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Performance Evaluation of LTE Physical Layer using OFDMA and SC-FDMA

A Research Submitted in Partial fulfillment for the Requirements of the Degree of B.Sc. (Honors) in Electronics Engineering

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استهلال

بسم الله الرحمن الرحيم

(أَلَمْ تَرَ أَنَّ اللَّهَ أنزلَ مِنَ السَّمَاء مَاء فَأَخْرَجْنَا بِهِ ثمَرَاتٍ مُّخْتَلِفًا أَلْوَانُهَا وَمِنَ الْجِبَالِ جُدَدٌ بِيضٌ وَحُمْرٌ مُّخْتَلِفٌ أَلْوَانُهَا وَغَرَابِيبُ سُودٌ وَمِنَ النَّاسِ وَالدَّوَابِّ وَالْأَنْعَامِ مُخْتَلِفٌ أَلْوَانُهُ كَذَلِكَ إِنَّمَا يَخْشَى اللَّهَ مِنْ عِبَادِهِ الْعُلَمَاء إِنَّ اللَّهَ عَزِيزٌ غَفُورٌ)

صدق الله العظيم

سورة فاطر الآيه 27

DEDICATION

We dedicate this work to the souls of those whom we love since our childhood and it remains forever, our beloved mothers, fathers. the moments and days with them shall not be forgotten.

Acknowledgement

First of all we give thanks to Allah for blessing us and giving us the power to achieve this work. With a deep sense of gratitude, we wish to express our sincere thanks to our supervisor Dr. Mohammed Hussein, we truly appreciate his esteemed guidance, encouragement and constructive criticisms from the beginning to the end of this thesis, without his help and support this thesis wouldn't has been done.

We would like to thank all people who support and motivate us to accomplish this work.

Most important of all, thanks to our families for their great support all the time.

Abstract

Since past few decades different types of cellular networks were launched and went successful on the radio links such as WiMAX, that became very popular because of its high data rate (70Mbps) and support for providing wireless internet services over 50km distance. The UMTS Long Term Evolution (LTE) is an emerging technology in the evolution of 3G cellular services. LTE runs on an evolution of the existing UMTS infrastructure already used by over 80 percent of mobile subscribers globally. We have very limited resources in cellular technologies and it is important to utilize them with high efficiency.

Single Carrier Frequency Division Multiple Access (SC-FDMA) & Orthogonal Division Multiple Access (OFDMA) are major part of LTE. OFDMA was well utilized for achieving high spectral efficiency in communication system. SC-FDMA is introduced recently and it became handy candidate for uplink multiple access scheme in LTE system that is a project of Third Generation Partnership Project (3GPP).

The Multiple Access Scheme in Advanced Mobile radio system has to meet the challenging requirements for example high throughput, good robustness, efficient Bit Error Rate (BER), high spectral efficiency, low delays, low computational complexity, low Peak to Average Power Ratio (PAPR), low error probability etc. Error probability is playing vital role

in channel estimation and there are many ways to do channel estimation, like Wiener Channel Estimation, Bayesian Demodulation etc.

In our thesis, we investigate the performance of SC-FDMA and OFDMA of LTE physical layer by considering different modulation schemes (BPSK, QPSK, 16QAM and 64QAM) on the basis of PAPR, BER, power spectral density (PSD) and error probability by simulating the model of SC-FDMA & OFDMA.

المستخلص

أطلقت منذ العقود السابقة أنواع مختلفة من الشبكات الخلوية ونجحت في الاتصالات الراديوية مثل شبكة واي ماكس التي أصبحت منتشرة جداً بسبب ارتفاع معدل نقل البيانات التي تصل إلى 70 ميجا بت للثانية كما أنها توفر خدمات الانترنت لاسلكياً لمسافة تصل لمسافة 50 كيلو متر.

الجيل الرابع (تطوير طويل الأجل) هي تقنية ناشئة من تطوير الجيل الثالث للخدمات الخلوية تعمل على تطوير البنية التحتية المستخدمة حالياً التي تمثل 80% من مستخدمين الهاتف النقال على مستوى العالم، لدنيا موارد بسيطة جداً في مجال التكنولوجيا الخلوية وانه من المهم الاستفادة منها بكفاءة عالية.

تقنية الوصول المتعدد ذات تردد الحامل الواحد وتقنية الوصول المتعدد ذات الترددات المتعامدة هما الجزء الأساسي في الجيل الرابع. تستخدم تقنية الوصول المتعدد ذات الترددات المتعامدة لتحقيق كفاءة طيفية عالية في نظام الاتصالات أما تقنية الوصول المتعدد ذات تردد الحامل الواحد عرضت مؤخراً واستخدمت لنظام الإرسال متعدد الوصول في الجيل الرابع (تطور طويل الأجل).

تقنية الوصول المتعدد في الأنظمة الراديوية المتنقلة المطورة تواجه تحديات لتلبية متطلبات صعبة على سبيل المثال إنتاجية عالية ، متانة جيدة ، كفاءة نسبة الخطأ في البت ، الكفاءة الطيفية العالية ، التأخير ، انخفاض التعديل الحسابي ، انخفاض الذروة إلى مستوى الطاقة وانخفاض احتمالية الخطأ. احتمال حدوث الخطأ يلعب دوراً حيوياً في تقييم القناة وهناك عدة طرق لتقييم القناة مثل وينير لتقيم القناة وبايزين الاستخلاص الخ.

في مشروعنا سنتحقق من كفاءة أدائية تقنية الوصول المتعدد ذو تردد الحامل الواحد. وتقنية الوصول المتعدد ذو الترددات المتعامدة في نظام الجيل الرابع (تطور طويل الأجل) باستخدام تقنيات تعديل مختلفة عن طريق الذروة على متوسط نسبة الطاقة ، نسبة الخطأ في البت ، كثافة قدرة الطاقة واحتمالية حدوث الخطأ وذلك بمحاكاة تقنية الوصول المتعدد ذات الترددات المتعامدة وتقنية الوصول المتعدد ذات تردد الحامل الواحد.

