CHAPTER ONE

INTRODUCTION

1.1 Introduction

In telecommunication, need for reducing cost per bit has driven efficient utilization of available frequency spectrum. Efficient modulation techniques play important role in achieving this goal of cost reduction. For any system to achieve next generation standard's data rate, has to transfer the information at faster speeds. For sending more data in a given time, data carrying symbol period needs to be as small as possible; this poses challenges for developers to face channel effects and hardware complexities. If all bandwidth is used as a single big resource, symbol duration should be kept low to pack more data in a unit time. However if the same large bandwidth resource is divided into number of small resources, then the large amount of incoming data stream can be sent onto many small streams simultaneously for a longer time. This is similar as passing one big stream of water through a shower faucet, into number of small streams at the output. The modulation scheme that achieves this is known as Orthogonal Frequency Division Modulation (OFDM) technique.In OFDM technique, the data is sent over small streams of Orthogonal (not interfering) frequencies termed as subcarriers. This division of frequency domain into many orthogonal subcarriers also has benefits of combating the channel in a simpler way as compared to the conventional systems. OFDM modulation technique, divides high speed data stream in number of low speed data streams, to increasing symbol time. Dividing the available frequency resource into Orthogonal Frequencies also improves spectral efficiency [1].

Single Carrier Frequency Division Multiple Access (SC- FDMA) & Orthogonal Division Multiple Access (OFDMA) are the major parts of the Long Term Evolution (LTE). OFDMA is used in the LTE downlink as a multiple access method as itprovides good bandwidth efficiency, immunity to multi-path and frequency selective fading, and less complexequalization at the receiver[2].

OFDMA is a multiple access technique which uses Orthogonal Frequency Division multiplexing (OFDM) for each user. In this technique each user is allotted separate channel and available frequency band of that channel is divided into number of orthogonal frequency subcarriers. The high speed serial data from each user is firstconverted into low speed parallel bit streams with increased symbol duration then it is modulated on each subcarrier using conventional modulation schemes. OFDMA allows achieving high data rate for each user. With little modification to air interface it can be deployed across different frequency bands. OFDMA reduce the effect of multipath fading because data from each user is modulated over several orthogonal frequencies rather than a fixed frequency for entire connection period. In addition, the OFDMA is bandwidth efficient as orthogonal frequency carriers with small spacing is used[2].

SC-FDMA is a multiple access method. Its structure is same as OFDMA with an addition of Fast FourierTransform (FFT) block. The parallel data streams are first passed through FFT block then are modulated on subcarriers because of this the SC-FDMA is also called DFT-Precoded OFDM. The main difference between OFDMA and SC-FDMA is, in OFDMA, each data symbol is carried on a separate subcarrier while, in SC-FDMA, multiple subcarriers carry each data symbol due to mapping of the symbols' frequency domain samples to subcarriers. As SC-FDMA is derived from OFDMA it has same basic advantages as OFDMA but the spreading of each data symbol over multiple subcarriers gives it the profound advantage of lower PAPR value as compare to that of OFDMA. Hence PAPR is a useful parameter for uplink it is used in uplink transmitter SC-FDMA one extra module DFT is added before IFFT module in the transmitter chain and IDFT is added inthe receiver chain. This converts OFDM chain into SC-FDMA chain. Without this two modules the chain is referred as OFDM transmit and receive chain. SC-FDMA system usually will have low PAPR (Peak toAverage Power Ratio) compare to OFDM system. SC-FDMA system is less sensitive to frequency offsetcompare to OFDM system[2].

1.2 Objective

Using OFDMA is power inefficient in uplink. In the uplink, the transmissions start from mobile devices, which are battery powered. The mobile devices are also constrained because they must be low cost to enable mass deployment.

The objective of this thesis investigate and implement the two multiple access techniques SC-FDMA and OFDMA with adaptive modulation techniques BPSK, QPSK, 16-QAM and 64-QAM. In my thesisinvestigatea reducing peak-to- average-power ratio (**PAPR**) transmission scheme for the uplink signal. This scheme is called single carrier frequency division multiple access (SC- FDMA).

1.3 Thesis Outline

Chapter onegivesbrief introduction to Single Carrier Frequency Division Multiple Access

(SC- FDMA) & Orthogonal Division Multiple Access (OFDMA).

ChapterTowWireless Communication & Modulation Schemes.

Chapter Three Contains System Model of both multiple access techniques SC-FDMA and OFDMA with block diagrams.

Chapter Four contains result analysis of the graphs based on MATLAB simulation of above described parameters. These graphs are taken for different modulation schemes.

Chapter Five shows the set of conclusions & recommendations of our thesis work based on result analysis.

CHAPTER TOW

WIRELESS COMMUNICATION & MODULATION SCHEMES

2.1 Introduction

The concept of wireless communication was first introduced in 1897 by Guglielmo Marconi [1]. It is widely used in broadcasting of television, radio, satellite transmission and cellular networks in today's world. Its approach is spreading quite sharp in transmission and reception of data and voice [3].

Wireless communication was effectively used in military and satellite purposes for quite long time, but after 1977 it started to grow rapidly in different applications. Before 1977 it was just offering one-way communication, either outgoing or incoming. First two-way communication also called as Full Duplex Mode was introduced as Advanced Mobile Phone System (AMPS) and it was a turning point in wireless communication. AMPS was based on analogue communication and was categorized as a first generation (1G) of wireless phones. After that more generations came with strong change in their characteristics[3]. Details are described below in Table 2.1.

Table 2.1: Mobile Phone Generations

Generation	Standard	Multiple Access	Frequency Band(MHz)	Throughput
2	GSM	TDAM/FDMA	890-960 1710-1880	9.6 Kbps
2.5	GPRS	TDMA/FDMA	890-960 1710-1880	171 Kbps
2.75	EDGE	TDMA/FDMA	890-960 1710-1880	384 Kbps
3	UMTS	WCDMA	1185-2025 2110-2200	2 Mbps
4	LTE	OFDMA/SC-FDMA	1920-1980 2110-2170	100 Mbps

2.2 Wireless Communication

Transmission of information from one place to another place is called communication and if transmitted through wireless medium then it is called wireless communication. The information can be data, voice and video[3].

2.3 Basic Structure of Communication Model

The basic communication model consists of three parts, transmitter, channel and receiver as shown in figure 2.1.

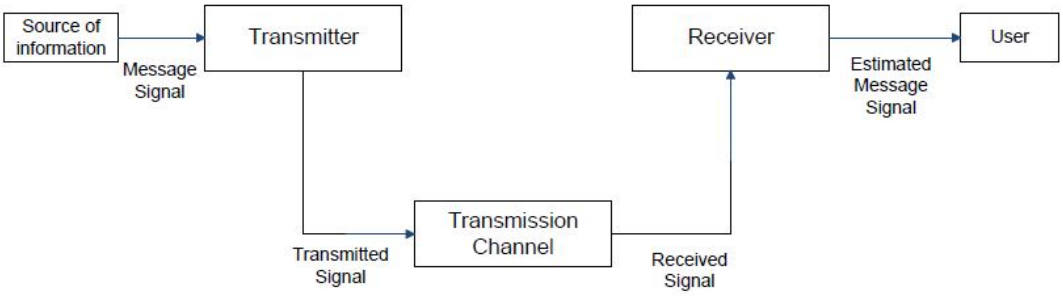

Figure 2.1: General Communication Model

Each part in the above model has a particular role to transmit the signal successfully, which is described as [3];

The transmitter converts the message signal into a form depends upon the medium used by the transmission channel[3].

The transmission channel is a bridge between transmitter and receiver and the medium for the transmission channel can be a pair of wires, a coaxial cable, an optical fibre or a free space (air). Every channel produces some sort of attenuation, fading and noise therefore the strength of the signal decreases with the increase of distance [3].

The receiver receives the data from the transmission channel and provides an output to the user or destination. Its operation includes compensation for transmission loss to recover the message signal as good as possible that is transmitted [3].

A suitable and more detailed communication model is given below.

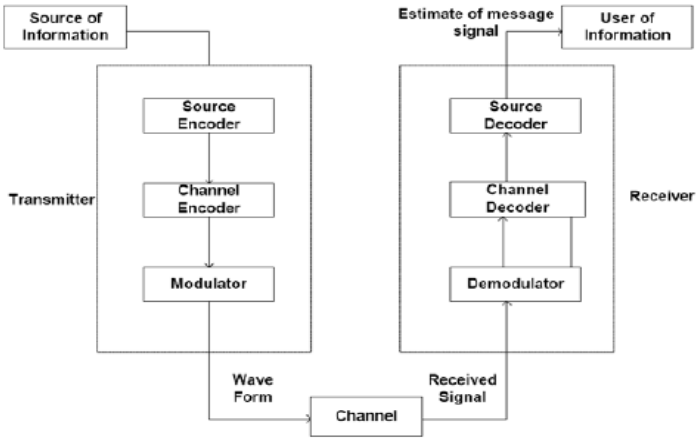

Figure 2.2: Communication System

In a communication system, modulator and demodulator are essential elements in order to achieve several numbers of channels for data transmission and for transmitting the basic information signal over a large distance with enough signal strength. A carrier frequency is added along with the information signal (modulation) at the transmitter side and removed from the information signal (demodulation) at the receiver side to retrieve the original signal [3].

The communication system can be analogue and it is difficult to recover the information at receiver because of presence of medium impairments like fading, noise etc. Digital communication system is more robust as compared to analogue system because of less sensitivity to environmental conditions (thermal noise), easy multiplexing and signaling, etc. Modulation scheme depends on the system; either it is analogue or digital [3]. Some other important blocks that are used in communication systems are;

- ✓ Multiplexer: It is an integral part of transmitter that transmits different signals through a single medium.
- ✓ Demultiplexer: It is used at the receiver end to separate these multiplexed signals.
- ✓ Multiple Access: It is a method which allows users to share the same channel on the basis of division of time, frequency and space or combination of these, for example;
  - Time Division Multiple Access (TDMA)
  - Code Division Multiple Access (CDMA)
  - Frequency Division Multiple Access (FDMA)

- Space Division Multiple Access (SDMA)
- Orthogonal Frequency Division Multiple Access (OFDMA)
- Single Carrier Frequency Division Multiple Access (SC-FDMA)

Channel Coding: This is used for detecting and correcting errors because of noisy channel and fading effects.

Source Coding: If the bit rate of input signal is larger than the capacity of the channel then source coding is used to reduce bit rate at the input signals.

2.4 Forms of Communication

Point-to-Point Communication: This type of communication occurs between two endpoints and normally used for long distance.

Point to Multipoint Communication: The communication occurs from one point to many points by using one transmitter. The transmitter sends data to every point for example video conferencing.

Simplex: In this form of communication, the signal transmits in one direction only.

Half Duplex: In half duplex, data can be transmit in both directions but one user at a time, it is a sharing of time between two users. Walkie Talkie is the popular example of half-duplex.

Full Duplex: It is a two-way communication, both the users can receive and send information at the same time, example is telephone.

2.5 Transmission Impairments

The transmission impairments cause information to be lost in a signal [3]. The message signal can be sent in any form, if the transmission media is ideal then the receiver will get the same data but practically it is not possible. The Transmission medium causes three major problems.

- Attenuation
- Fading
- Noise

2.5.1 Attenuation

The attenuation refers to any reduction in signal strength that is a natural consequence of signal transmission over long distances [3]. A signal must be strong enough so that the receiver can detect and interpret the signal. If attenuation is too high then the receiver might not be able to identify the signal at all. Attenuation is usually expressed in dB.

