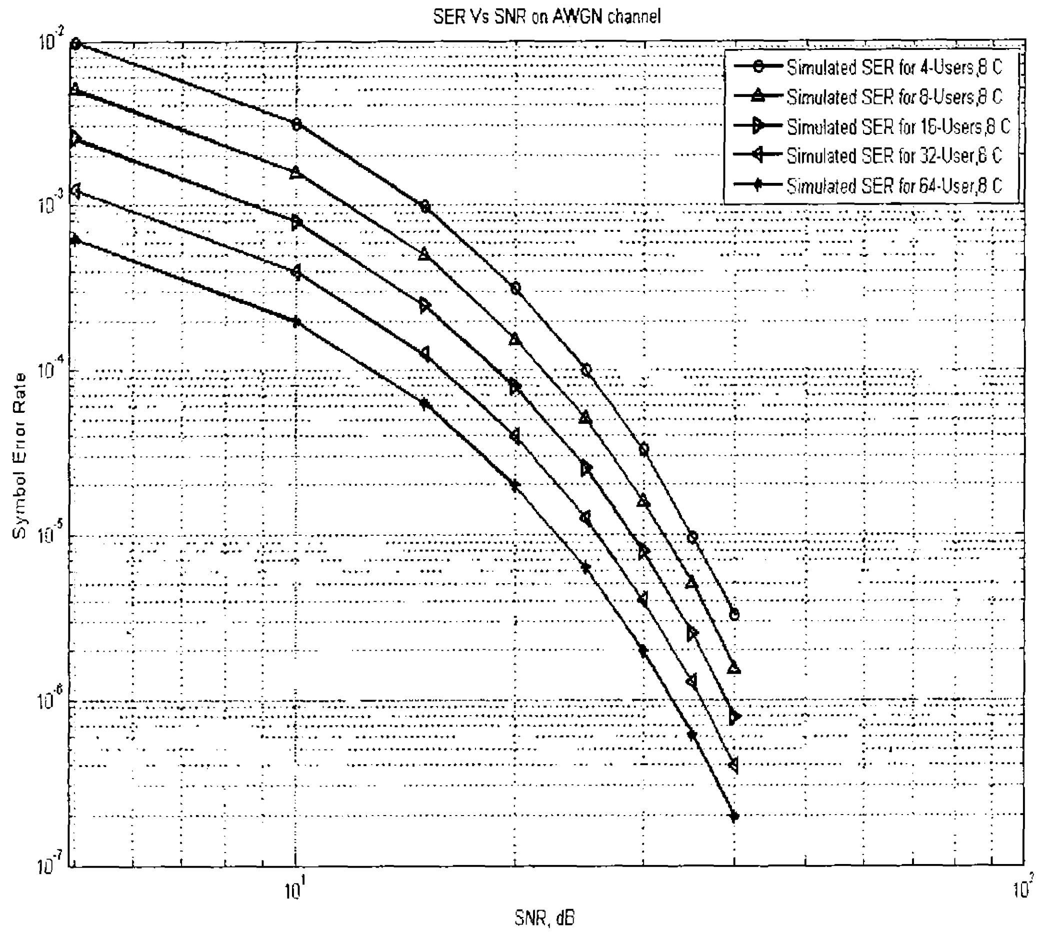


Figure 6. 3 SER Vs SNR at Fixed Carriers # 8

As the above figure clearly shows that I have accommodated the 4, 8, 16, 32 and 64-users at a time on AWGN Channel with length L = 8 and there is clear difference between 4-user, 8-user and up to 64-user, and if we compare the result of 4-user with 16-user or 4-user with 64-user, there is difference of error is $\mathbf{10^{-5.7}}$ to $\mathbf{10^{-6.9}}$ at fixed SNR = 40db. Similarly, you can see at different SNR, the probability of error is going down and down with the increasing of users. There is the result of same procedure at Rayleigh channel.

The graph with Rayleigh channel is given below, see the figure.

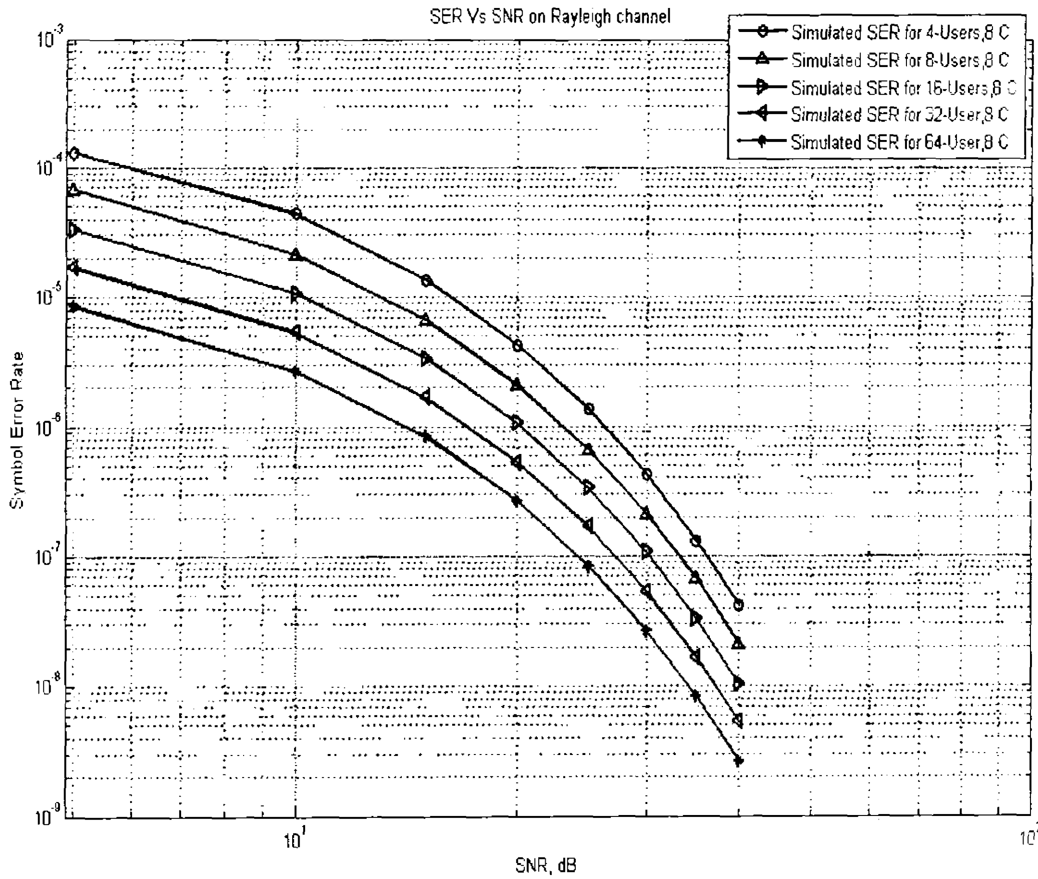


Figure 6. 4 SER Vs SNR at Fixed Carriers # 8

In above figure, when the numbers of users are less or equal to number of carrier, it gives not good results. But as I increased the number of users, it gives the better result. It is due to my proposed technique and algorithm. When the number of user increased as compare to number of carrier, the probability of error also decrease as shown in fig.

There is also a great difference when we compare the result of AWGN channel with Rayleigh Channel. Rayleigh Channel gives the better result with my proposed algorithm. The probability of error is very minute with Rayleigh Channel as compare to AWGN channel and the difference between these two channels is clearly showed in graphs.