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project
ACK	Acknowledgment
ARQ	Automatic Repeat Request
ASK	Amplitude Shift Keying
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCE	Control Channel Elements
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CQI	Channel Quality Indicators
CDMA	Code Division Multiple Access
CIR	Channel Impulse Response
DCI	Downlink Control Information
DFT	Discrete Fourier Transform
DL	Downlink
DM-RS	Demodulation Reference Signals
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FSK	Frequency Shift Keying
GSM	Global System for Mobile Communication
HARQ	Hybrid Automatic Repeat Request
ICI	Inter Carriers Interference
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
ISI	Inter Symbol Interference

LTE	Long Term Evolution
MAC	Medium Access Control Layer
MBMS	Multimedia Broadcast and Multicast Services
MIMO	Multiple Input Multiple Output
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplex Access
PAPR	Peak-to-Average Power Ratio
PE	Error Probability
PHY	Physical Layer
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SC-FDMA	Single Carrier Frequency Division Multiple Access
SFBC	Space Frequency Block Code
SDMA	Space Division Multiple Access
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
WCDMA	Wideband Code Division Multiple Access

Chapter one

Introduction

1.1 Preface

The long term evolution (LTE) is one of the latest steps in cellular 3G services. LTE is launched by 3rd Generation Partnership Project (3GPP) and that project was started in 2004. It brought many benefits to cellular networks in terms of bandwidth, latency, data rates, spectral efficiencies etc.

The OFDM is used in LTE as multiplexing scheme, LTE uses SCFDMA For uplink and OFDMA for downlink transmission.SC-FDMA was introduced in LTE in order to save power from uplink transmission. The LTE increases the system capacity and widens the spectrum From existing technology up to 20MHz. It can be deployed in any Bandwidth combination because of its flexible usage of spectrum (1.4 MHz to 20 MHz). It uses Frequency Division Duplex (FDD) and Time Division Duplex (TDD) to suit all types of spectrum resources [1].

Designing an efficient wireless communication system is always a challenge. There are many factors involved in the performance of a system. Single Carrier Frequency Division Multiple Access (SC-FDMA) & Orthogonal Division Multiple Access (OFDMA) are a major part of future mobile communication standards like Long Term Evolution (LTE), LTE-Advanced and Ultra Mobile Broadband (UMB). OFDMA is well utilized for achieving high spectral efficiency in communication systems. SC-FDMA was recently introduced and has become handy candidate for uplink multiple access scheme.

The multiple access schemes in an advanced mobile radio system have to meet the challenging requirements for example high throughput, good robustness, low Bit Error Rate (BER), high spectral efficiency, low delays, low computational complexity, low Peak to Average Power Ratio (PAPR), low error probability.

1.2 Scope

Evolution the performance of LTE physical layer using OFDMA and SCFDMA.

1.3 Problem Statement:

A principal weakness of OFDM is the high peak-to-average power ratio (PAPR). The transmitted signal is the sum of all the modulated subcarriers and high amplitude peaks are inevitable because many of the subcarriers are in phase for some input sequences. The amplitude peaks impose a heavy burden on the power amplifier of a transmitter. Relative to time-domain transmission techniques, OFDM is also more vulnerable to frequency offset and frequency selective fading.

1.4 Proposed Solution:

Performance evaluation and comparison between OFDMA and SC-FDMA in term of different modulations and parameters such as (PAPR , BER , SNR , Error probability and PSD) , and to overcome the drawbacks of OFDMA specially the PAPR , the SC-FDMA was used on uplink transmission .

1.5 Research Objectives:

To evaluate the performance of LTE physical layer in term of the following performance parameters: SNR, BER, PSD, PAPR and Probability of Error . Using different modulation techniques (BPSK, QPSK, 16-QAM and 64-QAM)

1.6 Methodology:

More studies were made on the background of LTE, OFDMA and SC-FDMA, and the drawbacks, uses of both of them.

A problem was discovered in the OFDAM downlink transmission

Called PAPR, MATLAB was used to simulate SC-FDMA and OFDMA systems with description of transmission and receiving processes with adaptive modulation techniques BPSK, QPSK, 16-QAM and 64-QAM. Considered SNR, BER, PSD, bit error probability and PAPR parameters to evaluate the performance of LTE physical layer for both uplink and downlink.

1.7 Research Outlines:

- Chapter 1: introduction, the Scope and objective, methodology, problem statement and proposed solution.
- Chapter 2: More information about LTE, Related works, LTE performance demand, frequency and bandwidth, multiple access schemes of OFDMA and SC-FDMA and MIMO.
- Chapter 3: system design and analyses for OFDMA and SC-FDMA.
- Chapter 4: Simulate results and discussion.
- Chapter 5: conclusion and recommendation for future works.

Chapter two

Literature Review

2.1. Introduction

The long term evolution (LTE) is one of the latest steps in cellular 3G services. LTE is launched by 3rd Generation Partnership Project (3GPP) and that project was started in 2004. It brought many benefits to cellular networks in terms of bandwidth, latency, data rates, spectral efficiencies etc.

The OFDM is used in LTE as multiplexing scheme; LTE uses SC-FDMA for uplink and OFDMA for downlink transmission. SC-FDMA was introduced in LTE in order to save power from uplink transmission.

The LTE increases the system capacity and widens the spectrum from existing technology up to 20MHz. It can be deployed in any bandwidth combination because of its flexible usage of spectrum (1.4 MHz to 20 MHz). It uses Frequency Division Duplex (FDD) and Time Division Duplex (TDD) to suit all types of spectrum resources.

2.2 LTE Performance Demands:

The main requirements for designing the LTE Systems are summarized as Date Rate, Bandwidth, Peak Spectral Efficiency, Spectral Efficiency of Cell Edge, Average Cell Spectral Efficiency and latency. [1]

For 20 MHz spectrum, the target for peak data rate is 50 Mbps (for uplink) and 100 Mbps (for downlink).

In 3GPP technology family, there were considered both the wideband (WCDMA with 5MHz) and the narrowband (GSM with 200 kHz). Therefore the new system is now required to facilitate frequency allocation flexibility with 1.25/2.5, 5, 10, 15 and 20 MHz allocations [1].

The peak spectral efficiency requirement for downlink is 5 bps/Hz or higher, and for uplink is 2.5 bps/Hz or higher.

The requirement for spectral efficiency of cell edge is 0.04-0.06 bps/Hz/user for downlink and 0.02-0.03 bps/Hz/user for uplink, with assumption of 10users/cell.

The average cell spectral efficiency required for downlink is 1.6-2.1 bps/Hz/cell and for uplink it is 0.66-1.0 bps/Hz/cell.