2.5.2 Noise

Unwanted energy from different sources other than the transmitter is called noise. Noise is categorized in different ways.

2.5.2.1 Cross Talk

Inductive coupling between two wires that are closed to each other causes cross talk. One example is the appearance of another user's voice in between the voice conversation of two users over a telephone network.

2.5.2.2 Thermal Noise

It is an agitation of the charge carriers inside the electric conductor and generated without applying any voltage source. It can be described mathematically as:

$$N = KTW$$

Where,

T = Temperature in Kelvin

K = The Boltzmann Constant ($K = 1.3806 \times 10^{-23}$ Joules per Kelvin ($J \cdot K^{-1}$))

W = Bandwidth in Hz

N = Noise Power in Watts

Impulse Noise

The occurrence of any momentary noise on a channel which exceeds significantly the normal noise peaks. Usually it is caused by an external electrical source.

Inter Symbol Interference (ISI)

ISI is a distortion in a signal which is caused by the interference of one symbol with subsequent symbols.

2.5.2.3 AWGN Noise

The AWGN is a noise with continuous and uniform frequency spectrum over specified frequency band.

2.5.2.4 Intermodulation

When two different frequency signals are transmitted through a medium then interference occurs due to the non linear characteristic of the medium.

2.5.3 Fading

Radio waves propagate from a transmitting antenna and passes through atmosphere where they are affected by reflection, diffraction, scattering and absorption. Therefore the transmitting signals arrive at receiver through several multipath and cause random fluctuations in the received signal. This random fluctuation in the received signals is called fading which is an important factor in wireless communication.

Types of fading due to multipath time delay spread [3];

- Flat Fading
- Frequency Selective Fading

Flat Fading

If a radio channel has a bandwidth that is greater than the bandwidth of the transmitted signal, then the received signal experience flat fading. In flat fading, the strength of the transmitted signal changes due to the fluctuation in the channel gain caused by multipath. Whereas, the spectrum characteristics remain preserved [3].

Frequency Selective Fading

If the bandwidth of the transmitted signal is greater than the channel, then that channel produce frequency selective fading on the received signal. The received signal consists of different faded and time delayed versions of the transmitted waveform. In the channel, the time dispersion of the transmitted symbol causes frequency selective fading [3].

Types of fading due to Doppler spread [3];

- Slow Fading
- Fast Fading

Slow Fading

The slowfading occurs when the coherence time is greater than the symbol period, in other words the reduction occurs in the signal strength at receiver, when the receiver moves away from the transmitter is called slow fading.

Fast Fading

The fast fading occurs in a transmission due to following reason;

- High Doppler spread in the channel
- Coherence time is less than the symbol period
- The channel variations become faster than the baseband signal variation

2.5.3.1 Rician Fading

The Rician fading occurs when there is a LOS (line of sight) path available along with the number of indirect multipath signals.

2.5.3.2 Rayleigh Fading

When there is no LOS path exists between transmitter and receiver and the transmission takes place only by multipath propagation then this type of fading is called Rayleigh fading. The received signal at the receiver is sum of all the reflected and scattered waves[3].

2.6 Digital Modulation

In digital modulation the carrier signal is usually in sinusoidal form and its frequency, phase, amplitude or combination of these is changed in order to transmit the information signal.

There are three basic types of digital modulation;

- ✓ Amplitude Shift Keying (ASK)
- ✓ Frequency Shift Keying (FSK)
- ✓ Phase Shift Keying (PSK)

2.6.1 Amplitude Shift Keying

In this type of modulation, the amplitude of carrier signal is changed depending upon the information while frequency and phase remains constant [5]. The carrier signal is transmitted with some amplitude for logic “1” and with zero amplitude for logic “0.” Figure 2.3 shows clear understanding of ASK.

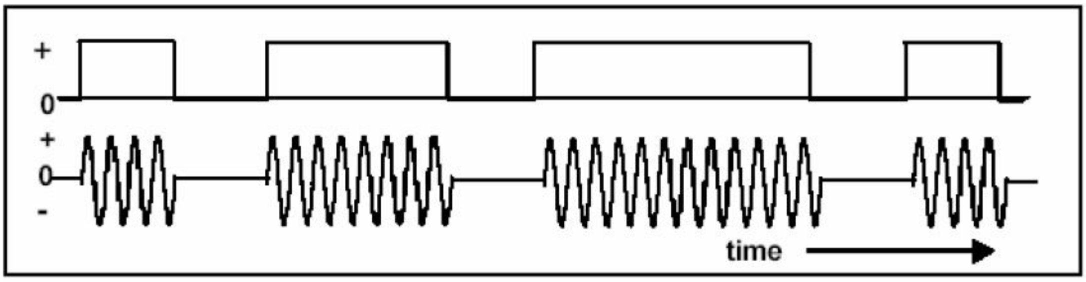

Figure 2.3: Amplitude Shift Keying

2.6.2 Frequency Shift Keying

In FSK the phase and amplitude remains constant while frequency is changed according to the information. Logic “0” represents lower frequency and logic “1” represents upper frequency as shown in figure 2.4 [3].

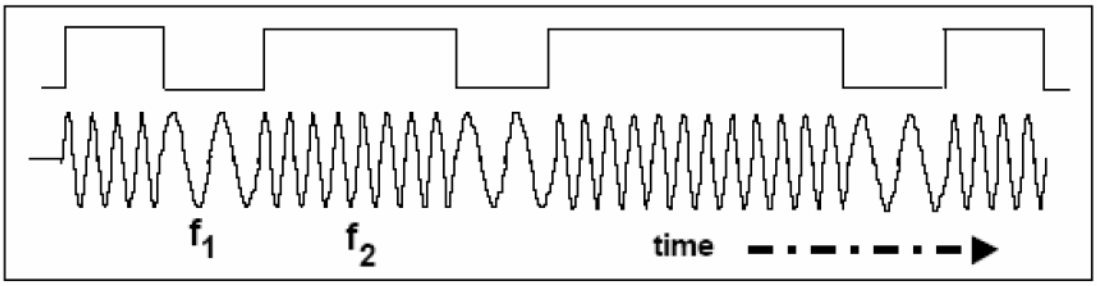

Figure 2.4: Frequency Shift Keying

2.6.3 Phase Shift Keying (PSK)

In PSK, frequency and amplitude of the carrier signal remains same but variations occur in the phase of sinusoidal signal. PSK has many methods but most simple method is Binary Phase Shit Keying (BPSK)

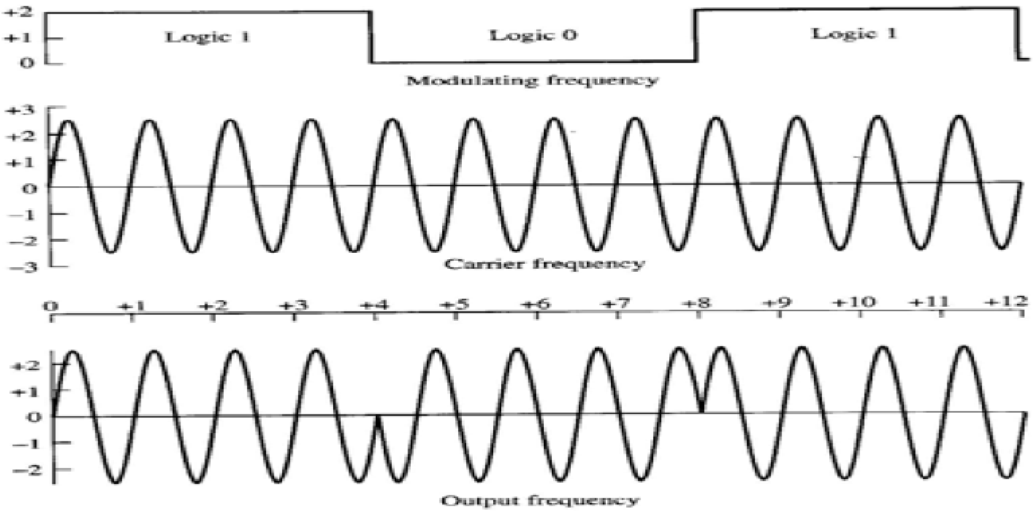

Figure 2.5: Phase Shift Keying

2.6.3.1 Binary Phase Shift Keying (BPSK)

It is a binary level digital modulation scheme of phase variation that has two theoretical phase angles, +90^{o} and -90^{o}. It is immune to noise and interference therefore it improves BER performance. Each modulation symbol represents a single phase. Constellation diagram is given in figure 2.6.

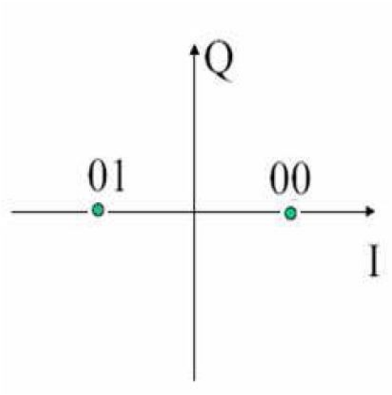

Figure 2.6: Binary Phase Shift Keying

2.6.3.2 Quadrature Phase Shift Keying (QPSK)

The QPSK uses four phases at 0, 90, -90 and 180 degrees. It gives high spectral efficiency and it is more efficient than BPSK because it uses two symbols at a time for modulation. Both BPSK and QPSK are power efficient in same way but QPSK is more bandwidth efficient than BPSK. Figure 2.7 shows the constellation diagram.

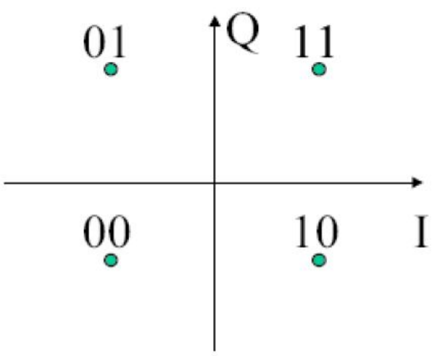

Figure 2.7 Quadrature Phase Shift Keying Constellation

Figure 2.7 clearly shows that QPSK uses two symbols at a time and at the receiver make decision between two symbols. Table 2.2 shows the change of angle with respect to change of state of the modulation bits.

Table 2.2: QPSK Signal Space Characteristics

Dibit	Phase Change in Degrees
01	0
00	90
10	180
11	270

2.6.4 Quadrature Amplitude Modulation (QAM)

QAM is a combination of amplitude modulation and phase shift keying [3]. Data is transferred by modulating two separate carrier signals (sine and cosine) that are out of phase by 90 degrees. It uses different types of phase; 16 QAM, 32 QAM, 64 QAM and 256 QAM. Each symbol state of QAM defines a particular phase and amplitude. By increasing number of levels, the efficiency of QAM increases with increase of complexity. QAM has increased the efficiency of transmission for radio communication systems by using both phase and amplitude together. It is more susceptible to noise because its symbols are very close to each other therefore rate of interference increases. It also has problem with the linearity of system because of using amplitude and phase simultaneously while in case of frequency and phase there is no need of linear amplifier [3].