Similarly, we see the simulated result of 3rd experiment. Here we fixed 16 carriers /sub channels for transmission, and try to pass the signal/information of 4-user, 8-user, 16-user, 32-user and 64-user. The figure is given below

SER Vs SNR at Fixed Carriers # 16 (AWGN Channel)

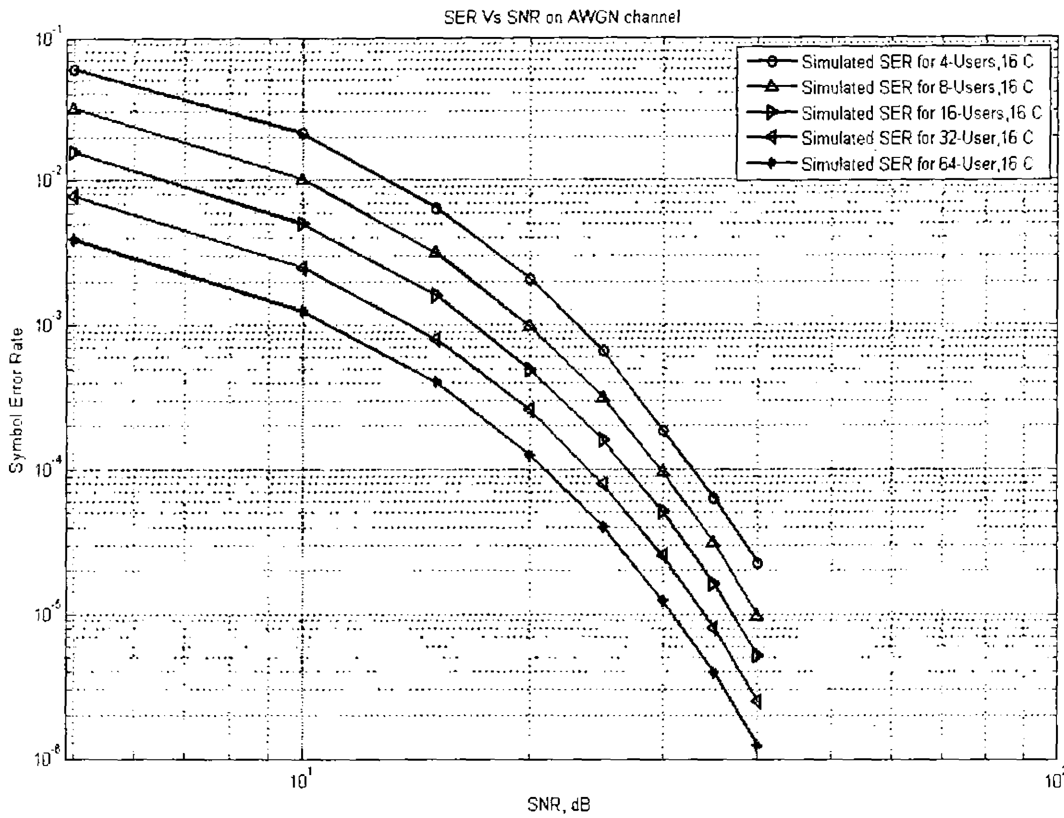


Figure 6. 5 SER Vs SNR at Fixed Carriers # 16

As the above figure clearly shows that I have accommodated the 4, 8, 16, 32 and 64-users at a time on AWGN Channel with length L = 16 and there is clear difference between 4-user, 8-user and up to 64-user, and if we compare the result of 4-user with 16-user or 4-user with 64-user, there is difference of error is $\mathbf{10^{-4.7}}$ to $\mathbf{10^{-5.95}}$ at fixed SNR = 40db. Similarly, you can see at different SNR, the probability of error is going down and down with the increasing of users. There is the result of same procedure at Rayleigh channel.

See the below figure.

SER Vs SNR at Fixed Carriers # 16 (Rayleigh Channel)

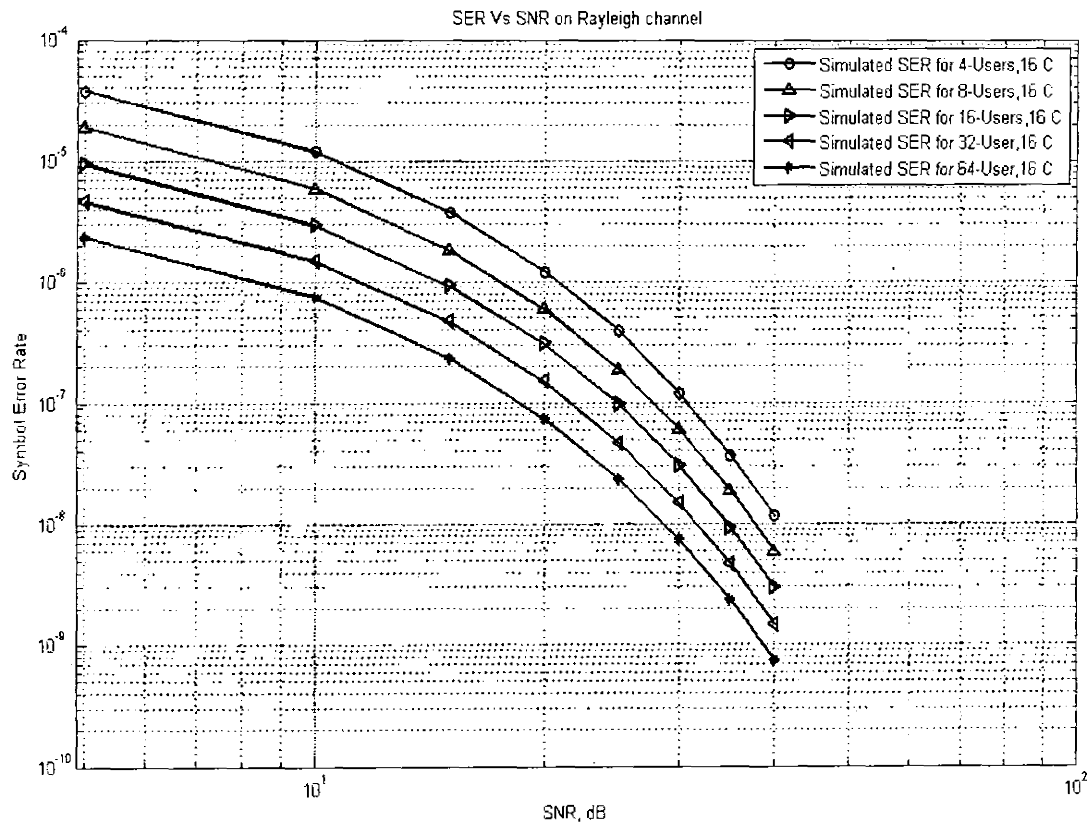


Figure 6. 6 SER Vs SNR at Fixed Carriers # 16

As the above figure shows, when the numbers of users are less or equal to number of carrier, it gives not fruitful result. But as I increased the number of users, it gives the better result. It is due to my proposed technique and algorithm. When the number of user increased as compare to number of carrier, the probability of error also decrease as shown in fig.

There is also a great difference when we compare the result of AWGN channel with Rayleigh Channel. Rayleigh Channel gives the better result with my proposed algorithm. The probability of error is very minute with Rayleigh Channel as compare to AWGN channel and the difference between these two channels is clearly showed in graphs.

Similarly, we see the simulated result of 4nd experiment. Here we fixed 32 carriers /sub channels for transmission, and try to pass the signal/information of 4-user, 8-user, 16-user, 32-user and 64-user. The figure is given below,

SER Vs SNR at Fixed Carriers # 32 (AWGN Channel)