The LTE control-plane latency (transition time to active state) is less than 100 ms (for idle to active), and is less than 50 ms (for dormant to active). The user-plane latency is less than 10 ms from UE (user end) to server.

Security and mobility in 3GPP technology is used at good level with the earlier systems starting from GSM and it is sustained at that level and higher.

2.3 Frequency and Bandwidth:

LTE operates in some of the existing cellular bands as well as newer bands. Different carriers use different bands depending upon the country of operation and the nature of their spectrum holdings. Most LTE phones use two of these bands, and they aren't the same from carrier to carrier.

Most of the bands are set up for frequency division duplexing (FDD), which uses two separate bands for uplink and downlink. The spacing between FDD channels in bands 1 through 28 varies considerably depending on carrier spectrum holdings. Bands 33 through

44 are used for time division duplexing (TDD), so the same frequencies are used for both uplink and downlink.

LTE is a broadband wireless technology that uses wide channels to achieve high data rates and accommodate lots of users. The standard is set up to permit bandwidths of 1.4, 3, 5, 10, 15, and 20 MHz. The carrier selects the bandwidth depending on spectrum holdings as well as the type of service to be offered. The 5- and 10-MHz widths are the most common. Some bandwidths cannot be used in different bands.

2.4 Multiple Input /multiple Output (MIMO):

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.

The two main formats for MIMO are given below:

- **Spatial diversity**: Spatial diversity used in this narrower sense often refers to transmit and receive diversity. These two methodologies are used to provide improvements in the signal to noise ratio and they are characterized by improving the reliability of the system with respect to the various forms of fading.

- **Spatial multiplexing**: This form of MIMO is used to provide additional data capacity by utilizing the different paths to carry additional traffic, i.e. increasing the data throughput capability.

As a result of the use multiple antennas, MIMO wireless technology is able to considerably increase the capacity of a given channel while still obeying Shannon's law. By increasing the number of receive and transmit antennas it is possible to linearly increase the throughput of the channel with every pair of antennas added to the system. This makes MIMO wireless technology one of the most important wireless techniques to be employed in recent years. As spectral bandwidth is becoming an ever more valuable commodity for radio communications systems, techniques are needed to use the available bandwidth more effectively. MIMO wireless technology is one of these techniques.

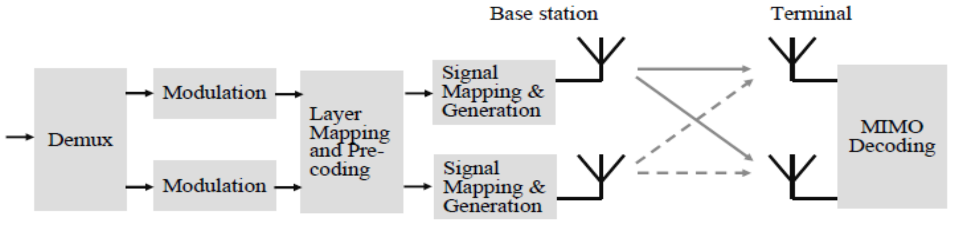

Figure 2-1: MIMO principle with two-by-two antenna configuration

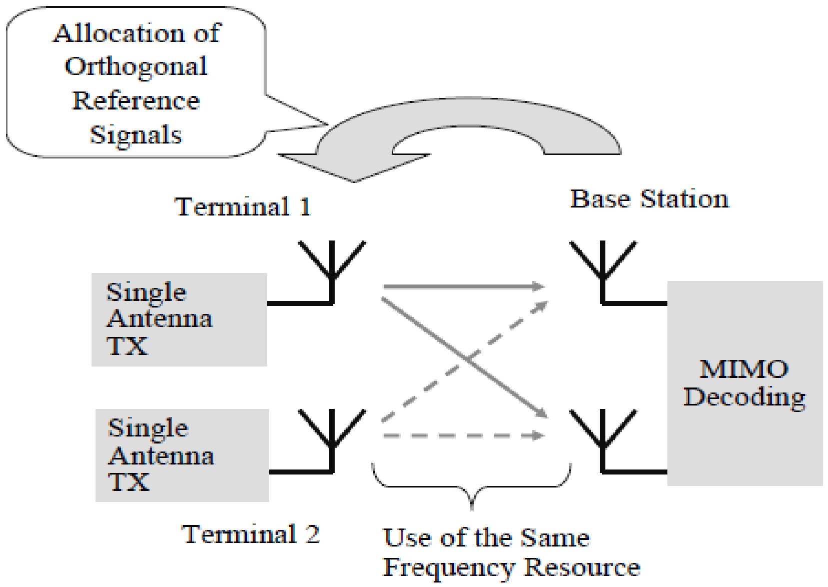

Figure 2-2 Multi-user MIMO principle with single transmit antenna devices

2.5 LTE Multiple Access Techniques:

The first major design in LTE was to adopt multicarrier approach for multiple access schemes [8]. After proposing this step the candidates for downlink were multiple WCDMA and OFDMA while the candidate for uplink were WCDMA, OFDMA and SC-FDMA. Finally in 2005 it was decided to select OFDMA as a downlink multiple access scheme and SC-FDMA for uplink.

Single-carrier means that the information is modulated to only one carrier by adjusting amplitude, phase or both of the carrier signal. The frequency can also be adjusted, but in LTE the frequency adjustment is not affected.

2.6 LTE Physical Layer:

The LTE Physical layer for downlink and uplink is quite different from each other. The downlink and uplink are treated separately; therefore it is described here accordingly.

2.6.1Generic Frame Structure:

The LTE frame structure is comprised of two types:

Type-1 LTE Frequency Division Duplex (FDD) mode systems

Type-2 LTE Time Division Duplex (TDD) mode systems.

2.6.1.1Type-1 LTE Frame Structure:

Type-1 frame structure works on both half duplex and full duplex FDD modes. This type of radio frame has duration of 10ms and consists of 20 slots, each slot has equal duration of 0.5ms [9]. A subframe consists of two slots; therefore one radio frame has 10 sub-frames as shown in figure 2-3. In FDD mode, downlink and uplink transmission is divided in frequency domain, such that half of the total sub-frames are used for downlink and half for uplink, in each radio frame interval of 10ms.