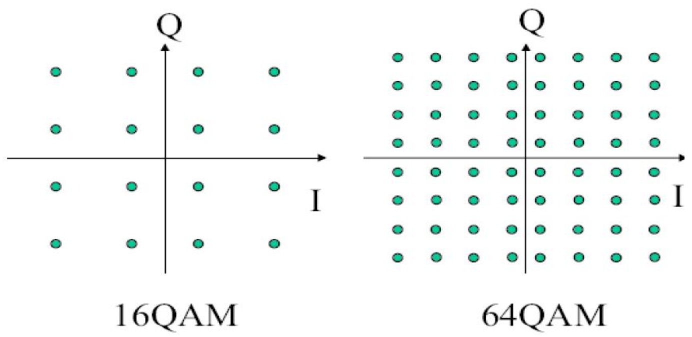

Figure 2.8: 16-QAM and 64-QAM

2.6.5 Adaptive Modulation

Adaptive modulation is an intelligent technique that is used to select proper modulation scheme for the channel if it is affected by fading, noise and variations. LTE takes great advantage of this, if signal conditions become bad, it switches from one modulation scheme to another that suits best for the signal. If modulation scheme changes then amount of deviation in throughput and spectral efficiencies also varies. 64-QAM has high throughput as compared to BPSK and QPSK. It is important to use higher modulation schemes in order achieve high spectral efficiency and high transmission throughput. Whereas the lower order modulation schemes are less vulnerable to noise and interference in the channel [3].

2.7 Multiple Access Schemes

Multiple access is a radio transmission scheme that allows many senders to transmit signals in the same time span without interfering with each other. There are different types of multiple access schemes;

- Time Division Multiple Access (TDMA)
- Frequency Division Multiple Access (FDMA)
- Code Division Multiple Access (CDMA)
- Space Division Multiple Access (SDMA)
- Orthogonal Frequency Division Multiple Access (OFDMA)
- Single Carrier Frequency Division Multiple Access (SC-FDMA)

2.7.1 Time Division Multiple Access (TDMA)

In TDMA, a frequency channel is divided in to number of time slots. Several users access the same frequency channel for different time slots and each user is assigned a separate time slot for a specific period that transmits signal in rapid succession. In TDMA, there are many receivers instead of one transmitter connected to one receiver. In mobile communication standards, TDMA is used in second generation (2G) and third generation (3G) [3].

2.7.2 Frequency Division Multiple Access (FDMA)

In FDMA, the frequency band allocated to a network is divided in many channels or sub-bands. One channel is assigned to each user for entire call duration and each frequency band has capability to carry either digital data or voice conversation. Advance Mobile Phone Service (AMPS) is 1G analogue cellular system and uses FDMA. This scheme is not so efficient because an assigned channel or sub-band is wasted during the unused period of call [3].

2.7.3 Code Division Multiple Access (CDMA)

CDMA uses spread spectrum technology. In CDMA, all users use the entire spectrum of the system based on codewords. The available bandwidth is distributed on a sequence of pseudo noise codes, each signal is multiplied by the code sequence of a large bandwidth signal [3]. All users in CDMA transmit concurrently on the same carrier frequency. The codeword of each user is orthogonal to all other users and the correlation operation is used at receiver side in order to retrieve the information for a specific codeword [3].

2.7.4 Space Division Multiple Access (SDMA)

In SDMA, the transmitted energy is controlled in the direction of particular user in space [3]. Spot beam antennas are used in order to radiate energy for each user separately using the same frequency. SDMA uses the same electromagnetic spectrum over multi transmission paths.

2.7.5 Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA is a type of frequency division multiplexing (FDM) in which available frequency band is divided into number of orthogonal frequency subcarriers. The data is first converted into parallel bit streams then it is modulated on each subcarrier using conventional modulation schemes. OFDMA allows low data rate from many users and has shorter and constant delay. It has flexibility in deployment across different frequency bands by need of little modification to air interface. The effect of multipath fading is reduced by using OFDMA because each user's data is modulated over several orthogonal frequencies rather than a fixed frequency for entire connection period. In addition, the OFDMA is not only facilitating the capacity sharing in available bandwidth but it also increases the capacity for each user because of using several frequencies[3].

2.7.6 Single Carrier Frequency Division Multiple Access (SC-FDMA)

SC-FDMA also deals with multiple users to share a communication resource. Its structure is like OFDMA with an addition of Discrete Fourier Transform (DFT) block. The data symbols first pass through DFT block then are modulated on subcarriers. At receiver side, the equalization is achieved by Fast Fourier Transform (FFT) calculations. As SC-FDMA is derived from OFDMA and has same basic structure, it also increases the capacity of users by using several frequencies for carrying data of a single user.

2.8 OrthogonalFrequency Division Modulation (OFDM)

Main basic difference between other modulation schemes and OFDM is use of orthogonal frequencies for improved spectral efficiency [1].

2.9 Working Principle of OFDM

OFDM modulation system is made up of a transmitter and receiver as in other modulation systems. This system basically consists of four main stages [1]. Those steps are, (i) splitting data stream into many parallel data streams,(ii) symbol generation, (iii) Converting data in to time domain and (ix) converting the parallel data streams back again in to serial time domain digital signal to deliver it to the transmission system. These stages are explained below.

2.10OFDM Transmitter

OFDM transmitter consists of following number of sub blocks and can be explained as,

2.10.1Serial to Parallel Converter

The data is considered to be in frequency domain unlike other systems which handle the data in the time domain. This frequency domain high-rate data stream is serial-to-parallel converted into a data block $S_k = [S_k[0]..S_k\ [M-1]]$ for modulation onto M parallel subcarriers. This increases the symbol duration (T_s) on each subcarrier by a factor of approximately M, such that it becomes significantly longer than the channel delay spread ($\tau\text{-}_{max}$)[1].

2.10.2Symbol Mapping

Symbols are then generated for each parallel stream using phase or amplitude modulation techniques such as QPSK, 16 QAM or 64QAM etc. The M parallel data streams are independently modulated resulting in the complex vector $X_k= [X_k\ [0]..X_k\ [M - 1]]^T$.

2.10.3Time Domain Conversion of the Data Stream

The symbols generated (**X_k**) from each stream are then converted into time domain signal using Inverse Fourier Transform (IFFT) resulting in a set of N complex time-domain samples $x_k = [x_k\ [0]..x_k\ [N-1]]^T$. (However, in a practical OFDM system, the number of processed subcarriers is greater than the number of modulated sub-carriers (i.e. $N \geq M$), with the unmodulated sub-carriers being padded with zero's.)

2.10.4 Adding Cyclic Prefix (CP)

The next interesting key operation is, generations of an OFDM signal with a guard period added at the beginning of each OFDM symbol. This eliminates the remaining impact of ISI caused by multipath propagation. When symbols are transmitted in the channel, due to channel delay spread, symbols travels through multiple paths and get delayed as compared to the direct path symbols. This delayed copy of previous symbol gets added in the direct path copy of the next symbol. This mixing of two symbols causes an interference termed as Inter Symbol Interference (ISI). To minimize this, the guard interval is added between the end of previous symbol and the start of new symbol. This interference is combated at theexpense of time resource. The transmitter block diagram is shown in Figure 2.9 [1].

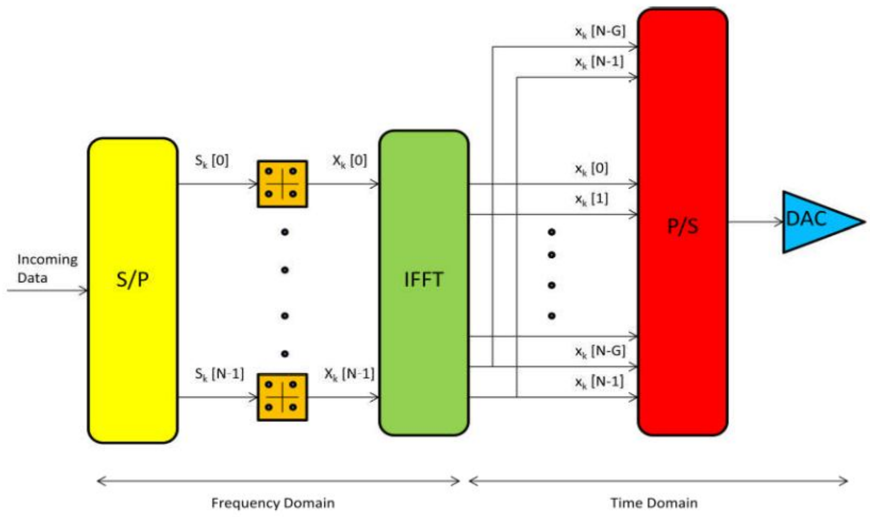

Figure 2.9 OFDM transmitter block diagram

At the receiver the reverse process is carried out to decide the data symbol received.

2.11OFDM Receiver

At the receiver, the reverse operations are performed to demodulate the OFDM signal. Assuming that time- and frequency-synchronization is achieved, a number of samples corresponding to the length of the CP are removed, such that only an ISI-free block of samples is passed to the DFT. The DFT output is passed through symbol demodulator and then resulting data parallel data stream is converted to serial stream to obtain received data stream [1].

2.12 OFDMA in LTE and WiMAX

In LTE and WiMAX, to support many users simultaneously, available bandwidth resource is divided in time and frequency to form smaller blocks [1]. Each block or a group of blocks is assigned to the users depending on channel condition and other parameters. These blocks are used for modulation using Orthogonal Frequency Division Multiple Access (OFDMA).

In OFDMA first the available spectrum is divided into number of orthogonal subcarriers with the spacing of Δf between them (Δf =15 KHz and 10.94 KHz for LTE and WiMAX respectively) [1]. Then fixed numbers of subcarriers are grouped together to form a Resource Block (12 and 18 subcarriers in LTE and WiMAX respectively). The RB is then defined in time for numbers of OFDM symbols in time (5 – 14 symbols) depending on the system configuration. RBs are then grouped in the frame 10ms in case of LTE and 5ms in case of WiMAX. Base station who is the main controller of the RB assigns one or many units of it to an active user for data transmission.

OFDMA has many advantages over other techniques and are listed below:

- Best spectral efficiency
- Channel equalization is done at lower complexity in the frequency domain
- Inter symbol interference can be minimized adjusting Cyclic Prefix
- Flat fading due to smaller Orthogonal Subcarrier Frequency spacing

2.13OFDM Drawbacks

This section highlights some of the main drawbacks of OFDM.

- OFDM is sensitive to the time and frequency offsets in the transmitter and receiver.
- Peak to Average Power Ratio is high and affects power amplifier in the later stages of transmitter.
- Synchronization is needed all the time to maintain communication.

2.14 Peak to Average Power Ratio (PAPR)

Power saving in transmission is an extensive issue for the multiple access techniques used in LTE, therefore we consider here an important transmission factor PAPR for both OFDMA and SC-FDMA. Peak to average power ratio is defined as “the ratio of peak signal power to the average signal power”[3].

The PAPR is calculated by representing a CCDF (Complementary Cumulative Distribution Function) of PAPR.The CCDF of PAPR is the probability that the PAPR is higher than a certain PAPR value $PAPR_0$ ($Pr\{PAPR>PAPR_0\}$). It is an important measure that is widely used for the complete description of the power characteristics of signals [3].

The PAPR of SC-FDMA signals are analyzed and compare it with that of OFDMA. Analytically derive the Time domain SC-FDMA signals and numerically compare PAPR characteristics using complementary cumulative distribution function (CCDF) of PAPR. The increase in PAPR is related to the number of sub carriers and their order of modulation [3].

Derives the time domain signals for each subcarrier mapping mode of SC- FDMA and the CCDF of PAPR obtained.