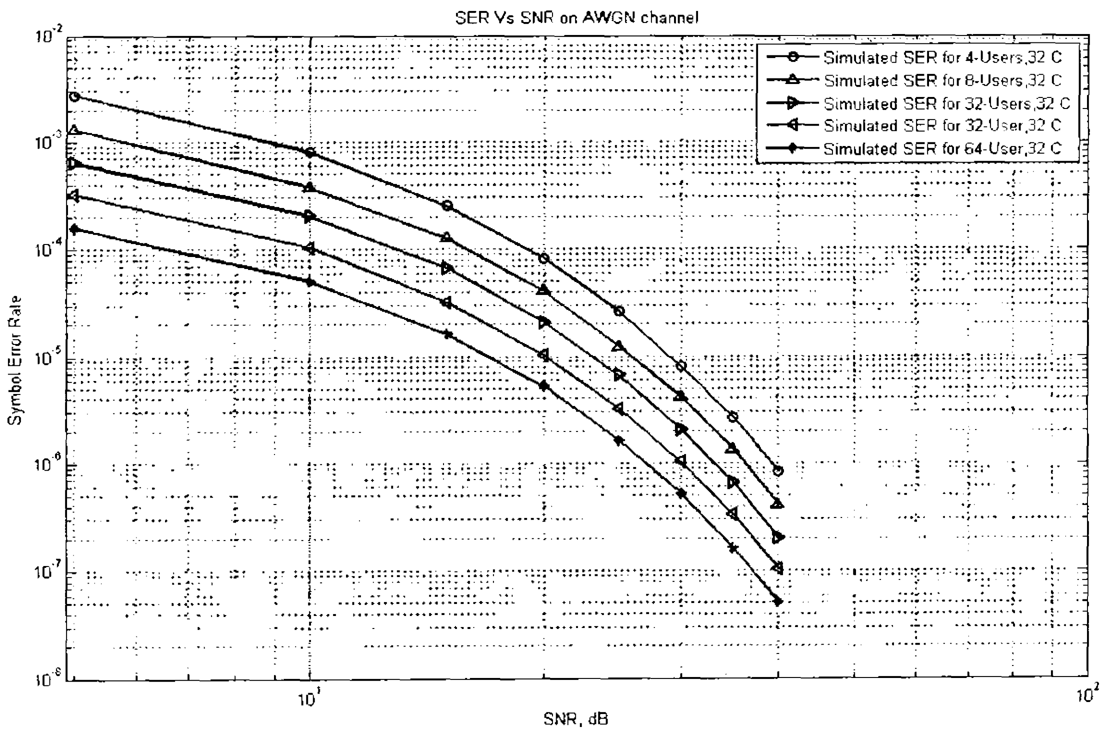


Figure 6. 7 SER Vs SNR at Fixed Carriers # 32

As the above figure clearly shows that I have accommodated the 4, 8, 16, 32 and 64-users at a time on AWGN Channel with length L = 32 and there is clear difference between 4-user, 8-user and up to 64-user, and if we compare the result of 4-user with 16-user or 4-user with 64-user, there is difference of error is $\mathbf{10^{-6.2}}$ to $\mathbf{10^{-7.4}}$ at fixed SNR = 40db. Similarly, you can see at different SNR, the probability of error is going down and down with the increasing of users. There is the result of same procedure at Rayleigh channel. See the below figure.

SER Vs SNR at Fixed Carriers # 32 (Rayleigh Channel)

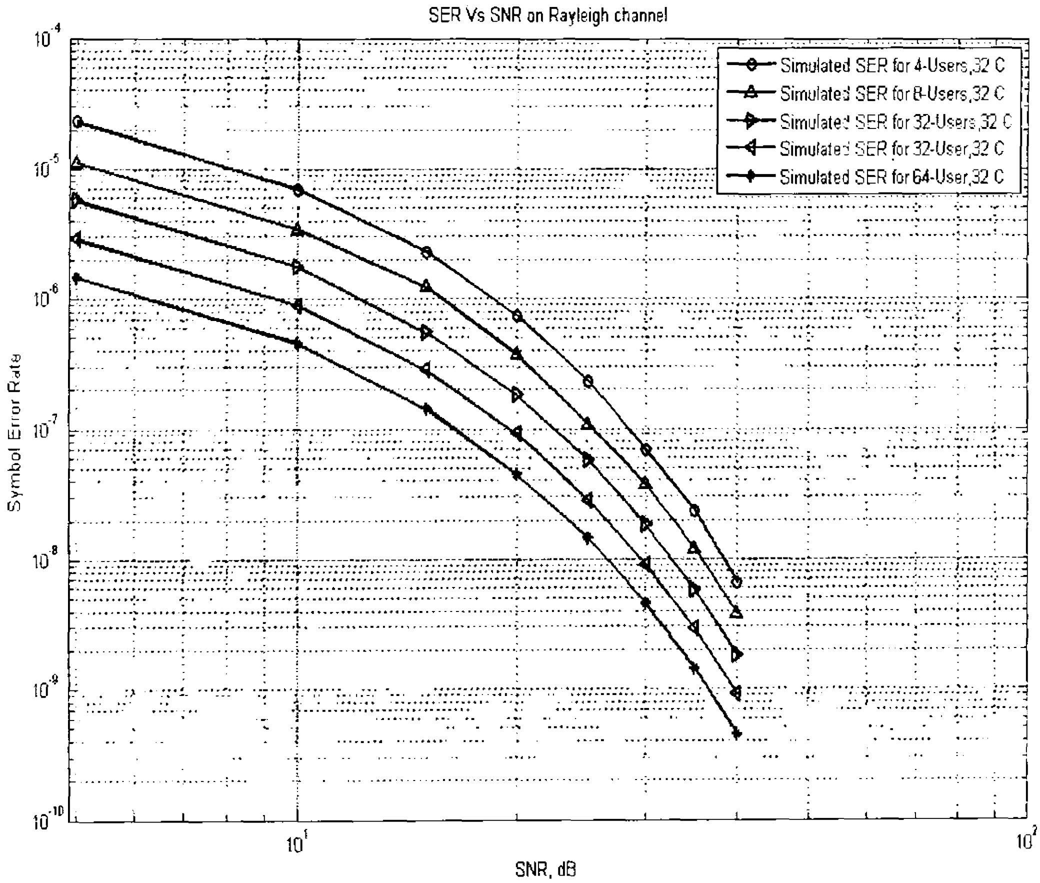


Figure 6. 8 SER Vs SNR at Fixed Carriers # 32

As the above figure shows, when the numbers of users are less or equal to number of carrier, it gives not fruitful result. But as I increased the number of users, it gives the better result. It is due to my proposed technique and algorithm. When the number of user increased as compare to number of carrier, the probability of error also decrease as shown in fig.

There is also a great difference when we compare the result of AWGN channel with Rayleigh Channel. Rayleigh Channel gives the better result with my proposed algorithm. The probability of error is very minute with Rayleigh Channel as compare to AWGN channel and the difference between these two channels is clearly showed in graphs.

Similarly, we can simulate the result of 5nd experiment. Here we fixed 64 carriers /sub channels for transmission, and try to pass the signal/information of 4-user, 8-user, 16-user, 32-user and 64-user.

2nd Technique:

In 2nd technique, there are a fix number of users, but the carrier are different like a 4-users will pass through a 4-carrier,8-carrier,16-carrier,32-carrier and 64-carrier too,

Below given figure shown the average SNR versus symbol error rate SER of specific users on a different carriers. The below figure shows the result of channel affect on a distinct users.