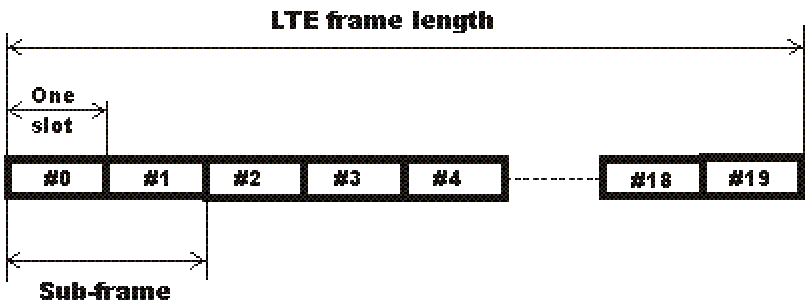

Figure 2-3: Type-1 LTE Frame Structure

2.6.1.2Type-2 LTE Frame Structure:

Type-2 frame structure is composed of two identical half frames of 5ms duration each. Both half frames have further 5 sub-frames of 1ms duration as illustrated in figure 2-4 [9].

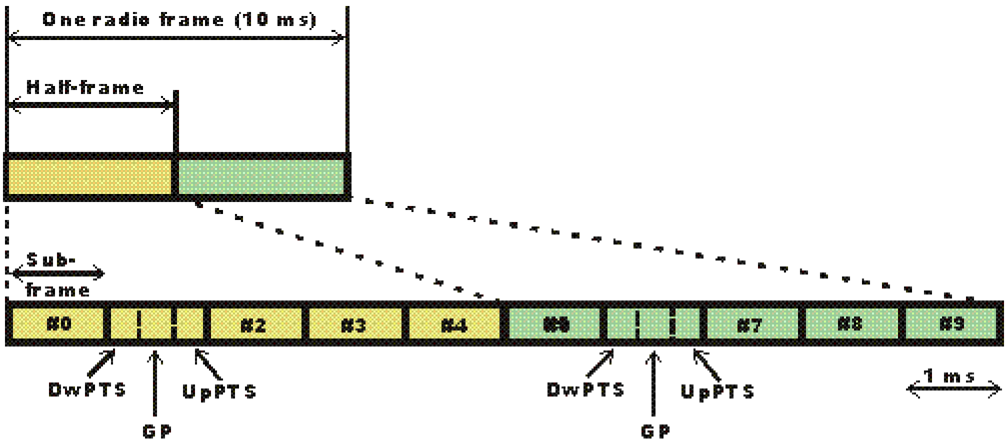

Figure 2-4: Type-2 LTE Frame Structure

2.7 Motivation of LTE

The work towards 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) started in 2004 with the definition of the targets. Even though HSDPA was not yet deployed at that time, it became evident that work for the next radio system should be started. It takes more than 5 years from setting the system targets to commercial deployment using interoperable standards. Therefore, system standardization must be started early enough to be ready by the time the need is there. A few driving forces can be identified advancing LTE development: wire line capability evolution, the need for additional wireless capacity, the need for lower cost wireless data delivery and the competition of other wireless technologies. As wire line technology keeps improving, a similar evolution is required in the wireless domain to make sure that the applications also work fluently in the wireless domain. There are also other wireless technologies – including IEEE 802.16 – which promise high data capabilities. 3GPP technologies must match and exceed the competition. More capacity is a clear requirement for taking maximum advantage of the available spectrum and base station sites. These reasons are summarized in Figure 2-5.

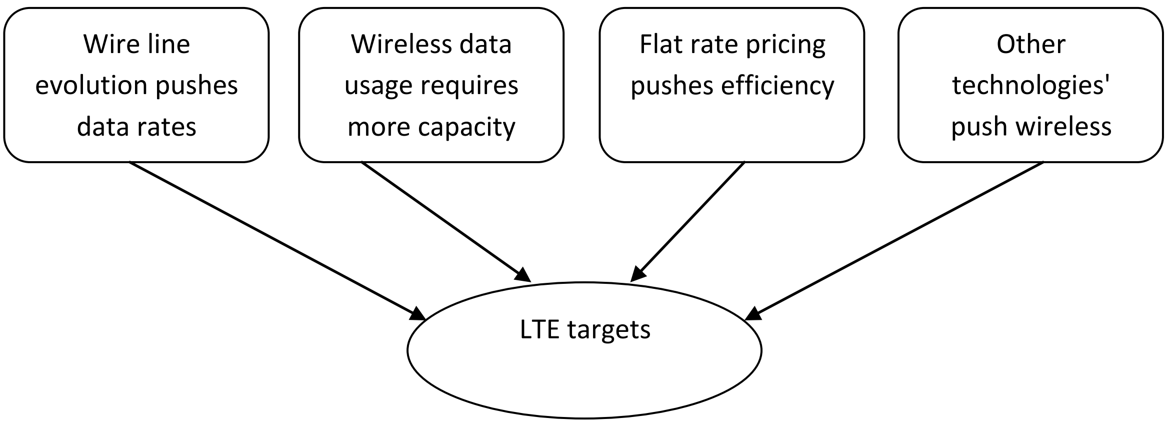

Figure 2-5: Driving LTE development

LTE must be able to deliver superior performance compared to existing 3GPP networks based on High Speed Packet Access (HSPA) technology. The performance targets in 3GPP are defined relative to HSPA in Release 6. The peak user throughput should be minimum 100 Mbps in downlink and 50 Mbps in uplink, which is ten times more than HSPA Release 6. Also the latency must be reduced in order to improve the end user performance. The terminal power consumption must be minimized to enable more usage of the multimedia applications without recharging the battery [1] [2].

2.8 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

2.9 Multiple Access Schemes:

Multiple accesses is 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)

2.9.1 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).

2.9.2 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.

2.9.3 Code Division Multiple Access (CDMA):

CDMA uses spread spectrum technology. In CDMA, all users use the entire spectrum of the system based on code words. 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 [9]. 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.

2.9.4 Space Division Multiple Access (SDMA):

In SDMA, the transmitted energy is controlled in the direction of particular user in space [9]. 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.

2.9.5 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.

2.9.6 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.

The LTE uses SC-FDMA for uplink and OFDMA for downlink transmission then we discuss OFDMA and SC-FDMA basics in details in the next sections.