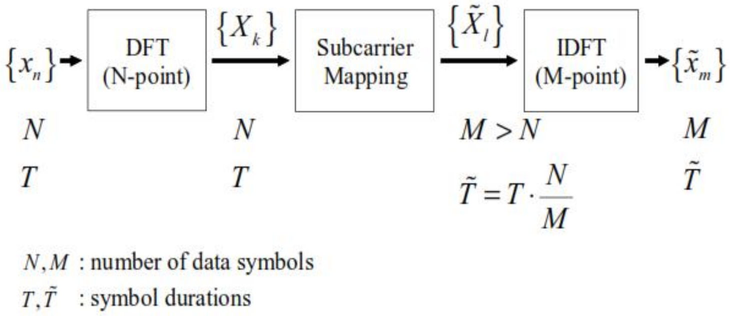

Figure 2.10 Generation of SC-FDMA transmits symbols. There are M total number of carriers, among which N (< M) subcarriers are occupied by the input data.

The PAPR of the SC-FDMA signal areanalyzed as in Figure 2.10.

Let $\{x_n$: n = 0,1,..,N-1} data symbols to be modulated.

Let $\{X_k$: k= 0,1,..,N-1} are the Frequency domain samples after DFT $\{x_n$: n= 0,1,..,N-1}.

$\{\tilde{X}_l$: l = 0,1,….,M-1} are Frequency domain samples after subcarrier mapping.

$\{\tilde{x}_m: m = 0,1,..,M-1\}$ are Time domain symbols after IDFT of $\{\tilde{X}_l$:l =0,1,….,M-1}

The complex (*Pass-band Transmit Signal*) of SC-FDMA x(t) for a block of data is represented as :

$x(t) = e^{j\omega_c t} \sum_{m=0}^{M-1} \tilde{x}_m \, r(t-m\tilde{T})$ (2.1)

Where

ω_c is the carrier frequency of the system.

r(t) is the baseband pulse.

M number of subcarrier , N subcarrier occupied by the input data.

$\tilde{T}$symbol duration compressed where ($\tilde{T} = \frac{N}{M} \cdot T$) After going through SC-FDMA modulation.

The ***raised cosine pulse***[8] is used , which is a widely used pulse shape [*Pulse shaping is essential for making the signal fit in its frequency band by reducing out of band signal energy*] in wireless communications, defined as follows in the time domain The impulse response of such a filter is given by:

$$r(t) = \text{sinc}\left(\pi \frac{t}{T}\right) \frac{\cos\left(\frac{\pi\alpha t}{\tilde{T}}\right)}{1 - \frac{4t^2\alpha^2}{\tilde{T}}} \qquad (2.2)$$

Roll-Off factor α (ranges between 0 and 1), is a measure of the *excess bandwidth* of the filter, i.e. the bandwidth occupied beyond the *Nyquist bandwidth* [3] of $\frac{1}{2T}$ (T symbol period). If we denote the *Excess Bandwidth*as Δf, then:

$$\alpha = \frac{\Delta f}{\left(\frac{1}{2T}\right)} = \frac{\Delta f}{\frac{R_S}{2}} = 2T\,\Delta f \qquad (2.3)$$

Where$R_s = \frac{1}{T}$istheSymbol Rate.

The PAPR is defined as follows for transmit signal x(t).

$$\text{PAPR} = \frac{\text{Peak power of x(t)}}{\text{Averge power of x(t)}} = \frac{\max_{0 \le t \le M\tilde{T}} |x(t)|^2}{\frac{1}{M\tilde{T}} \int_0^{M\tilde{T}} |x(t)|^2 dt} \qquad (2.4)$$

In the simulations, 10^3 uniformly random symbols (OFDMA and SC-FDMA symbols) per user were generated and 4 times oversampling was used to obtain the CCDF of PAPR. The Transmission Bandwidth of 5 MHz was assumed and was used when calculating PAPR. The total numbers of subcarriers M were set to 512, input data block size N to 16, and Q to 32.

2.15BER

The BER is ratio of error bits and total number of bits transmitted during time interval.

BER = Error Bits / Number of Transmitted Bits (2.5)

2.16SNR

The SNR is the ratio of bit energy (E_b) to the noise power spectral density (N_0) and it is expressed in dB.

$$SNR = E_b / N_0 \qquad (2.6)$$

2.17BERvs SNR

For any modulation scheme, the BER is expressed in terms of SNR. BER is measured by comparing the transmitted signal with received signal, and compute the error counts over total number of bits transmitted.

2.18Error Probability

The probability of error or error probability (P_e) is the rate of errors occurs in the received signal. The symbol error probability of M-ary PSK and M-ary QAM in the AWGN channel is determined by following expressionsfor M-ary PSK the P_e is given by [1];

$$Pe \cong 2\left(1 - \frac{1}{\sqrt{M}}\right) erfc\left(\sqrt{\frac{3E_{av}}{2(M-1)N_0}}\right) \qquad (2.7)$$

Where

E_{av}= average value of transmitted symbol energy in M-ary QAM

N_0 = Noise density in AWGN

erfc =complementary error function

2.19 Power Spectral Density

The power spectral density (PSD) is an important function that describes the power distribution of a signal with respect to frequency. In mobile communication, to perform the correct decision of radio resource management (RRM) at base station, the PSD plays a vital role, especially for the transmission format allocation including modulation and bandwidth. In the base station terminal, if PSD is unknown then it may cause to spent high transmission bandwidth as compared to the maximum UE power capabilities [3].

The total power in the frequency band for the periodic signal with N period would be

$$P_{xx}(m) = \frac{1}{f_s}\frac{1}{N}|DFT_N\{x(n)\}|^2 \qquad (2.8)$$

Where

f_s = sampling frequency(10MHz)

N= Number of FFT points (512 = total subcarriers)

Calculate the PSD at the output of IFFT block in the transmitter of both OFDMA and SC-FDMA.

2.20 Single CarrierOrthogonalFrequency Division Multiple Access

In OFDMA data is mapped to the symbols and are directly modulated on the subcarrier using IFFT as shown in the previous section. In SC-FDMA the signal is the liner combination of all data symbols modulated on the subcarrier. Hence all transmitted subcarrier in the group carry the component of each symbol in that group for that particular symbol. This gives SC-FDMA it’s curtail single carrier property which lowers the PAPR as compared to OFDMA[1].

2.20.1 SC-FDMA Transmitter Structure

The structure of the transmitter for SC-FDMA is similar to that of OFDMA transmitter except for one change. The generation of an SC-FDMA signal uses a Discrete Fourier Transform (DFT) to spread the signal before it is fed to the IFFT stage [1]. The first step of the transmitter is to convert the serial bits to the parallel blocks of bits for modulate them in to M symbols. Then the important step, M modulated symbols are then are passed to the M point DFT block where it spreads the signal. These M signals are zero padded to match N point IFFT input. Note that M < N. There are two types of configurations in which zeros can be padded.

- ✓ Localized transmission
- ✓ Distributed transmission

After zeros are padded, the signal is then mapped to the input of the N point IFFT. After this point, the transmitter structure of SC-FDMA becomes same like OFDMA.

2.20.2 Subcarrier Mapping

Figure 2.11 shows two methods of assigning theM frequency domain modulationsymbols to subcarriers: distributed subcarrier mapping and localized subcarrier mapping. In the localized subcarrier mapping mode, the modulation symbols are assigned to M adjacent subcarriers. In the distributed mode, the symbols are equally spaced across the entire channel bandwidth. In both modes, the IDFT in the transmitter assigns zero amplitude to the N − M unoccupied subcarriers. Refer to the localized subcarrier mapping mode of SC-FDMA as localized FDMA (LFDMA) and distributed

subcarrier mapping mode of SC-FDMA as distributed FDMA (DFDMA). The case of N = Q ×M for the distributed mode with equidistance between occupied subcarriers is referred to as Interleaved FDMA (IFDMA). IFDMA is a special case of SC-FMDA and it is very efficient in that the transmitter can modulate the signal strictly in the time domain without the use of DFT and IDFT [4].

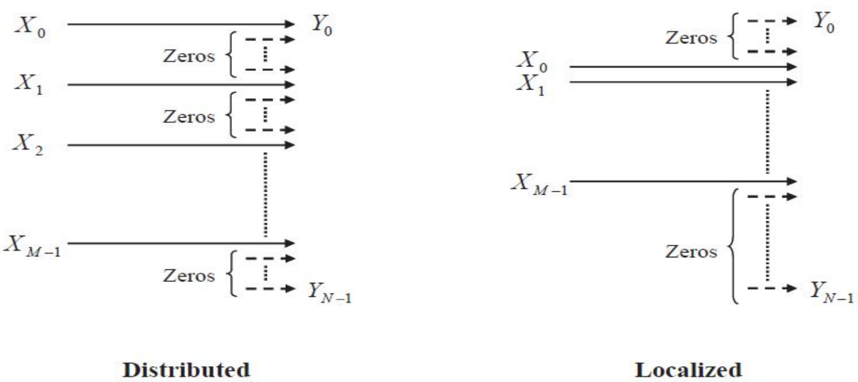

Figure 2.11 Subcarrier mapping modes; distributed and localized

Figure 2.12 illustrates three examples of SC-FDMA transmit symbols inthe frequency domain for M = 4 symbols per block, N = 12 subcarriers, and Q = N/M = 3 terminals.

In the localized mode, the four modulation symbols occupy subcarriers 0, 1, 2, and 3: $Y_0 = X_0$, $Y_1 = X_1$, $Y_2 = X_2$, $Y_3 = X_3$, and $Y_i = 0$ for $i \neq 0, 1, 2, 3$. In the distributed mode with modulation symbols equally spaced over all the subcarriers, Y0 = X_0, $Y_2 = X_1$, $Y_4 = X_2$, $Y_6 = X_3$, and in the interleaved mode, $Y_0 = X_0$, $Y_3 = X_1$, $Y_6 = X_2$,$Y_9 = X_3$.

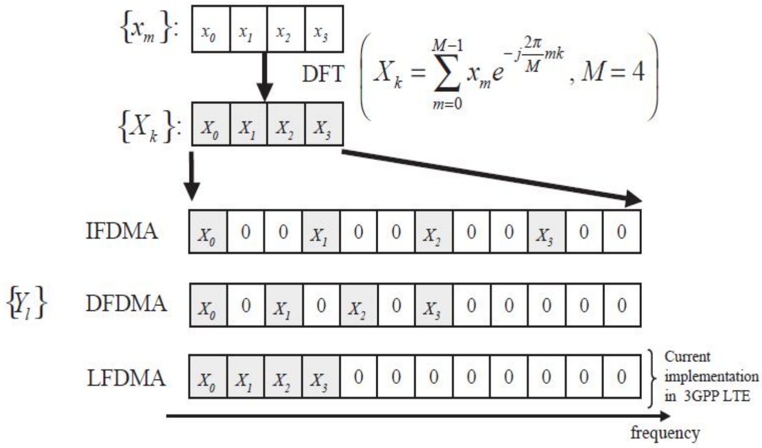

Figure 2.12An example of different subcarrier mapping schemes for M = 4, Q = 3, and N = 12

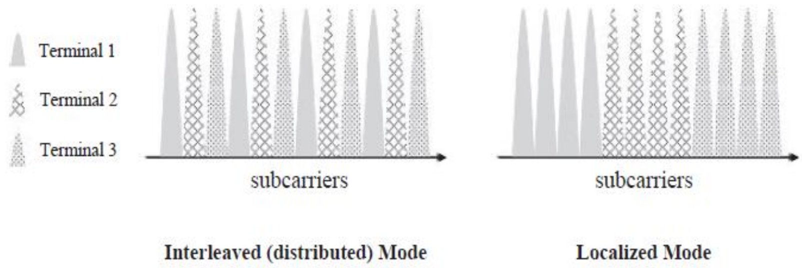

Figure 2.13 Subcarrier allocation methods for multiple users (3 users, 12 subcarriers,and 4 subcarriers allocated per user)

Figure 2.13 shows IFDMA and LFDMA demonstrating that the signalsof the three different terminals arriving at a base station occupy mutually exclusive sets of subcarriers. From a resource allocation point of view, subcarrier mapping methods are further divided into static scheduling and channel-dependent scheduling (CDS) methods. CDS assigns subcarriers to users according to the channel frequency response of each user. For both scheduling methods, distributed subcarrier mapping provides frequency diversity because the transmitted signal is spread over the entire bandwidth. With distributed mapping, CDS incrementally improves performance. By contrast, CDS is of great benefit with localized subcarrier mapping because it provides significant multi-user diversity[4].