SER Vs SNR at Fixed User # 4

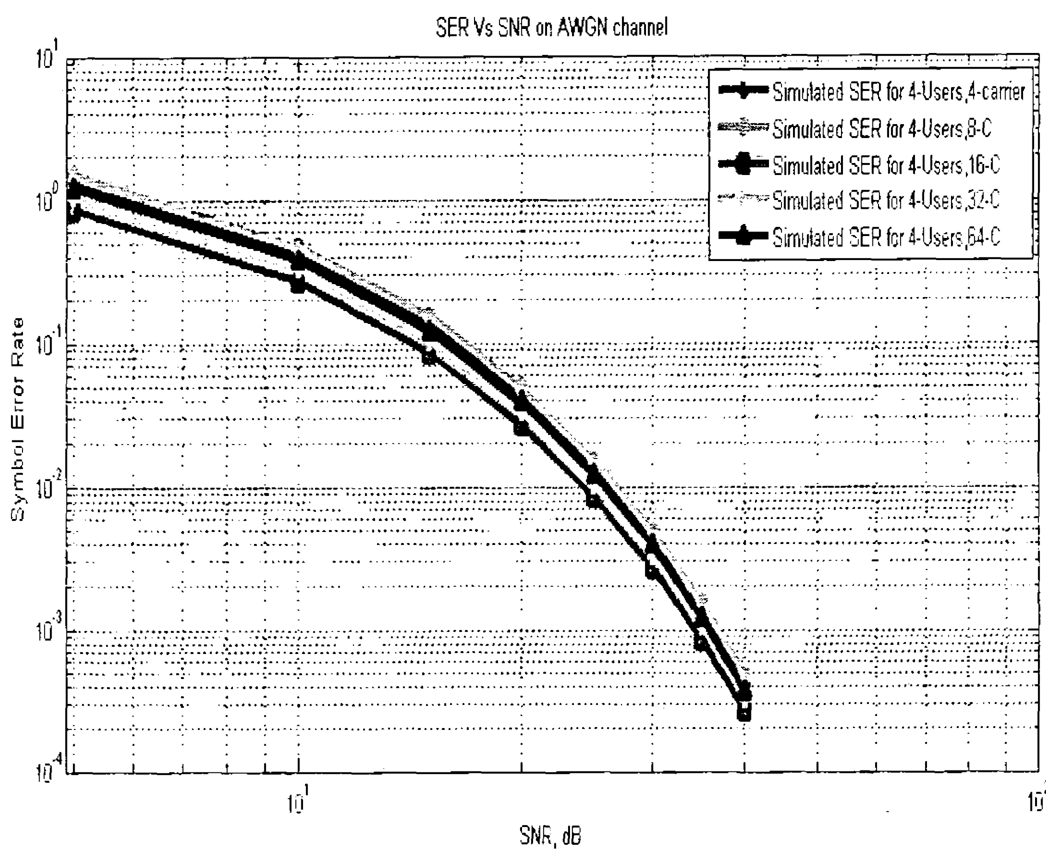


Figure 6. 9 SER Vs SNR at Fixed User # 4

Here, I tried to pass the fixed user with different carrier/channel length like 4, 8, 16, 32 and 64-Carriers at a time on AWGN Channel and there is not a big difference of probability of error between different carriers. If we compare the result of passing the signal of 4-user with different carrier like 4-carrier,8-carrier,16-carrier or 32-carrier, there is difference of error is very low with respect to different SNR. Similarly, you can see at different SNR, the probability of error is common with the increasing of carriers. There is the result of same procedure at Rayleigh channel. See the below figure.

SER Vs SNR at Fixed User # 4 with Rayleigh Channel

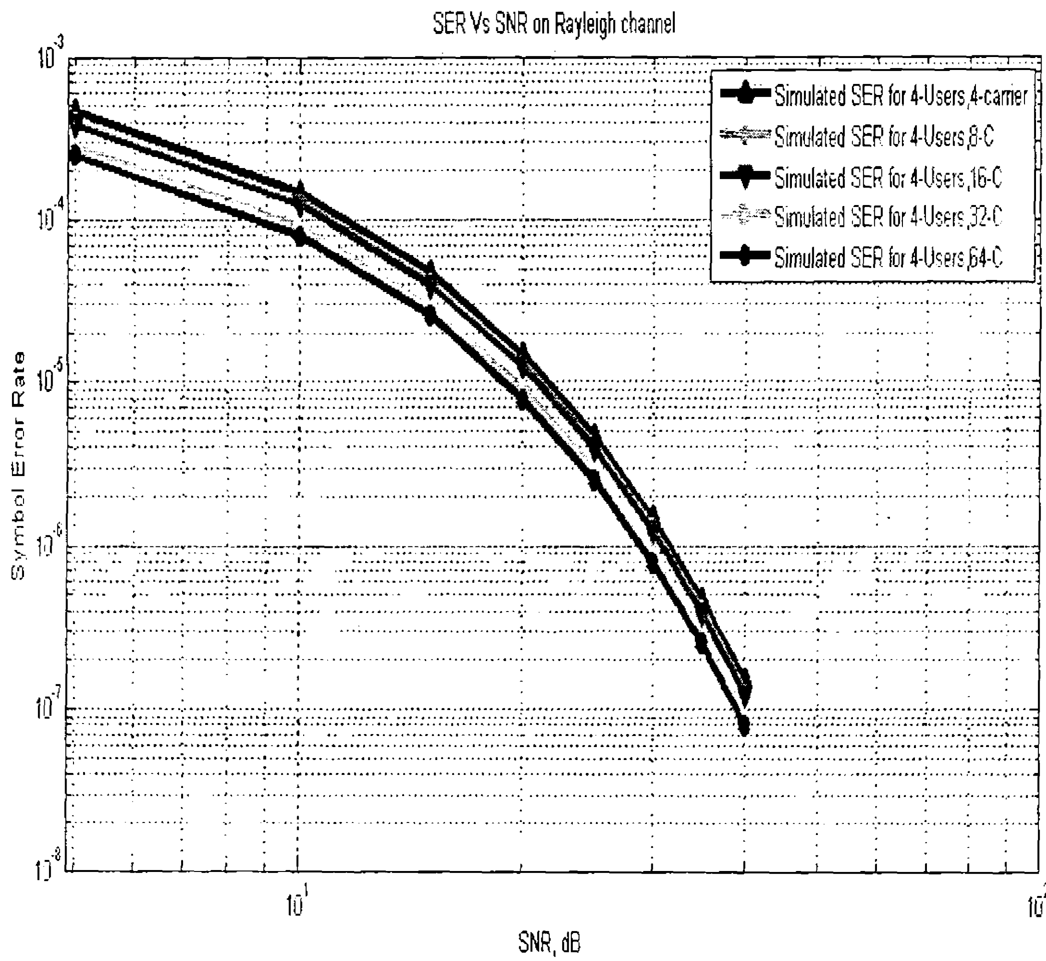


Figure 6. 10 SER Vs SNR at Fixed User # 4

As above figure shows, that when we fixed the number of users and pass the signal of these users at different carrier length, there is very minute difference of error between carriers at distinct SNR.

There is also a great difference when we compare the result of AWGN channel with Rayleigh Channel. Rayleigh Channel gives the better result with my proposed algorithm. The probability of error is very minute with Rayleigh Channel as compare to AWGN channel and the difference between these two channels is clearly showed in graphs.

Similarly, we can see the result of other users like a specific 8-user, 16-user, 32-user and 64-user on a different sub channels.

SER Vs SNR at Fixed User # 8 With AWGN Channel

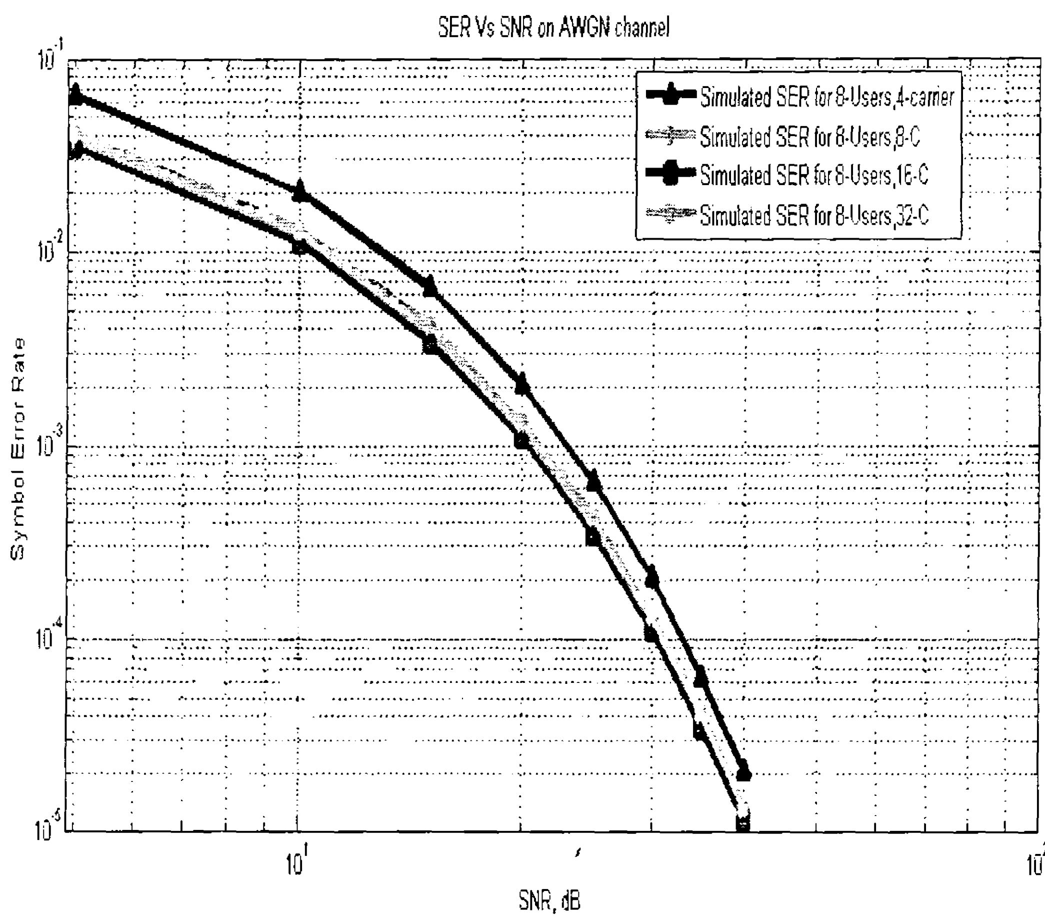


Figure 6. 11 SER Vs SNR at Fixed User # 8

Here. I tried to pass the fixed user with different carrier/channel length like 4. 8. 16. 32 and 64-Carriers at a time on AWGN Channel and there is not a big difference of probability of error between different carriers. If we compare the result of passing the signal of 8-user with different carrier like 4-carrier,8-carrier,16-carrier or 32-carrier, there is difference of error is very low with respect to different SNR. Similarly, you can see at different SNR. the probability of error is common with the increasing of carriers. There is the result of same procedure at Rayleigh channel.