2.10 OFDMA Basics

The practical implementation of an OFDMA system is based on digital technology and more specifically on the use of Discrete Fourier Transform (DFT) and the inverse operation (IDFT) to move between time and frequency domain representation. The resulting signal feeding a sinusoidal wave to the Fast Fourier Transform (FFT) block is illustrated in Figure 2-6 the practical implementations use the FFT. The FFT operation moves the signal from time domain representation to frequency domain representation

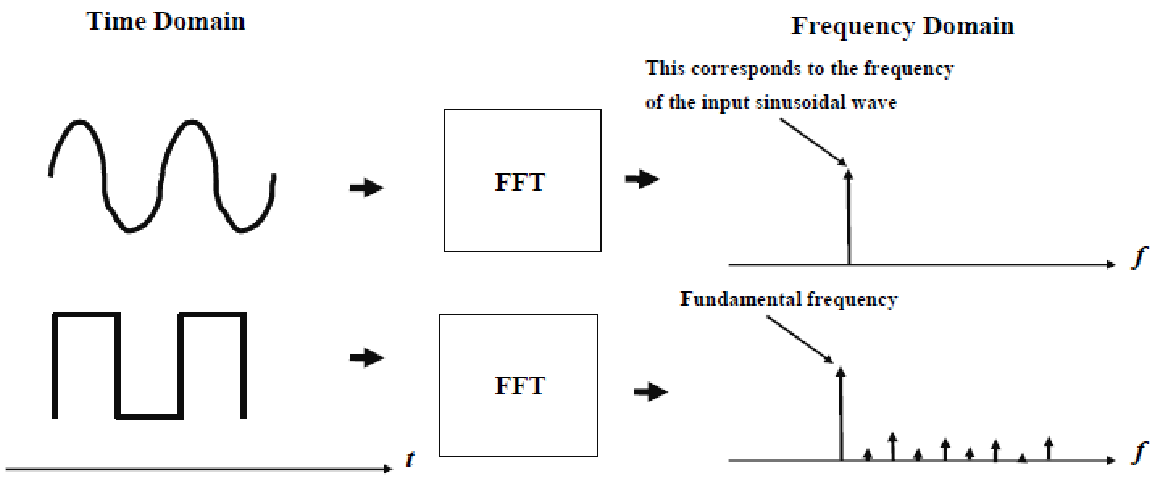

Figure 2-6: Results of the FFT operation with different input

The FFT operation moves the signal from time domain representation to frequency domain representation. The Inverse Fast Fourier Transform (IFFT) does the operation in the opposite direction. For the sinusoidal wave, the FFT operation's output will have a peak at the corresponding frequency and zero output elsewhere. If the input is a square wave, then the frequency domain output contains peaks at multiple frequencies as such a wave contains several frequencies covered by the FFT operation. An impulse as an input to FFT would have a peak on all frequencies. As the square wave has a regular interval *T*, there is a bigger peak at the frequency 1/*T* representing the fundamental frequency of the waveform, and a smaller peak at odd harmonics of the fundamental frequency. The FFT operation can be carried out back and forth without losing any of the original information, assuming that the classical requirements for digital signal processing in terms of minimum sampling rates and word lengths (for the numeric's) are fulfilled. The implementation of the FFT is well researched and optimized (low amount of multiplications) when one can stay with power of lengths. Thus for LTE the necessary FFT lengths also tend to be powers of two, such as 512, 1024, etc. From the implementation point of view it is better to have, for example, a FFT size of 1024 even if only 600 outputs are used (see later the discussion on sub-carriers), than try to have another length for FFT between 600 and 1024. The transmitter principle in any OFDMA system is to use narrow, mutually orthogonal subcarriers. In LTE the sub-carrier spacing is 15 kHz regardless of the total transmission bandwidth. Different sub-carriers are orthogonal to each other, as at the sampling instant of a single subcarrier the other sub-carriers have a zero value the transmitter of an OFDMA system uses IFFT block to create the signal. The data source feeds to the serial to parallel conversion and further to the IFFT block. Each input for the IFFT block corresponds to the input representing a particular sub-carrier (or particular frequency component of the time domain signal) and can be modulated independently of the other sub-carriers. The IFFT block is followed by adding the cyclic extension (cyclic prefix), the motivation for adding the cyclic extension is to avoid inter-symbol interference. When the transmitter adds a cyclic extension longer than the channel impulse response, the effect of the previous symbol can be avoided by ignoring (removing) the cyclic extension at the receiver. [6]

2.11 SC-FDMA Basics

In the uplink direction 3GPP uses SC-FDMA for multiple access, it use single carrier for transmission valid for both FDD and TDD modes of operation. The basic form of SC-FDMA could be seen as equal to the QAM modulation, where each symbol is sent one at a time similarly to Time Division Multiple Access (TDMA) systems such as GSM. Frequency domain generation of the signal, as shown in Figure 2-7, adds the OFDMA property of good spectral waveform in contrast to time domain signal generation with a regular QAM modulator. Thus the need for guard bands between different users can be avoided, similar to the downlink OFDMA principle. As in an OFDMA system, a cyclic prefix is also added periodically – but not after each symbol as the symbol rate is faster in the time domain than in OFDMA – to the transmission to prevent inter-symbol interference and to simplify the receiver design. The receiver still needs to deal with inter-symbol interference as the cyclic prefix now prevents inter symbol interference between a block of symbols, and thus there will still be inter-symbol interference between the cyclic prefixes. The receiver will thus run the equalizer for a block of symbols until reaching the cyclic prefix that prevents further propagation of the inter-symbol interference.