2.20.3 SC-FDMA Receiver Structure

SC-FDMA receiver is very similar to the OFDMA receiver with addition of IDFT dispreading block at the output of the IFFT block to undo the transmitter procedures. As shown in Figure 2.14, the received signal is passed through the RF stage. Then CP is removed to mitigate multipath interference. This multipath interference free symbol is then passed to FFT where the time domain signal is converted to frequency domain signal. De-mapping off the subcarrier according to localized or distributed scheme used by the transmitter is done at the subcarrier de-map stage. Then important stage in SC-FDMA is to de-spread the signal using IDFT to convert to the data in to the symbols and then they are converted into original bit stream using detection logic [1].

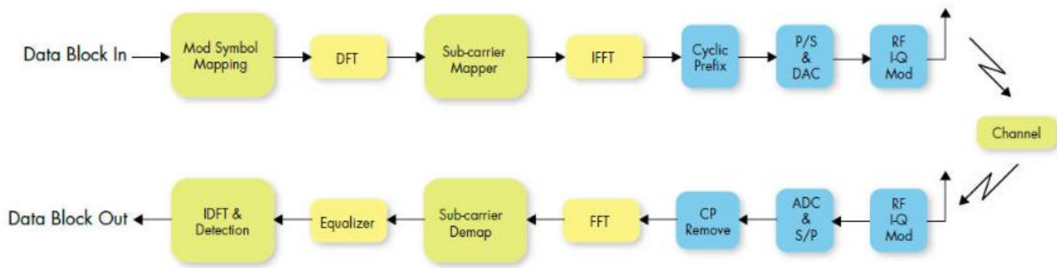

Figure 2.14 Block diagram of SC-FDMA transmitter and receiver

The block diagram of the transmitter and receiver is shown below. Also the signals if frequency and time domain of SC-FDMA receiver are shown for subcarrier spacing of 15KHz and M = 4, in Figure 2.15 [1].

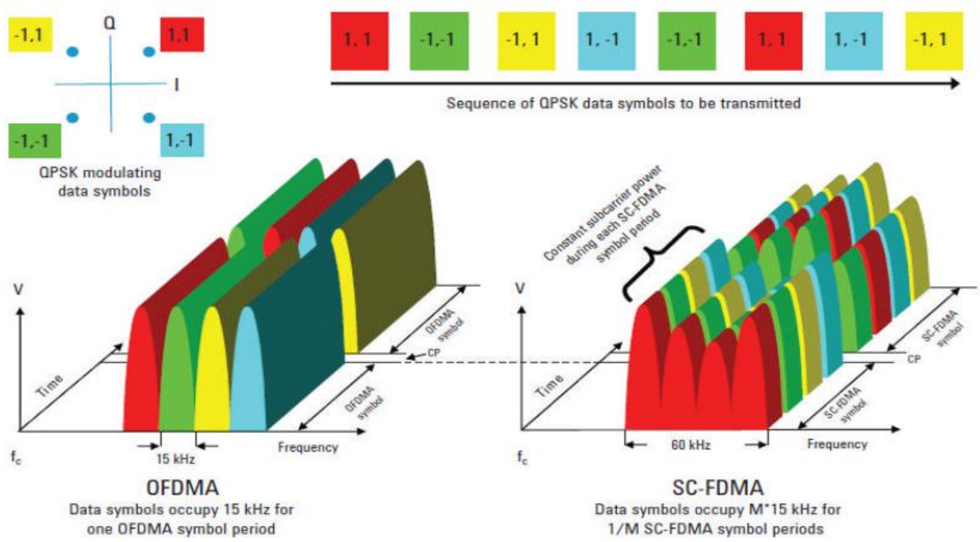

Figure 2.15 SC-FDMA signals in frequency and time domain for LTE, with M = 4 and subcarrier spacing Δf = 15KHz.

2.21 Parametersfor OFDMA and SC-FDMA in LTE andWiMAX

LTE and WiMAX both use a slightly different set of parameters for OFDMA by design [1]. OFDMA is used in Downlink transmission i.e. transmission from base station to user, in both LTE and WiMAX. However for Uplink, SC-FDMA is used in LTE and OFDMA is used in WiMAX. However for completeness of the discussion on the modulation techniques some basic parameters are listed for LTE and WiMAXin Table 2.3 [1].

Table 2.3 Physical Layer Parameters for LTE and WiMAX

IEEE 802.16m Mobile WiMAX	3GPP LTE-Advanced	Feature
Downlink: OFDMA Uplink: OFDMA	Downlink: OFDMA Uplink: SC-FDMA	Multiple Access Scheme
18 sub-carriers x 6 OFDM symbols = 108 Resource elements	12 sub-carriers x 14 OFDM/SCFDMA Symbols = 168 Resource elements	Physical Resource Block Size
864 sub-carriers x 10.9375 kHz (sub-carrier spacing) = 9.45 MHz (Spectrum Occupancy = 94.5%)	600 sub-carriers x 15 kHz (subcarrier spacing) = 9 MHz (Spectrum Occupancy = 90%)	Usable Bandwidth at 10 MHz
44064 Resource Elements	42000 Resource Elements	Usable Resource Elements per 5 ms
32 Levels	27 Levels	Modulation and Coding Scheme Levels

Source: Ahmadi, Sassan. Mobile WiMAX A Systems Approach to Understanding

IEEE 802.16m Radio Access Technology. Burlington: Elsevier Press, 2011.

The Modulation schemes like BPSK, QPSK, 16QAM or 64 QAM are used.

2.22Physical Layer Frame Structure

The physical layer supports the two multiple access schemesOFDMA on the downlink and SC-FDMA on the uplink. In addition, both paired and unpaired spectrums are supported using frequency division duplexing (FDD) and time division duplexing (TDD), respectively. Although the LTE downlink and uplink use different multiple access schemes, they share a common frame structure. The frame structure defines the frame, slot, and symbol in the time domain. Two radio frame structures are defined for LTE and shown in figure 2.16 and figure 2.17. Frame structure type 1 is defined for FDD mode. Each radio frame is 10 ms long and consists of 10 subframes. Each subframe contains two slots. In FDD, both the uplink and the downlink have the same frame structure though they use different spectra[5].

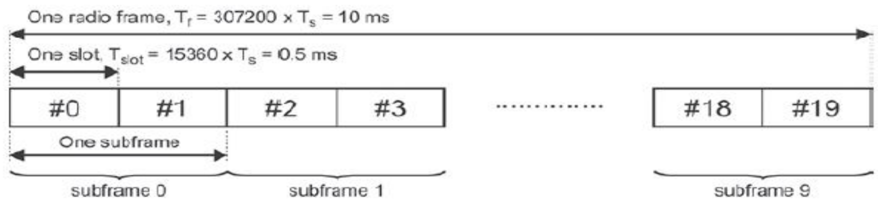

Figure 2.16 - Frame Structure TYPE 1

Frame structure type 2 is defined for TDD mode. An example is shown in figure 16. This example is for 5 ms switch-point periodicity and consists of two 5 ms half-frames for a total duration of 10 ms.Subframes consist of either an uplink or downlink transmission or a special subframe containing the downlink and uplink pilot timeslots (DwPTS and UpPTS) separated by a transmission gap guard period (GP). The allocation of the subframes for the uplink, downlink, and special subframes is determined by one of seven different configurations. Subframes 0 and 5 are always downlink transmissions, subframe 1 is always a special subframe, and subframe 2 is always an uplink transmission. The composition of the other subframes varies depending on the frame configuration. For a 5 ms switch-point configuration, subframe 6 is always a special subframe as shown below. With 10 ms switch-point periodicity, there is only one special subframe per 10 msframe[5].

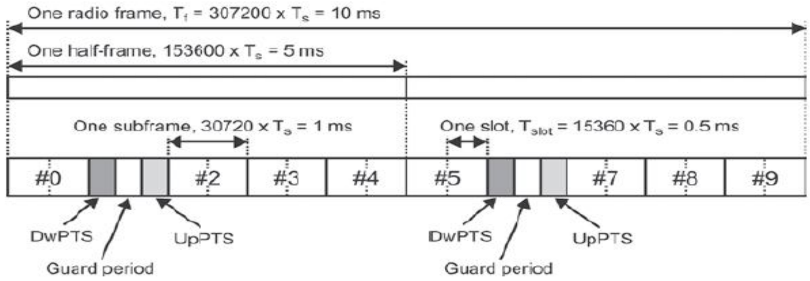

Figure 2.17 - Frame Structure TYPE 2

One of the key advantages in OFDM systems (including SC-FDMA in this context) is the ability to protect against multipath delay spread. The long OFDM symbols allow the introduction of a guard period between each symbol to eliminate inter-symbol interference due to multipath delay spread. If the guard period is longer than the delay spread in the radio channel, and if each OFDM symbol is cyclically extended into the guard period (by copying the end of the symbol to the start to create the cyclic prefix), then the inter-symbol interference can be completely eliminated. Figure 2.18 shows theseven symbols in a slot for the normal cyclic prefix case[5].

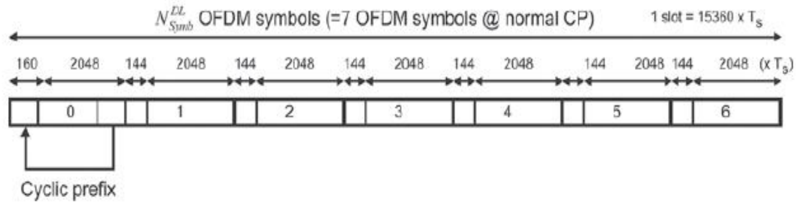

Figure 2.18 - OFDM Symbol Structure

Cyclic prefix lengths for the downlink and the uplink are shown in Table 4. In the downlink case, Δf represents the 15 kHz or 7.5 kHz subcarrier spacing. The normal cyclic prefix of 144 x Ts protects against multi-path delay spread of up to 1.4 km. The longest cyclic prefix provides protection for delay spreads of up to 10 km[5].