See the below figure.

SER Vs SNR at Fixed User # 8 With Rayleigh Channel

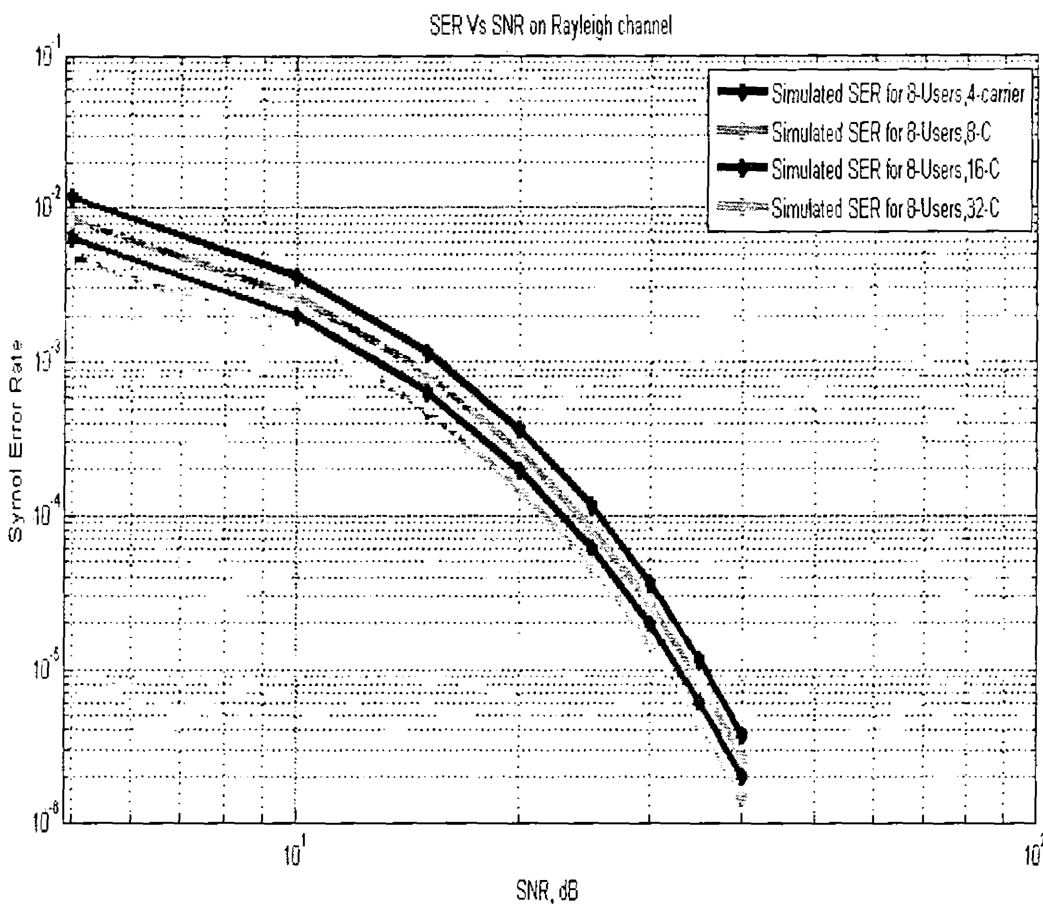


Figure 6. 12 SER Vs SNR at Fixed User # 8

As above figure shows, that when we fixed the number of users and pass the signal of these users at different carrier length, there is very minute difference of error between carriers at distinct SNR.

There is also a great difference when we compare the result of AWGN channel with Rayleigh Channel. Rayleigh Channel gives the better result with my proposed algorithm. The probability of error is very minute with Rayleigh Channel as compare to AWGN channel and the difference between these two channels is clearly showed in graphs.

Chapter 7

Conclusion and Future work

7 Chapter Conclusion and Future Work

7.1 Conclusion

In this work we have employed the OFDM based CDMA system to provide the enhanced performance. OFDM is backbone of WiMax and is power full candidate of future communication. It has gained popularity with the help of DSP chips to applied in software. Similarly CDMA is a technique to provide the multiple access based on unique codes assigned to different users. By combing the above two technique we are able to communicate multiple of the users provided by each individual that is in case of MIMO systems the data of each antenna can be separated by using CDMA, which is problem of source separation. OFDM is used subsequently to retrieve the data of each user on a single antenna. In other words the CDMA converts the MIMO problems to SISO where as OFDM is used to fight out ISI at SISO level.

The simulation results are evident for the validity of the proposed idea. The simulations have been carried out at diversified channels with different number of antennas and different code lengths.

7.2 Future Work

In future, I will try to make the adaptive OFDM based CDMA system with the help of Channel State Information Enhanced for the downlink in a frequency selective fading environment. The main feature of the system will be the optimization of resources in a downlink situation. it will provide flexible and high date rate in the downlink for multimedia applications.

<u>The main Objective will be:</u>

- ✓ Optimization of Resource allocation.
- ✓ Minimizing the BER Error rate.
- ✓ To reduce the probability of blocking of the system.
- ✓ Coverage area may be improved in a cellular system by using the proposed algorithm.

The simulations studies will be performed under various cases and from the simulation by the results we shall be in posture improve the resource allocation. Hence, the blocking probability of the system will be reduced. Also the coverage area will try to be improved in a cellular system by using proposed algorithm. Even in adverse condition. the bandwidth will tried to be maximized and significant BER is expected to be achieved.

8 References

[1] Saunders S.R. (1999) ***Antennas and Propagation for Wireless Communication Systems.*** John Wiley & Sons, New York, 426 p.

[2] Cavers J.K. (2000) ***Mobile Channel Characteristics***. Kluwer Academics Publishers.

[3] Cimini L.J. (1985) ***Analysis and Simulation of a Digital mobile Channel Using Orthogonal Frequency Division Multiplexing.*** IEEE Transactions on Communications, pp. 665–675.

[4] Bingham J.A.C. (1990) ***Multicarrier Modulation for Data Transmission:*** AnIdea Whose Time Has Come. IEEE Communications Magazine, pp. 5–14.

[5] Nee R. & Prasad R. (2000) ***OFDM Wireless Multimedia Communications***. Artech House, London, 260 p.

[6] Viterbi A.J. (1995) ***CDMA : Principles of Spread Spectrum Communication*** Addison-Wesley Wireless Communications.

[7] Yee N., J-P.Linnartz & Fettweis G. (1993) ***Multi-Carrier CDMA in Indoor Wireless Radio Networks.*** In: Proceedings of the IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), pp. 109–113

[8] Hara S. & Prasad R. (1997) ***Overview of Multicarrier CDMA. IEEE Communications Magazine,*** pp. 126–133.

[9] Gui X.& Ng T.S. (1999) ***Performance of Asynchronous Orthogonal Multicarrier CDMA System in Frequency Selective Fading Channel.*** In: IEEE Transactions on Communications, Vol. 47, pp. 1084–1091.

[10] Hara S. & Prasad R. (1999) ***Design and Performance of Multicarrier CDMA System in Frequency-Selective Rayleigh Fading Channels.*** IEEE Transactions non Vehicular Technology,pp-1584–1595

[11] Flikkema P.G. (1997) ***Spread-Spectrum Techniques for Wireless Communication*** .IEEE Signal Processing Magazine, pp. 26–36.