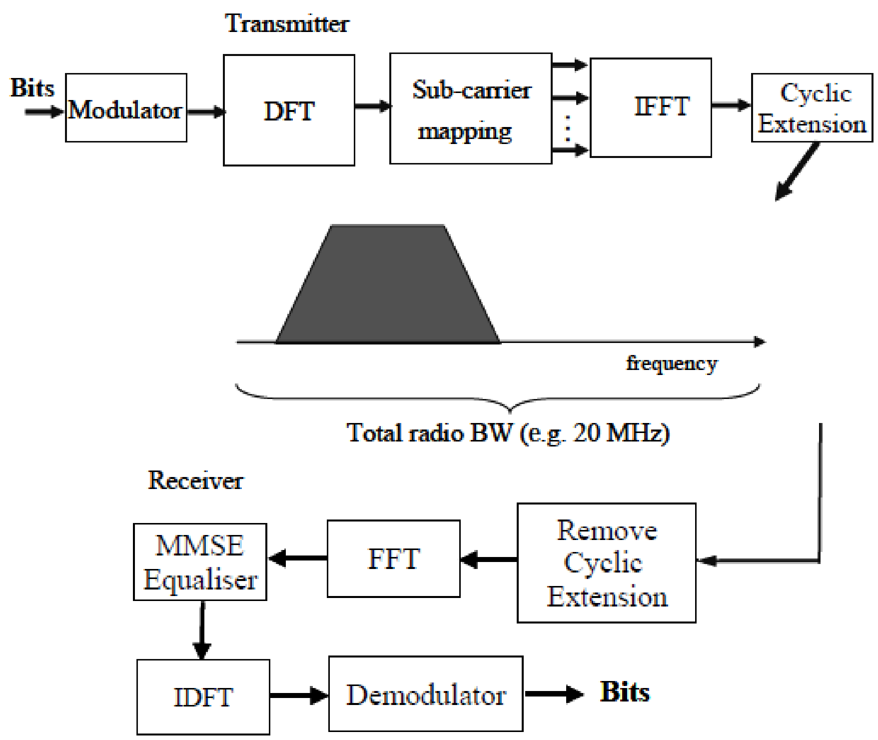

Figure 2-7: SC-FDMA transmitter and receiver with frequency domain signal generation

The transmission occupies the continuous part of the spectrum allocated to the user, and for LTE the system facilitates a 1 ms resolution allocation rate. When the resource allocation in the frequency domain is doubled, so is the data rate, assuming the same level of overhead. The individual transmission (with modulation) is now shorter in time but wider in the frequency domain. That in the new resource allocation the existing frequency resource is retained and the same amount of additional transmission spectrum is allocated, thus doubling the transmission capacity. In reality the allocations do not need to have frequency domain continuity, but can take any set of continuous allocation of frequency domain resources. The practical signaling constraints define the allowed amount of 180 kHz resource blocks that can be allocated. The maximum allocated bandwidth depends on the system bandwidth used, which can be up to 20 MHz The resulting maximum allocation bandwidth is somewhat smaller as the system bandwidth Definition includes a guard towards the neighboring operator. For example, with a 10 MHz system channel bandwidth the maximum resource allocation is equal to 50 resource blocks thus having a transmission bandwidth of 9 MHz The relationship between the *Channel bandwidth* (*BW Channel*) and *Transmission bandwidth configuration* (*NRB*). The SC FDMA resource block for frequency domain signal generation is defined using the same values used in the OFDMA downlink, based on the 15 kHz sub-carrier spacing. Thus even if the actual transmission by name is a single carrier, the signal generation phase uses a subcarrier term. In the simplest form the minimum resource allocated uses 12 sub-carriers, and is thus equal to 180 kHz. The complex valued modulation symbols with data are allocated to the resource elements not needed for reference symbols (or control information) in the resource block as After the resource mapping has been done the signal is fed to the time domain signal generation that creates the SC-FDMA signal, including the selected length of the cyclic prefix. Reference symbols are located in the middle of the slot. These are used by the receiver to perform the channel estimation. There are different options for the reference symbols to be used; sometimes a reference symbol hopping pattern is also used.

2.12 Transmission Impairments:

The transmission impairments cause information to be lost in a signal [2][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
- Noise
- Fading

Attenuation:

The attenuation refers to any reduction in signal strength that is a natural consequence of signal transmission over long distances [4]. 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.

Noise:

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

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.

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:

$$N = KTW \text{ --} (1)$$

Where,

T = Temperature in Kelvin

K = the Boltzmann Constant (K = 1.3806 x 10^{-23} Joules per Kelvin (J · 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.

AWGN Noise:

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

Inter modulation:

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

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 :

- 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.

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.

Types of fading due to Doppler spread;

- Slow Fading
- Fast Fading

Slow Fading:

The slow fading 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

Rician Fading:

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

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.

2.4 Related Works

As wireless multimedia applications become more wide-spread, demand for higher data rate is leading to utilization of a wider transmission bandwidth. With a wider transmission bandwidth, frequency selectivity of the channel becomes more severe and thus the problem of Inter-Symbol Interference (ISI) becomes more serious. In a conventional single carrier communication system, time domain equalization in the form of tap delay line filtering is performed to eliminate ISI. However, in case of a wide band channel, the length of the time domain filter to perform equalization becomes prohibitively large since it linearly increases with the channel response length. One way to mitigate the frequency-selective fading seen in a wide band channel is to use a multicarrier technique which subdivides the entire channel into smaller sub- bands, or subcarriers.

Orthogonal Frequency Division Multiplexing (OFDM) is a kind of multi-carrier transmission technique with a relatively large number of subcarriers which uses orthogonal subcarriers to convey information. In the frequency domain, since the bandwidth of a subcarrier is designed to be smaller than the coherence bandwidth, each sub- channel is seen as a flat fading channel which simplifies the channel equalization process. In the time domain, by splitting a high-rate data stream into a number of lower-rate data stream that are transmitted in parallel, OFDM resolves the problem of ISI in wide band communications.

Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple access of OFDM and it has been avoided in mobile systems because it has very high Peak-to-Average Power Ratio (PAPR) signals and it creates due to the parallel transmission of many hundreds of closely-spaced subcarriers [4]. For mobile devices this high PAPR is problematic for both power amplifier design and battery consumption [5]. Another problem with OFDMA in cellular uplink transmissions derives from the inevitable offset in frequency references among the different terminals that transmit simultaneously. Frequency offset destroys the orthogonally of the transmissions, thus introducing multiple access interference [3]. To overcome these disadvantages, Third Generation Partnership Project (3GPP) is investigating a modified form of OFDMA for uplink transmissions in the Long Term Evolution (LTE) of cellular systems. The modified version of OFDMA is referred to as Single Carrier Frequency Division Multiple Access (SC-FDMA) [3].