Table2.4 - OFDM (DL) and SC-FDMA (UL) Cyclic Prefix Lenght

OFDM configuration (downlink)		Cyclic prefix length $N_{CP,l}$
Normal cyclic prefix	Δf = 15 kHz	160 for $l = 0$ 144 for $l = 1,2,\ldots,6$
Extended cyclic prefix	Δf = 15 kHz	512 for $l = 0,1,\ldots,5$
	Δf = 7.5 kHz	1024 for $l = 0,1,2$
SC-FDMA configuration (uplink)		**Cyclic prefix length $N_{CP,l}$**
Normal cyclic prefix		160 for $l = 0$ 144 for $l = 1,2,\ldots,6$
Extended cyclic prefix		512 for $l = 0,1,\ldots,5$

2.23Resource Element and Resource Block

A resource element is the smallest unit in the physical layer and occupies one OFDM or SC-FDMA symbol in the time domain and one subcarrier in the frequency domain. This is shown in Figure 2.19.

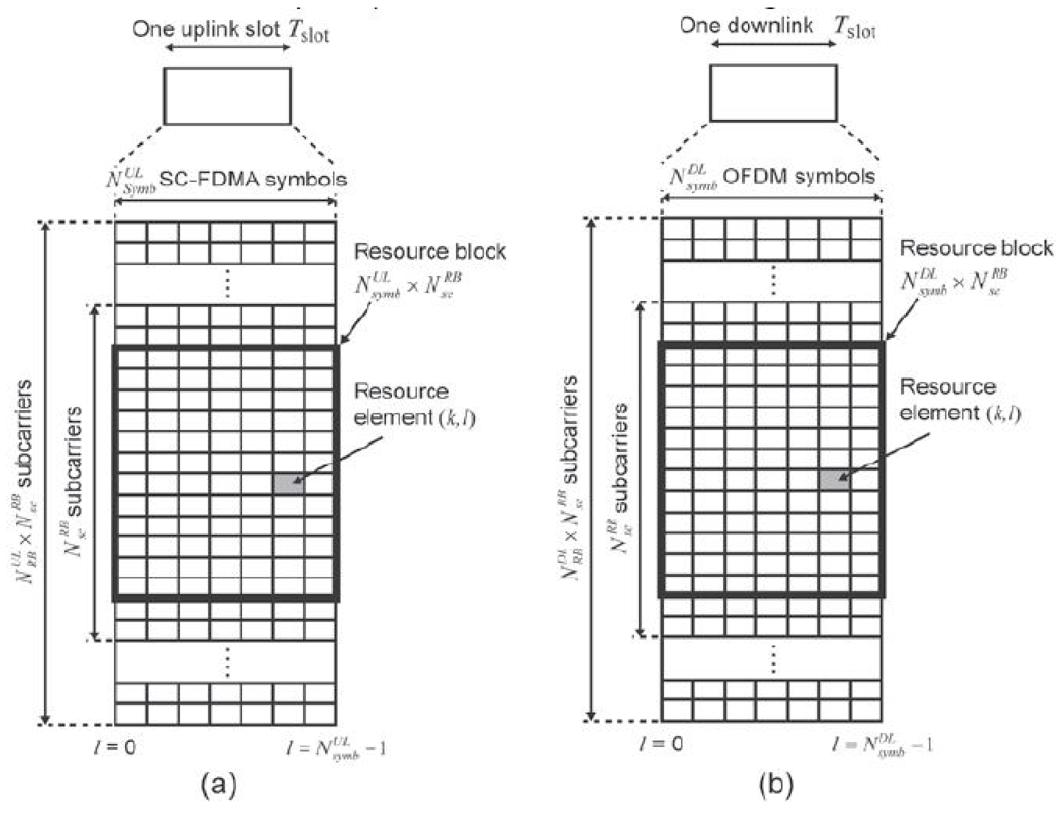

Figure 2.19 ResourceGrid for UPLINK (A) and DOWNLINK (B)

A resource block (RB) is the smallest unit that can be scheduled for transmission. An RB physicaly occupies 0.5 ms (1 slot) in the time domain and 180 kHz in the frequency domain. The number of subcarriers per RB and the number of symbols per RB vary as a function of the cyclic prefix length and subcarrier spacing, as shown in Figure 2.20. The obvious difference between the downlink and uplink is that the downlink transmission supports 7.5 kHz subcarrier spacing, which is used for multicast/broadcast over single frequency network (MBSFN). The 7.5 kHz subcarrier spacing means that the symbols are twice as long, which allows the use of a longer CP to combat the higher delay spread seen when receiving from multiple MBSFN cells[5].

Downlink configuration		N_{sc}^{RB}	N_{symb}^{DL}
Normal cyclic prefix	Δf = 15 kHz	12	7
Extended cyclic prefix	Δf = 15 kHz		6
	Δf = 7.5 kHz	24	3
Uplink configuration		N_{sc}^{RB}	N_{symb}^{UL}
Normal cyclic prefix		12	7
Extended cyclic prefix		12	6

Figure 2.20 Physical Resource Block Parameters

CHAPTER THREE
SYSTEM MODEL

3. Transmission Model of OFDMA and SC-FDMA

The simulation model of OFDMA and SC-FDMA in Matlab. The block diagrams of OFDMA and SC-FDMA are given in figure 3.1 and figure 3.2 respectively.

Practically there are some losses in the system as compared to theoretical values, therefore i used the Additive White Gaussian Noise (AWGN) channel, which is commonly used to simulate the background noise of the channel. I used a built-in MATLABfunction awgn in which the noise level is described by SNR per sample, which is the actual input parameter to the awgn function.

Also introduce the frequency selective (multipath) fading in the channel and use the Rayleigh fading model which is a reasonable statistical fading model for multipath situation in the absences of LOS component.

Description of model:

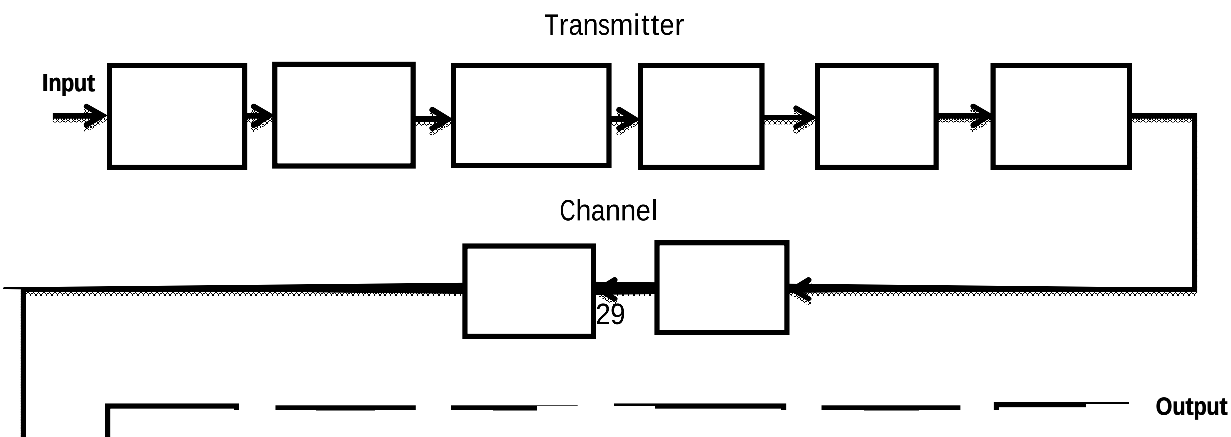

Figure 3.1: OFDMA Transmission Model

Description of model:

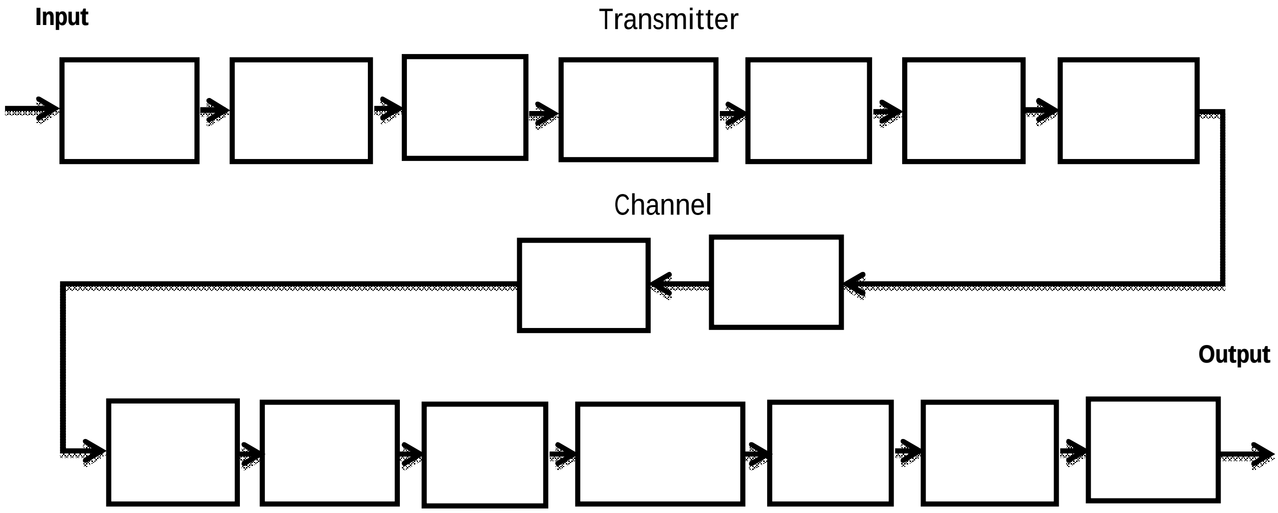

Figure 3.2: SC-FDMA Transmission Model

The adaptive modulation schemes bellow used to analyze the Peak to Average Power Ratio (PAPR), Bit Error Rate (BER), Signal to Noise Ratio (SNR), Error Probability (Pe) and Power Spectral Density (PSD) for both OFDMA and SC-FDMA.

- ✓ Binary Phase Shift Keying (BPSK)
- ✓ Quadrature Phase Shift Keying (QPSK)
- ✓ 16-Quadrature Amplitude Modulation (16-QAM)
- ✓ 64-Quadrature Amplitude Modulation (64-QAM)

The parameters selected for simulation are given in table 3.1.

Table 3.1 Parameters used for Simulation

PARAMETERS	ASSUMPTION
Number of Sub-carriers	512
Modulation	BPSK, QPSK,16QAM,64QAM
Data Block Size	16 (Number of Symbols)
System Bandwidth	5 MHz
Number of iterations	10^3
Oversampling factor	4
Fading	Rayleigh (frequency selective)
Rayleigh fading parameters	Input sample period = 1e^{-3} sec Maximum Doppler shift = 100 Hz Vector path delays = [0 2 e^{-5}] sec Average path gain vector = [0 -9] dB
Channel	AWGN (SNR = 100 dB)
Confidence Interval	32 times
CP Length	64
Range of SNR in dB	0 to 30

CHAPTER FOUR

SIMULATION RESULTS

4.1 BER vs SNR of OFDMA and SC-FDMA

The BER vs SNR of OFDMA and SC-FDMA are shown in figure 4.1 and figure 4.2 respectively.

In Table 4.1 and 4.2, theobservations are taken for a specific value of BER ($1e^{-3}$). In both OFDMA and SC-FDMA, the BPSK and QPSK have same SNR values of 6.8 and 6.5 respectively, but a sudden change occur in 16-QAM and 64-QAM. The 64-QAM has highest value of SNR (16.4) which shows that 64-QAM is more efficient in terms BER.