9 Appendix – A

9.1 Simulation codes

```
%%%%   OFDM based CDMA system for 4- users in AWGN channel
clear;
clc;
user=4;        % Number of Users

% -----------------Generation of Walsh code------------------------------

n =4;                        %Number of  Data Sub-Carriers
walsh=hadamard(n);
code1=walsh(1,:);            %Taking 2nd row of walsh code for User1
code2=walsh(2,:);            %Taking 4rd row of walsh code for User2
code3=walsh(3,:);            %Taking 6nd row of walsh code for User3
code4=walsh(4,:);            %Taking 8rd row of walsh code for User4

%%*****************generating the Channel martix ********

%L=raylrnd(1:4);       %%generating the L random numbers i,e (L=4)
L=randn(1,4);          %%generating the L random numbers i,e (L=4)
h=fft(L,4);            %%taking its k-bits fft(L)=h[k]
C = gallery('circul',h);        %%making the circular matrix
H=fft(eye(4)*C*ifft(eye(4))); %%applying the FFT & IFFT on Channel Matrix
H1=inv(H);                      %%Taking the inverse of Channel matrix
% -----------------Generating data for User1------------------------------

M=2^12                        %%bits length declaring [4096]
TrDataBit = randint(1,M);     %%[0 1] bits

            % QAM Modulation of Encoded Bits

    TrDataMod1 = null(1,M/2);

    ii=1;
    for n=1:2:M
      if TrDataBit(n)==0 & TrDataBit(n+1)==0
         temp= 1 + (0*j);
      elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
         temp=  0 + j;
      elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
         temp= 0 - j;
      elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
         temp= -1 + 0*j ;
      end
         TrDataMod1(1,ii)=temp;
```

```
            ii=ii+1;
        end

%         scatterplot(TrDataMod); %%graphicall represntation of QAM signal symbol
msg1=TrDataMod1;               %%save the data symbol to msg1
user1=zeros(2048,4);           %%for user1 making the vector of k bits where [k=Nx4]
for i=1:1:2048                 %%This loop will go to 2048 with the difference 1
  user1(i,1:4)=(TrDataMod1(i))'*code1;%% spreading data
end
% -----------------Generating data for User2-----------------------------
M=2^12           %%length declaring [4096]
N=2;
TrDataBit2 = randint(1,M,N); %%[0 1]bits

%----------------- QPSK Modulation of Encoded Bits----------------------

        TrDataMod2 = null(1,M/2);

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
            temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
            temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
            TrDataMod2(1,ii)=temp;
            ii=ii+1;
        end

%         scatterplot(TrDataMod2);
msg2=TrDataMod2;
user2=zeros(2048,4);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
  user2(i,1:4)=(TrDataMod2(i))'*code2;
end

% -----------------Generating data for User3-----------------------------

M=2^12           %%length declaring [4096]
N=2;
TrDataBit = randint(1,M,N); %%[0 1]bits

%----------------- QPSK Modulation of Encoded Bits----------------------
```

```
        TrDataMod3 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
             temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
             temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
             temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
             temp= -1 + 0*j ;
          end
             TrDataMod3(1,ii)=temp;
             ii=ii+1;
        end

%          scatterplot(TrDataMod2);
msg3=TrDataMod3;
user3=zeros(2048,4);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user3(i,1:4)=(TrDataMod3(i))'*code3;
end

% -----------------Generating data for User4-----------------------------

M=2^12          %%length declaring [4096]
N=2;
TrDataBit = randint(1,M,N); %%[0 1]bits

%----------------- QAM Modulation of Encoded Bits-----------------------

        TrDataMod4 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
             temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
             temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
             temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
             temp= -1 + 0*j ;
          end
             TrDataMod4(1,ii)=temp;
             ii=ii+1;
        end
```

```
%          scatterplot(TrDataMod2);
msg4=TrDataMod4;
user4=zeros(2048,4);  %%for user1 making the vector of k bits where [k=Nx4]
for i=1:1:2048
   user4(i,1:4)=(TrDataMod4(i))'*code4;
end
num_iteration=2048;
j=1;
for SNR=5:5:40              %%Singal to Noise ratio is putting here
   for i=1:num_iteration   %% this loop will go to maximium num_iteration "(2048)"

%---------------------Adding data for Transmission of All User-----------

tx_user=user1(i,:)+user2(i,:)+user3(i,:)+user4(i,:);

% %----------------transmitting on flat fading channel-------------------

        R=H*tx_user';
        y=awgn(R,SNR);
        est_s=H1*y;

% %----------------DeSpreading Users-----------------------------

         Despdata_user1=(code1*(est_s))/4;
         Despdata_user2=(code2*(est_s))/4;
         Despdata_user3=(code3*(est_s))/4;
         Despdata_user4=(code4*(est_s))/4;

         RxDataMod1(1,i)=Despdata_user1;
         RxDataMod2(1,i)=Despdata_user2;
         RxDataMod3(1,i)=Despdata_user3;
         RxDataMod4(1,i)=Despdata_user4;

    end
    %***************Finding                                          symbol
error*****************************************

        error_u1(1,j)=(((msg1-RxDataMod1))*((msg1-RxDataMod1))')/2048;
        error_u2(1,j)=(((msg2-RxDataMod2))*((msg2-RxDataMod2))')/2048;
        error_u3(1,j)=(((msg3-RxDataMod3))*((msg3-RxDataMod3))')/2048;
        error_u4(1,j)=(((msg4-RxDataMod4))*((msg4-RxDataMod4))')/2048;
    symerr_4(1,j)=sum(error_u1(1,j)+error_u2(1,j)+error_u3(1,j)+error_u4(1,j))/4;

            j=j+1;
end

%
```

```
%%%   OFDM based-CDMA system for 8- users in AWGN cannel

users=8;          % Number of Users

% -----------------Generation of Wals code------------------------------

n =8;                        %Number of  Data Sub-Carriers
walsh=hadamard(n);
code1=walsh(1,:);            %Taking 1nd row of wals code for User1
code2=walsh(2,:);            %Taking 2rd row of wals code for User2
code3=walsh(3,:);            %Taking 3nd row of wals code for User3
code4=walsh(4,:);            %Taking 4rd row of wals code for User4
code5=walsh(5,:);            %Taking 5nd row of walsh code for User5
code6=walsh(6,:);            %Taking 6rd row of walsh code for User6
code7=walsh(7,:);            %Taking 7nd row of walsh code for User7
code8=walsh(8,:);            %Taking 8rd row of walsh code for User8

% -----------------Generating data for User1------------------------------

msg1=TrDataMod1;
user1=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user1(i,1:8)=(TrDataMod1(i))'*code1;
end
% -----------------Generating data for User2------------------------------
msg2=TrDataMod2;
user2=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user2(i,1:8)=(TrDataMod2(i))'*code2;
end
% -----------------Generating data for User3------------------------------
msg3=TrDataMod3;
user3=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user3(i,1:8)=(TrDataMod3(i))'*code3;
end

% -----------------Generating data for User4------------------------------
msg4=TrDataMod4;
user4=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user4(i,1:8)=(TrDataMod4(i))'*code4;
end
% -----------------Generating data for User5------------------------------

M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits
```

```
%----------------- QAM Modulation of Encoded Bits----------------------

        TrDataMod5 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
            temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
            temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
            TrDataMod5(1,ii)=temp;
            ii=ii+1;
        end

%           scatterplot(TrDataMod2);
msg5=TrDataMod5;
user5=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user5(i,1:8)=(TrDataMod5(i))'*code5;
end
% -----------------Generating data for User6-----------------------------
M=2^12              %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%----------------- QAM Modulation of Encoded Bits----------------------

        TrDataMod6 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
            temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
            temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
            TrDataMod6(1,ii)=temp;
            ii=ii+1;
        end
```

```
%          scatterplot(TrDataMod2);
msg6=TrDataMod6;