Chapter Three

System Design and Model

3.1 OFDMA Transmitter and Receiver:

In OFDMA transmitter, the available spectrum is divided into number of orthogonal subcarriers [7]

The subcarrier spacing for LTE system is 15 KHz with 66.67µs OFDMA symbol duration. The high bit-rate data stream passes through modulator, where adaptive modulation schemes such as (BPSK, QPSK, 16-QAM, 64-QAM) is applied. This multilevel sequence of modulated symbols is converted into parallel frequency components (subcarriers) by serial to parallel converter. The IFFT stage converts these complex data symbols into time domain and generates OFDM symbols. A guard band is used between OFDMA symbols in order to cancel the Inter symbol Interference at receiver. In LTE, this guard band is called Cyclic Prefix (CP) and the duration of the CP should greater than the channel impulse response or delay spread. The receiver does not deal with the ISI but still have to consider the channel impact for every single subcarrier that have experienced amplitude changes and frequency dependent phase. In LTE, the OFDMA uses two types of CP that are normal CP and extended CP. The normal CP is used for high frequencies (urban areas) and extended CP for lower frequencies (rural areas) , As shown in figure (3-1) below .

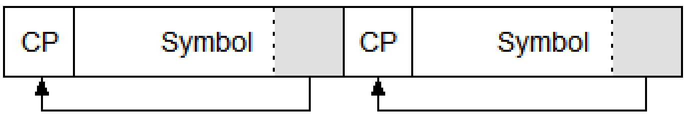

Figure: 3-1 Cyclic Prefix

At receiver, the CP is removed first and then subcarriers are converted from parallel to serial sequence. The FFT stage further converts the OFDM symbols in to frequency domain followed by equalizer and demodulation [7].

The Cyclic Prefix Length:

The increase in CP length reduces ISI affect at the expense of higher transmitted power loss. In LTE standard, normal cyclic prefix (around 5.7 µs) and extended cyclic prefix (around 16.67 µs) corresponds to seven and six OFDM symbols per slot respectively [12].

3.2 Transmission Model of OFDMA

OFDMA model was simulated by Matlab using m-file. The block diagram of OFDMA is given in figure 3-2.

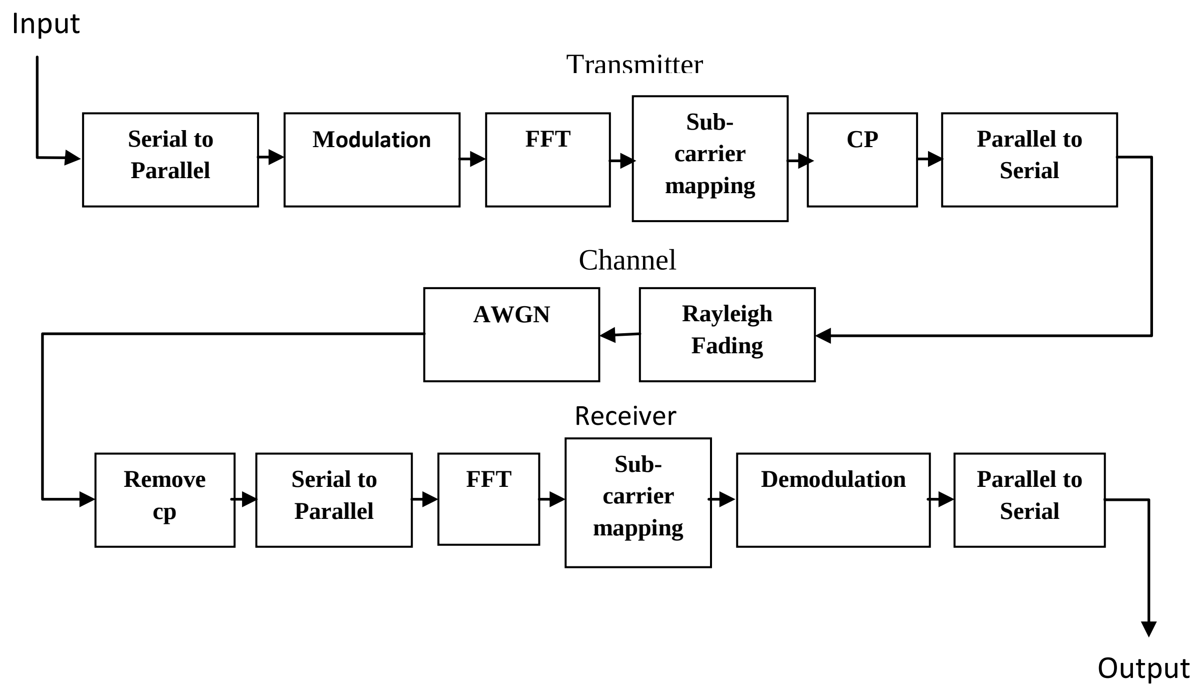

Figure 3-2: OFDMA transmission model

3.3 SC-FDMA Transmitter and Receiver:

SC-FDMA uses an additional N-point DFT stage at transmitter and an N-point IDFT stage at receiver. The basic block diagram of SC-FDMA transmitter is shown in figure 3.3. The input to transmitter is a stream of modulated symbols.

In SC-FDMA, the data is mapped into signal constellation according to the QPSK, 16-QAM, or 64- QAM modulation, depending upon the channel conditions similarly as in OFDMA. Whereas, the

QPSK/QAM symbols do not directly modulate the subcarriers. These symbols passes through a serial to parallel converter followed by a DFT block that produce discrete frequency domain representation of the QPSK/QAM symbols. Pulse shaping is followed by DFT element, but it is optional and sometimes needs to shape the output signal from DFT. If pulse shaping is active then in the actual signal, bandwidth extension occurs. The discrete Fourier symbols from the output of DFT block are then mapped with the subcarriers in subcarrier mapping block. After mapping this frequency domain modulated subcarriers pass through IDFT for time domain conversion. The rest of transmitter operation is similar as OFDMA.

The sub-carrier mapping plays an important role in the transmitter of SC-FDMA. It maps each of the N DFT output on a single subcarrier out of M subcarriers, where M is the total number of subcarriers for available bandwidth. The subcarrier mapping is achieved by two methods; localized subcarrier mapping and distributed subcarrier mapping. The modulation symbols in localized subcarrier mapping are assigned to M adjacent subcarriers, whereas in distributed mode, the symbols are uniformly spaced across the whole channel bandwidth. Localized subcarrier mapping also referred as localized SCFDMA (LFDMA) whereas distributed subcarrier mapping referred as distributed SCFDMA (DFDMA). In transmitter, the IDFT assigns zero amplitude to the unoccupied subcarriers in both modes of subcarrier mapping. The IFDMA is more efficient in SC-FDMA, in that the transmitter can modulate the signal in time domain without using DFT and IDFT. If Q = M×N for the distributed mode with equidistance between subcarriers then it is called Interleaved FDMA (IFDMA) [11]. Where M is number of subcarriers, Q is number of users and N is number of subcarriers allocated per users. In distributed mapping, N-discrete frequency signals are mapped uniformly spaced sub-carriers, where as in localized mapping, N-discrete frequency signals are mapped on N consecutive subcarriers.