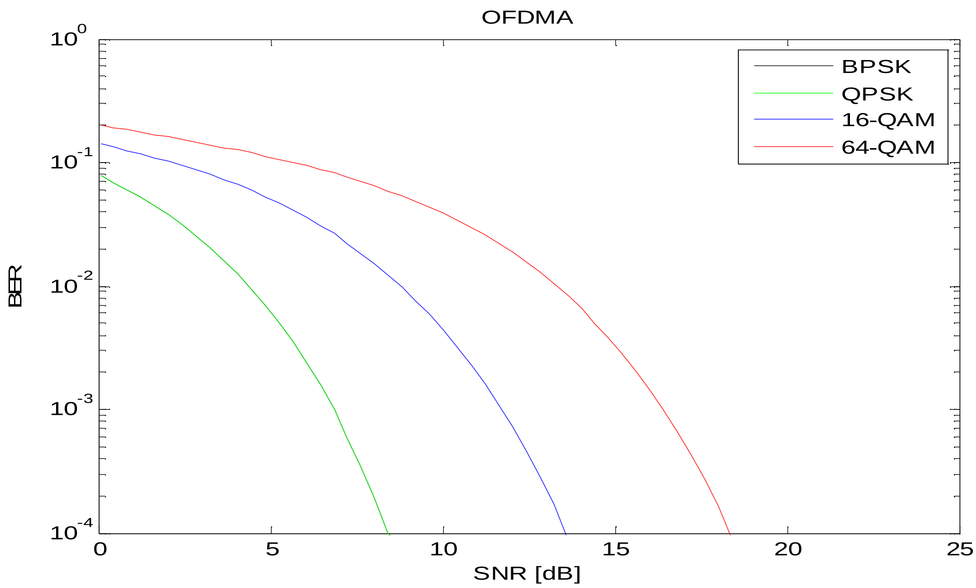

Figure 4.1: BER vs SNR of OFDMA with Adaptive Modulation

Table 4.1: BER vs SNR for OFDMA

Modulation Scheme	Bits per Symbol	SNR(db)
BPSK	1	6.8
QPSK	2	6.8
16-QAM	4	11.6
64-QAM	6	16.4

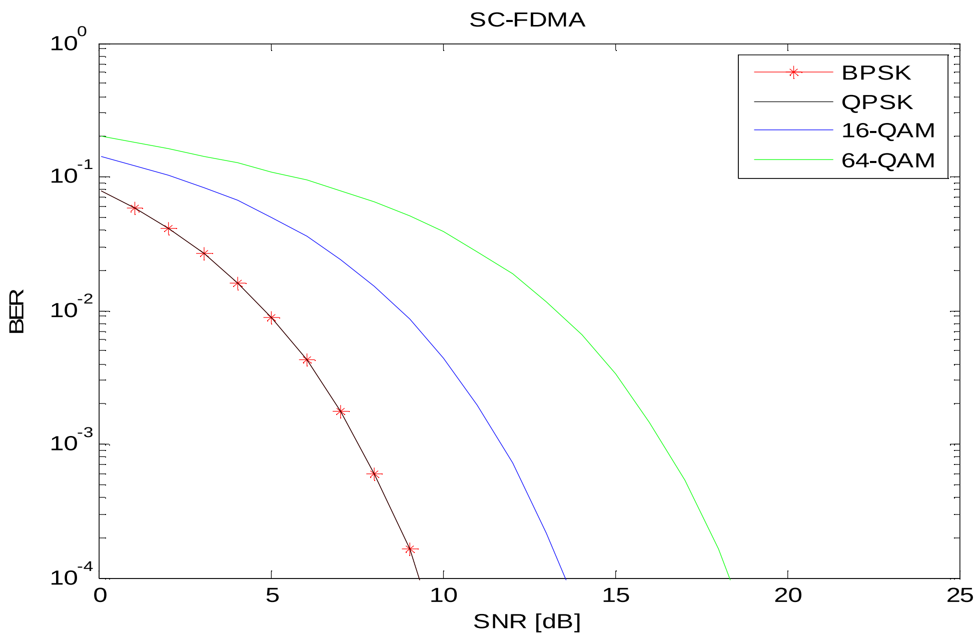

Figure 4.2: BER vs SNR of SC-FDMA with Adaptive Modulation

Table 4.2: BER vs SNR for SCFDMA

Modulation Scheme	Bits per Symbol	SNR(db)
BPSK	1	6.5
QPSK	2	6.5
16-QAM	4	11.7
64-QAM	6	16.4

4.2Error Probability of OFDMA and SC-FDMA for Adaptive Modulation

The error probability graphs of OFDMA and SC-FDMA are shown in figure 4.3 and figure 4.4 respectively.

From Table 4.3 and 4.4, observed that for a specific value of P_e ($1e^{-0.5}$) the BPSK modulation has less value of SNR as compared to other modulations. The 64-QAM has higher SNR values in both OFDMA and SC-FDMA.

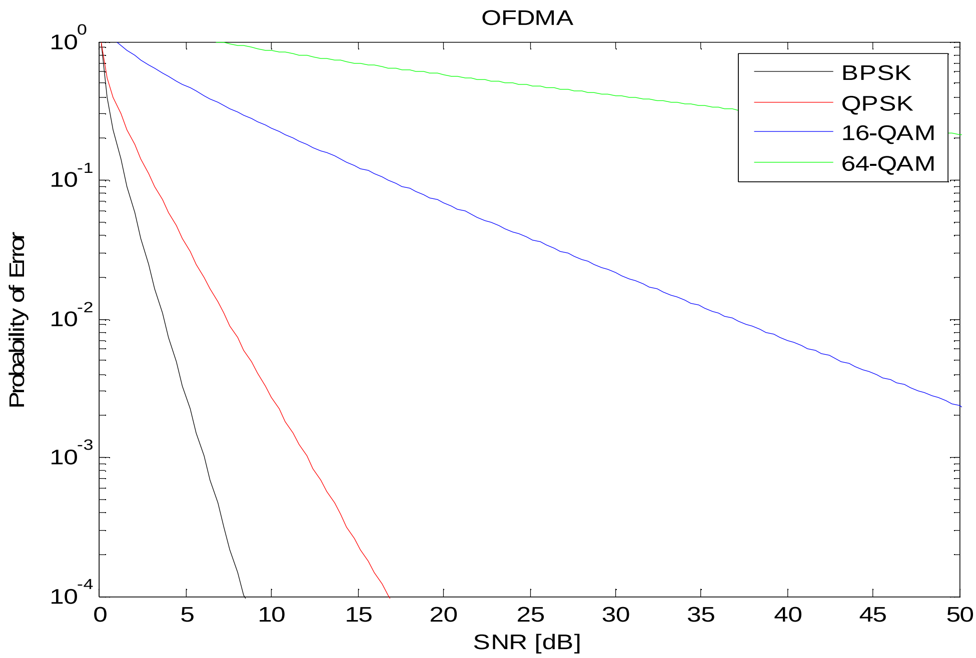

Figure4.3:ProbabilityError of OFDMA

Table 4.3: Error Probability for OFDMA

Modulation Scheme	Bits per Symbol	SNR(db)
BPSK	1	1
QPSK	2	2.6
16-QAM	4	8.4
64-QAM	6	56

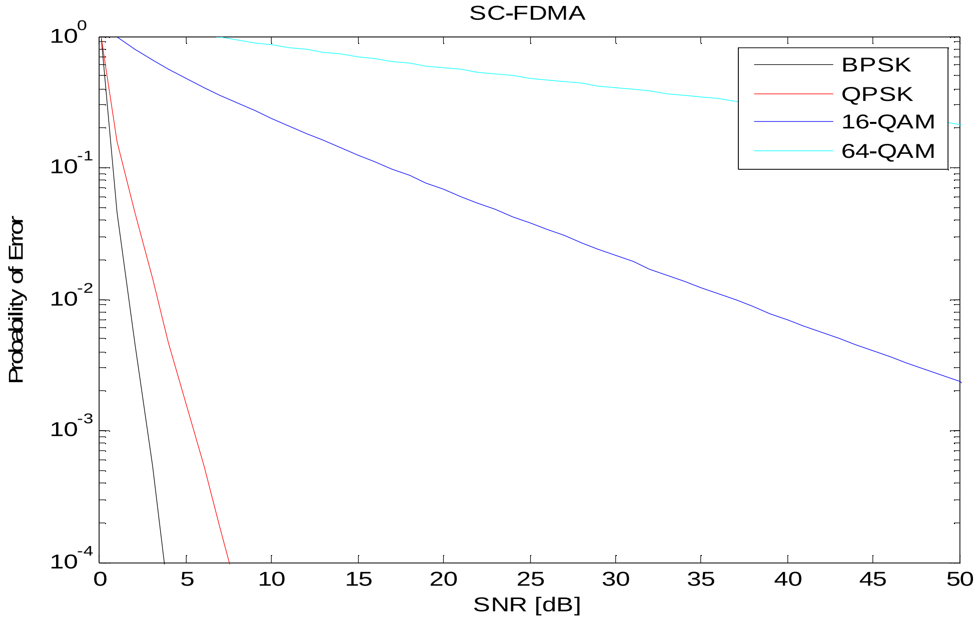

Figure4.4:ErrorProbability of SC-FDMA

Table 4.4: Error Probability for SC-FDMA

Modulation Scheme	Bits per Symbol	SNR(db)
BPSK	1	1
QPSK	2	2
16-QAM	4	8
64-QAM	6	39

4.3 Power Spectral Density of OFDMA and SC-FDMA

The power spectral density of OFDMA and SC-FDMA are shown in figure 4.5 and figure 4.6 respectively.

Figure 4.5 and Figure 4.6 shows the power spectral density of the OFDMA and SC-FDMArespectively. We observed that the average power of all SC-FDMA symbols (512) is nearly-375dB, whereas, in case of OFDMA the average power of all symbols is nearly -400dB.This shows that the SC-FDMA symbols have inherently more average power as compared to OFDMA at all frequencies. This result also shows the transmit power requirements of OFDMA and SC-FDMA symbols which is covered in next section of PAPR.