user6=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user6(i,1:8)=(TrDataMod6(i))'*code6;
end
% ------------------Generating data for User7------------------------------
M=2^12             %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QPSK Modulation of Encoded Bits-----------------------

        TrDataMod7 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
           if TrDataBit(n)==0 & TrDataBit(n+1)==0
              temp= 1 + (0*j);
           elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
              temp=  0 + j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
              temp= 0 - j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
              temp= -1 + 0*j ;
           end
              TrDataMod7(1,ii)=temp;
              ii=ii+1;
        end

%          scatterplot(TrDataMod2);
msg7=TrDataMod7;
user7=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user7(i,1:8)=(TrDataMod7(i))'*code7;
end
% ------------------Generating data for User8------------------------------
M=2^12             %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits-----------------------

        TrDataMod8 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
           if TrDataBit(n)==0 & TrDataBit(n+1)==0
              temp= 1 + (0*j);
           elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
```

```
            temp= 0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
            TrDataMod8(1,ii)=temp;
            ii=ii+1;
        end

%           scatterplot(TrDataMod2);
msg8=TrDataMod8;
user8=zeros(2048,8);  %%for user1 making the vector of k bits where [k=1x8]
for i=1:1:2048
   user8(i,1:8)=(TrDataMod8(i))'*code8;
end

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

num_iteration=2048;
est_s=0;
j=1;
for SNR=5:5:40
   for i=1:num_iteration

%---------------------Adding data for Transmission of All User-----------
        for k=1:4:8

tx_user=user1(i,k:k+3)+user2(i,k:k+3)+user3(i,k:k+3)+user4(i,k:k+3)+user5(i,k:k+3)+us
er6(i,k:k+3)+user7(i,k:k+3)+user8(i,k:k+3);
% %----------------transmitting on flat fading channel-------------------
         R=H*tx_user';
         y=awgn(R,SNR);
         est_s_4=H1*y;
        est_s(k:k+3,1)=est_s_4;
        end
 % %----------------DeSpreading Users-----------------------------

          Despdata_user1=(code1*(est_s))/8;
          Despdata_user2=(code2*(est_s))/8;
          Despdata_user3=(code3*(est_s))/8;
          Despdata_user4=(code4*(est_s))/8;
          Despdata_user5=(code5*(est_s))/8;
          Despdata_user6=(code6*(est_s))/8;
          Despdata_user7=(code7*(est_s))/8;
          Despdata_user8=(code8*(est_s))/8;

          RxDataMod11(1,i)=Despdata_user1;
```

```
        RxDataMod22(1,i)=Despdata_user2;
        RxDataMod33(1,i)=Despdata_user3;
        RxDataMod44(1,i)=Despdata_user4;
        RxDataMod55(1,i)=Despdata_user5;
        RxDataMod66(1,i)=Despdata_user6;
        RxDataMod77(1,i)=Despdata_user7;
        RxDataMod88(1,i)=Despdata_user8;

    end
    %**************symbol error****************************************

      error_u1(1,j)=(((msg1-RxDataMod11))*((msg1-RxDataMod11))')/2048;
      error_u2(1,j)=(((msg2-RxDataMod22))*((msg2-RxDataMod22))')/2048;
      error_u3(1,j)=(((msg3-RxDataMod33))*((msg3-RxDataMod33))')/2048;
      error_u4(1,j)=(((msg4-RxDataMod44))*((msg4-RxDataMod44))')/2048;
      error_u5(1,j)=(((msg5-RxDataMod55))*((msg5-RxDataMod55))')/2048;
      error_u6(1,j)=(((msg6-RxDataMod66))*((msg6-RxDataMod66))')/2048;
      error_u7(1,j)=(((msg7-RxDataMod77))*((msg7-RxDataMod77))')/2048;
      error_u8(1,j)=(((msg8-RxDataMod88))*((msg8-RxDataMod88))')/2048;


symerr_8(1,j)=sum(error_u1(1,j)+error_u2(1,j)+error_u3(1,j)+error_u4(1,j)+error_u5(1,j)
+error_u6(1,j)+error_u7(1,j)+error_u8(1,j))/8;

          j=j+1;
end

% %%%%   OFDM based CDMA system for 16-users in AWGN channel

user=16;        % Number of Users

% ----------------Generation of Walsh code----------------------------

n =16;                     %Number of  Data Sub-Carriers
walsh=hadamard(n);
code1=walsh(1,:);            %Taking 1st  row of walsh code for User1
code2=walsh(2,:);            %Taking 2nd  row of walsh code for User2
code3=walsh(3,:);            %Taking 3rd  row of walsh code for User3
code4=walsh(4,:);            %Taking 4th  row of walsh code for User4
code5=walsh(5,:);            %Taking 5th  row of walsh code for User5
code6=walsh(6,:);            %Taking 6th  row of walsh code for User6
code7=walsh(7,:);            %Taking 7th row of walsh code for User7
code8=walsh(8,:);            %Taking 8th  row of walsh code for User8
code9=walsh(9,:);            %Taking 9th  row of walsh code for User9
code10=walsh(10,:);           %Taking 10th  row of walsh code for User10
code11=walsh(11,:);           %Taking 11th  row of walsh code for User11
code12=walsh(12,:);           %Taking 12th row of walsh code for User12
code13=walsh(13,:);           %Taking 13th  row of walsh code for User13
```

```
code14=walsh(14,:);          %Taking 14th row of walsh code for User14
code15=walsh(15,:);          %Taking 15th row of walsh code for User15
code16=walsh(16,:);          %Taking 16th row of walsh code for User16

% ------------------Generating data for User1------------------------------

msg1=TrDataMod1;
user1=zeros(2048,16); %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user1(i,1:16)=(TrDataMod1(i))'*code1;
end
% ------------------Generating data for User2------------------------------
msg2=TrDataMod2;
user2=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user2(i,1:16)=(TrDataMod2(i))'*code2;
end

% ------------------Generating data for User3------------------------------
msg3=TrDataMod3;
user3=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user3(i,1:16)=(TrDataMod3(i))'*code3;
end

% ------------------Generating data for User4------------------------------
msg4=TrDataMod4;
user4=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user4(i,1:16)=(TrDataMod4(i))'*code4;
end
% ------------------Generating data for User5------------------------------
msg5=TrDataMod5;
user5=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user5(i,1:16)=(TrDataMod5(i))'*code5;
end
% ------------------Generating data for User6------------------------------
msg6=TrDataMod6;
user6=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user6(i,1:16)=(TrDataMod6(i))'*code6;
end
% ------------------Generating data for User7------------------------------
msg7=TrDataMod7;
user7=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user7(i,1:16)=(TrDataMod7(i))'*code7;
```

```
end
% ------------------Generating data for User8-------------------------------
msg8=TrDataMod8;
user8=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user8(i,1:16)=(TrDataMod8(i))'*code8;
end
% ------------------Generating data for User9-------------------------------
M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits------------------------

        TrDataMod9 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
           if TrDataBit(n)==0 & TrDataBit(n+1)==0
              temp= 1 + (0*j);
           elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
              temp=  0 + j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
              temp= 0 - j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
              temp= -1 + 0*j ;
           end
              TrDataMod9(1,ii)=temp;
              ii=ii+1;
        end

%          scatterplot(TrDataMod2);

msg9=TrDataMod9;
user9=zeros(2048,16);  %%for user9 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user9(i,1:16)=(TrDataMod9(i))'*code9;
end
% ------------------Generating data for User10-------------------------------
M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits------------------------

        TrDataMod10 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
           if TrDataBit(n)==0 & TrDataBit(n+1)==0
```

```
            temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
            temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
            TrDataMod10(1,ii)=temp;
            ii=ii+1;
        end

%         scatterplot(TrDataMod2);
msg10=TrDataMod10;
user10=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
  user10(i,1:16)=(TrDataMod10(i))'*code10;
end

% -------------------Generating data for User11------------------------------
M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits-----------------------

        TrDataMod11 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
            temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
            temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
            TrDataMod11(1,ii)=temp;