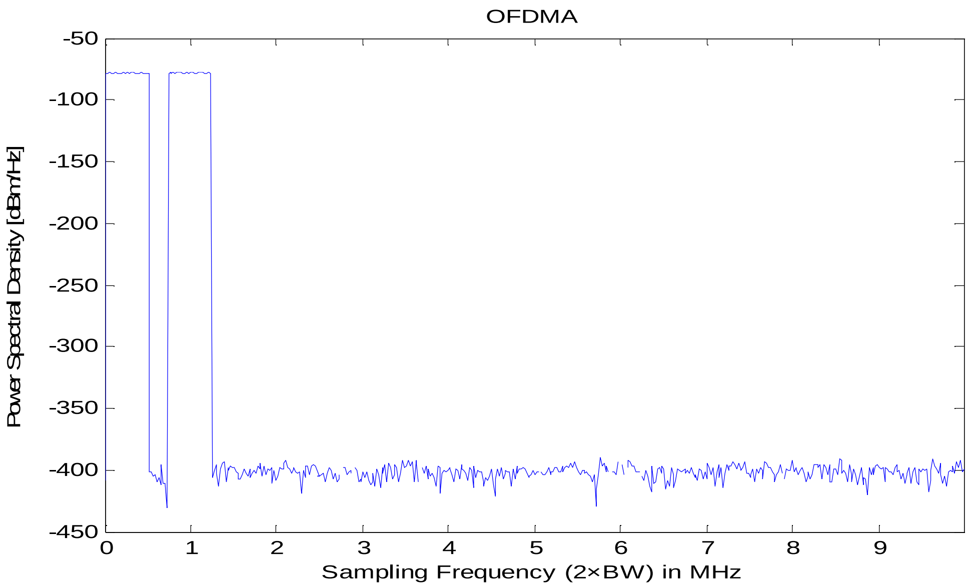

Figure 4.5: Power Spectral Density of OFDMA

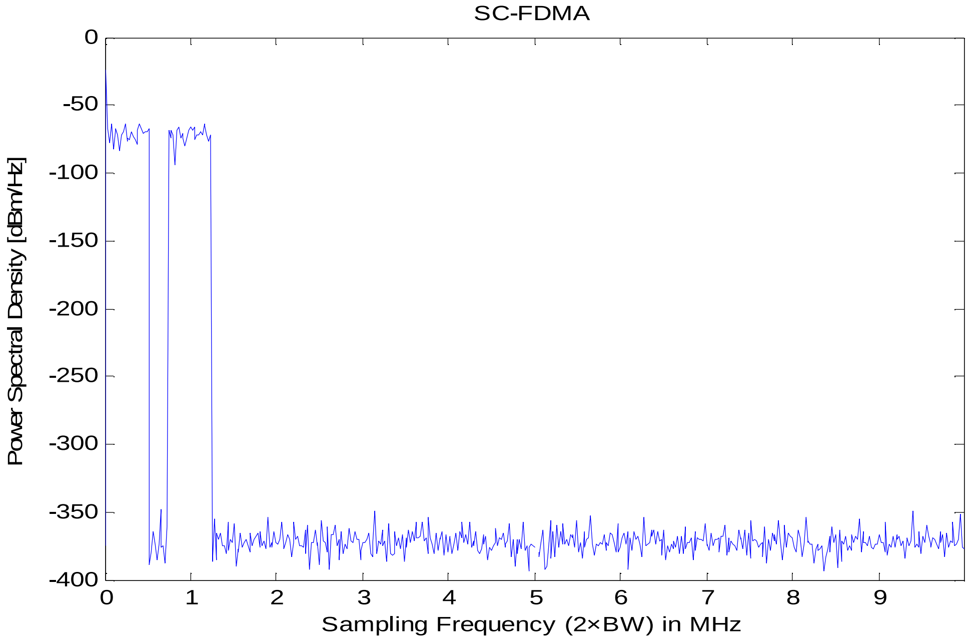

Figure 4.6: Power Spectral Density of SC-FDMA

4.4 PAPR of OFDMA and SC-FDMA for Adaptive Modulation

4.4.1 BPSK and QPSK:

The PAPR of OFDMA and SC-FDMA for BPSK and QPSK modulations are shown in figure 4.7 and figure 4.8 respectively.From figure 4.7 and figure 4.8, we observed that the PAPR value of SC-FDMA is almost similar for both modulation schemes i.e.

7dB. Whereas the PAPR value of OFDMA slightly decreases in case of QPSK modulation.

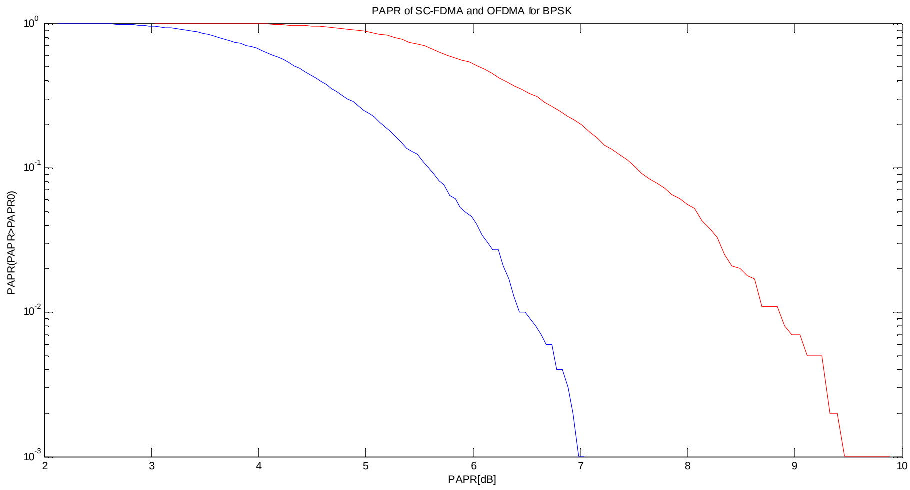

Figure4.7: PAPR ofOFDMA andSC-FDMAforBPSK

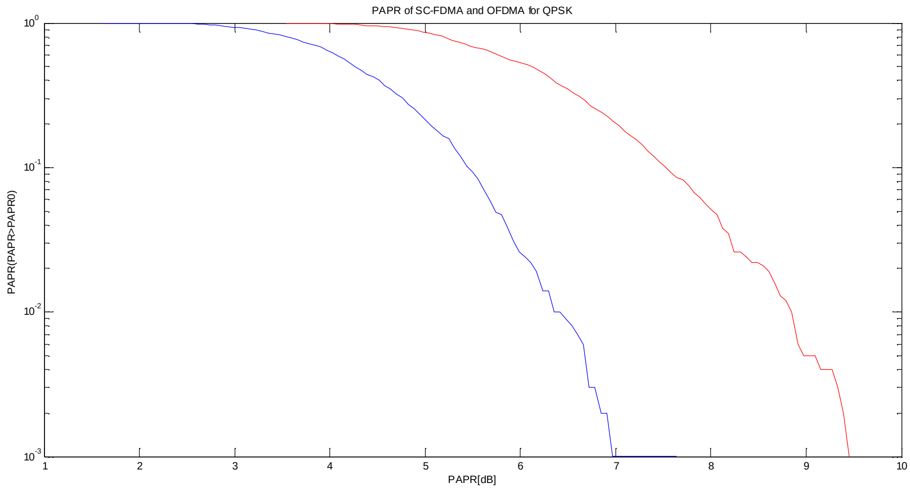

Figure 4.8: PAPR of OFDMA and SC-FDMA for QPSK

4.4.2 16-QAM and 64-QAM

The PAPR of OFDMA and SC-FDMA for 16-QAM and 64-QAM are shown in figure 4.9 and figure 4.10 respectively.From figure 4.9 and figure 4.10, we observed that by increasing the order of modulation, the PAPR of SC-FDMA increases from 7.7 dB to 8.1 dB (in case of 16-QAM) and becomes 8.1db (in case of 64- QAM). Hence for SC-FDMA the PAPR increases for higher order modulation, whereas for OFDMA the PAPR decreases for higher order modulation (64-QAM).

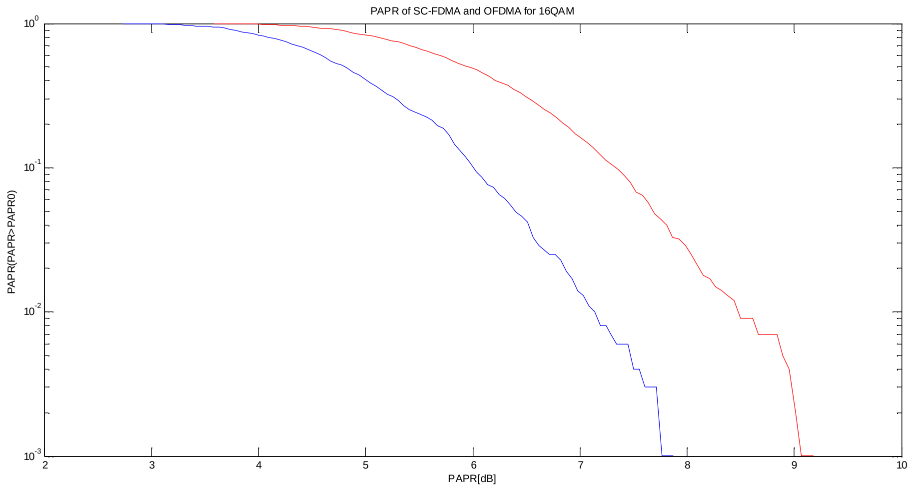

Figure 4.9: PAPR of OFDMA and SC-FDMA for 16-QAM

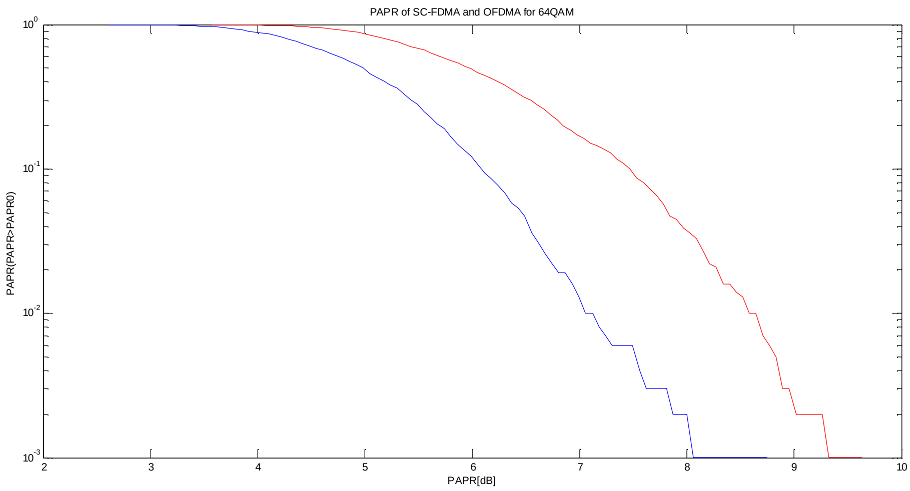

Figure4.10: PAPR ofOFDMA andSC-FDMAfor64-QAM

CONCLUSIONS& RECOMMENDATIONS

BER is the key parameter for indicating the system performance of any data link. In our research we analyze that for a fix value of SNR, the BER increases for high order modulation (16-QAM and 64-QAM) in both the multiple access techniques (OFDMA and SC-FDMA). On the other hand, the lower order modulation schemes (BPSK and QPSK) experience less BER at receiver thus lower order modulations improve the system performance in terms of BER and SNR. If considered the bandwidth efficiency of these modulation schemes, the higher order modulation accommodates more data within a given bandwidth and is more bandwidth efficient as compare to lower order modulation. Thus there exists a tradeoff between BER and bandwidth efficiency among these modulation schemes.

Also conclude from our results that, the error probability increases as order of modulation scheme increases. Therefore the selection of modulation schemes in adaptive modulation is quite crucial based on these results.

The power consumption at the user end such as portable devices is again a vital issue for uplink transmission. From my simulation results also conclude that the higher order modulation schemes have an impact on the PAPR of both OFDMA and SC-FDMA. The PAPR increases in SC-FDMA and slightly decreases in OFDMA for higher order modulation schemes. The overall value of PAPR in SC-FDMA is still less than that of OFDMA in all modulation schemes, and that is why it has been adopted for uplink transmission in LTE system. Based on my result conclude to adopt low order modulation scheme i.e. BPSK, QPSK and 16-QAM for uplink in order to have less PAPR at user end.

The conclusive remarks on PAPR are also supported by the results of PSD calculations. The average power distributed on all frequencies in SC-FDMA is greater than OFDMA. Therefore the peak transmits power requirements of SC-FDMA is relatively less as compare to OFDMA. Thus SC-FDMA is more power efficient.