            ii=ii+1;
        end

%         scatterplot(TrDataMod2);
msg11=TrDataMod11;
user11=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
  user11(i,1:16)=(TrDataMod11(i))'*code11;
end
```

```
% ------------------Generating data for User12-----------------------------
M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits-----------------------

        TrDataMod12 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
            temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
            temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
            TrDataMod12(1,ii)=temp;
            ii=ii+1;
        end

%         scatterplot(TrDataMod2);
msg12=TrDataMod12;
user12=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
  user12(i,1:16)=(TrDataMod12(i))'*code12;
end
% ------------------Generating data for User13-----------------------------
M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits-----------------------

        TrDataMod13 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
          if TrDataBit(n)==0 & TrDataBit(n+1)==0
            temp= 1 + (0*j);
          elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
            temp=  0 + j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
            temp= 0 - j;
          elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
            temp= -1 + 0*j ;
          end
```

```
            TrDataMod13(1,ii)=temp;
            ii=ii+1;
        end

%        scatterplot(TrDataMod2);
msg13=TrDataMod13;
user13=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
  user13(i,1:16)=(TrDataMod13(i))'*code13;
end
% ------------------Generating data for User14------------------------------
M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits-----------------------

        TrDataMod14 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
           if TrDataBit(n)==0 & TrDataBit(n+1)==0
              temp= 1 + (0*j);
           elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
              temp=  0 + j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
              temp= 0 - j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
              temp= -1 + 0*j ;
           end
              TrDataMod14(1,ii)=temp;
              ii=ii+1;
        end

%        scatterplot(TrDataMod2);
msg14=TrDataMod14;
user14=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
  user14(i,1:16)=(TrDataMod14(i))'*code14;
end
% ------------------Generating data for User15------------------------------
M=2^12            %%length declaring [4096]
TrDataBit = randint(1,M); %%[0 1]bits

%------------------ QAM Modulation of Encoded Bits-----------------------

        TrDataMod15 = null(1,M/2);    %------

        ii=1;
```

```
        for n=1:2:M
           if TrDataBit(n)==0 & TrDataBit(n+1)==0
              temp= 1 + (0*j);
           elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
              temp=  0 + j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
              temp= 0 - j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
              temp= -1 + 0*j ;
           end
              TrDataMod15(1,ii)=temp;
              ii=ii+1;
        end

%         scatterplot(TrDataMod2);
msg15=TrDataMod15;
user15=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
for i=1:1:2048
   user15(i,1:16)=(TrDataMod15(i))'*code15;
end
% -----------------Generating data for User16------------------------------

M=2^12             %% length declaring [4096]

TrDataBit = randint(1,M); %%[0 1]bits

%----------------- QAM Modulation of Encoded Bits-----------------------

        TrDataMod16 = null(1,M/2);    %------

        ii=1;
        for n=1:2:M
           if TrDataBit(n)==0 & TrDataBit(n+1)==0
              temp= 1 + (0*j);
           elseif TrDataBit(n)==0 & TrDataBit(n+1)==1
              temp=  0 + j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==0
              temp= 0 - j;
           elseif TrDataBit(n)==1 & TrDataBit(n+1)==1
              temp= -1 + 0*j ;
           end
              TrDataMod16(1,ii)=temp;
              ii=ii+1;
        end

%         scatterplot(TrDataMod2);
msg16=TrDataMod16;
user16=zeros(2048,16);  %%for user1 making the vector of k bits where [k=1x16]
```

```
for i=1:1:2048
   user16(i,1:16)=(TrDataMod16(i))'*code16;
end


%%*****************generating the H********
num_iteration=2048;
j=1;
for SNR=5:5:40

   for i=1:num_iteration
%---------------------Adding data for Transmission of All User-----------
        for k=1:4:16

tx_user=user1(i,k:k+3)+user2(i,k:k+3)+user3(i,k:k+3)+user4(i,k:k+3)+user5(i,k:k+3)+us
er6(i,k:k+3)+user7(i,k:k+3)+user8(i,k:k+3)+user9(i,k:k+3)+user10(i,k:k+3)+user11(i,k:k
+3)+user12(i,k:k+3)+user13(i,k:k+3)+user14(i,k:k+3)+user15(i,k:k+3)+user16(i,k:k+3);
% %----------------transmitting on flat fading channel-------------------

        R=H*tx_user';
        y=awgn(R,SNR);
        est_s_4=H1*y;
        est_s(k:k+3,1)=est_s_4;
        end
%            est_s=1*R;
% %----------------DeSpreading Users------------------------------

         Despdata_user1=(code1*(est_s))/16;
         Despdata_user2=(code2*(est_s))/16;
         Despdata_user3=(code3*(est_s))/16;
         Despdata_user4=(code4*(est_s))/16;
         Despdata_user5=(code5*(est_s))/16;
         Despdata_user6=(code6*(est_s))/16;
         Despdata_user7=(code7*(est_s))/16;
         Despdata_user8=(code8*(est_s))/16;
         Despdata_user9=(code9*(est_s))/16;
         Despdata_user10=(code10*(est_s))/16;
         Despdata_user11=(code11*(est_s))/16;
         Despdata_user12=(code12*(est_s))/16;
         Despdata_user13=(code13*(est_s))/16;
         Despdata_user14=(code14*(est_s))/16;
         Despdata_user15=(code15*(est_s))/16;
         Despdata_user16=(code16*(est_s))/16;

         RxDataMod1(1,i)=Despdata_user1;
         RxDataMod2(1,i)=Despdata_user2;
         RxDataMod3(1,i)=Despdata_user3;
         RxDataMod4(1,i)=Despdata_user4;
```

```
        RxDataMod5(1,i)=Despdata_user5;
        RxDataMod6(1,i)=Despdata_user6;
        RxDataMod7(1,i)=Despdata_user7;
        RxDataMod8(1,i)=Despdata_user8;

        RxDataMod9(1,i)=Despdata_user9;
        RxDataMod10(1,i)=Despdata_user10;
        RxDataMod11(1,i)=Despdata_user11;
        RxDataMod12(1,i)=Despdata_user12;
        RxDataMod13(1,i)=Despdata_user13;
        RxDataMod14(1,i)=Despdata_user14;
        RxDataMod15(1,i)=Despdata_user15;
        RxDataMod16(1,i)=Despdata_user16;

    end
    %***************symbol error*****************************************

       error_u1(1,j)=(((msg1-RxDataMod1))*((msg1-RxDataMod1))')/2048;
       error_u2(1,j)=(((msg2-RxDataMod2))*((msg2-RxDataMod2))')/2048;
       error_u3(1,j)=(((msg3-RxDataMod3))*((msg3-RxDataMod3))')/2048;
       error_u4(1,j)=(((msg4-RxDataMod4))*((msg4-RxDataMod4))')/2048;
       error_u5(1,j)=(((msg5-RxDataMod5))*((msg5-RxDataMod5))')/2048;
       error_u6(1,j)=(((msg6-RxDataMod6))*((msg6-RxDataMod6))')/2048;
       error_u7(1,j)=(((msg7-RxDataMod7))*((msg7-RxDataMod7))')/2048;
       error_u8(1,j)=(((msg8-RxDataMod8))*((msg8-RxDataMod8))')/2048;
       error_u9(1,j)=(((msg9-RxDataMod9))*((msg9-RxDataMod9))')/2048;
       error_u10(1,j)=(((msg10-RxDataMod10))*((msg10-RxDataMod10))')/2048;
       error_u11(1,j)=(((msg11-RxDataMod11))*((msg11-RxDataMod11))')/2048;
       error_u12(1,j)=(((msg12-RxDataMod12))*((msg12-RxDataMod12))')/2048;
       error_u13(1,j)=(((msg13-RxDataMod13))*((msg13-RxDataMod13))')/2048;
       error_u14(1,j)=(((msg14-RxDataMod14))*((msg14-RxDataMod14))')/2048;
       error_u15(1,j)=(((msg15-RxDataMod15))*((msg15-RxDataMod15))')/2048;
       error_u16(1,j)=(((msg16-RxDataMod16))*((msg16-RxDataMod16))')/2048;
      symerr_16(1,j)                                                      =
sum(error_u1(1,j)+error_u2(1,j)+error_u3(1,j)+error_u4(1,j)+error_u5(1,j)+error_u6(1,j)
+error_u7(1,j)+error_u8(1,j)+error_u9(1,j)+error_u10(1,j)+error_u11(1,j)+error_u12(1,j)
+error_u13(1,j)+error_u14(1,j)+error_u15(1,j)+error_u16(1,j))/16;
    j=j+1;
end

figure

  SNR=5:5:40
  semilogy(SNR,symerr_4,'-ok','LineWidth',2); %%graph of 4-Users
  hold on
  semilogy(SNR,symerr_8,'-^k','LineWidth',2); %%graph of 8-Users
  hold on
  semilogy(SNR,symerr_16,'->k','LineWidth',2); %%graph of 16-Users
```

```
grid on
legend('Simulated SER for 4-Users,4-Carrier','Simulated SER for 8-Users,4-Carrier','Simulated SER for 16-Users,4-Carrier');
xlabel('SNR, dB');
ylabel('Symbol Error Rate');
title('SER Vs SNR on AWGN channel')
```

Similarly, we can make the channel of length L=8, L=16, L=32, and we can accommodate maximum 64-users, when the channel matrix is [8x8] and so on…