SC-FDMA receiver is shown in figure 3.3. It is almost same as conventional OFDMA with additional blocks of subcarrier demapping, IDFT and optional shaping filter. This filter corresponds to the spectral shaping used in the transmitter. The subcarrier demapping of M-mapped subcarrier results N- discrete signals. In the end, IDFT converts the SC-FDMA signal to the signal constellation.

3.4 Transmission Model of SC-FDMA

SC-FDMA model was simulated by Matlab using m-file. The block diagram of SC-FDMA is given in figure 3-3.

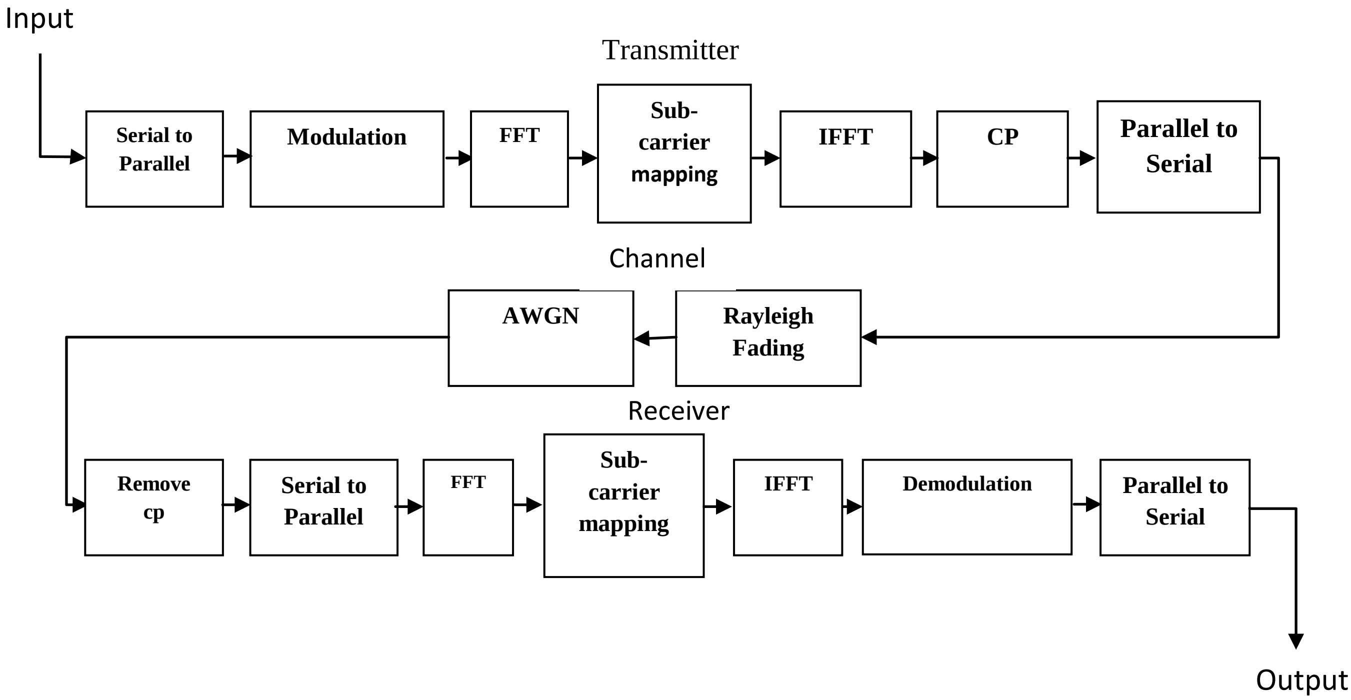

Figure 3-3: SC-FDMA transmission model

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

We 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. We use a built-in Matlab function Rayleigh channel for

Rayleigh fading and the parameters used for that are given below in table 3-1.

Table 3-1: Parameters used for System Simulation

PARAMETERS	**ASSUMPTION**
Number of Sub-carriers	512 (FFT Length)
CP Length	64
Range of SNR in dB	0 to 30
Modulation	BPSK, QPSK, 16-QAM, 64-QAM
Data Block Size	16 (Number of Symbols)
Channel	AWGN (SNR = 100 dB)
System Bandwidth	5 MHz
Confidence Interval used	32 times
Fading	Rayleigh (frequency selective)
Rayleigh fading parameters	Input sample period = 1.00e-3 sec Maximum Doppler shift = 100 Hz Vector path delays = [0 2.00e-5] sec Average path gain vector = [0 -9] dB

We use following adaptive modulation schemes 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).

3.2 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.

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 PAPR0 (Pr {PAPR>PAPR0}) [11]. It is an important measure that is widely used for the complete description of the power characteristics of signals.

3.3 BER

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

BER = Error Bits / Number of Transmitted Bits

3.4 SNR

The SNR is the ratio of bit energy (E_b) to the noise power spectral density (N0) and it is expressed in dB. $SNR = E_b / N_0$……(3.0)

3.5 BER VS SNR Process

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.

3.6 Error Probability

The probability of error or error probability (Pe) is the rate of errors occurs in the received signal. For coherent detection, the symbol error probability of M-ary PSK and M-ary QAM in the AWGN channel is determined by following expressions.

For M-ary PSK the Pe is given by [10].

$$P_e = 2Q\left[\sqrt{\frac{2\,E_b \log_2 M}{N_0}} \sin\left(\frac{\pi}{M}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where,

$E_b \log_2 M$ = E (Transmitted signal energy per symbol)

N_0 = Noise density in AWGN

Q = Q-Function

Therefore;

$$p_e \cong \left[\sqrt{\frac{2E}{N_0}} \sin\left(\frac{\pi}{M}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

In our simulation, we use the complementary error function (erfc) instead of Q. Therefore, the symbol error probability in terms of erfc is given by [14];

$$P_e \cong erfc\left[\sqrt{\frac{E}{N_0}} \sin\frac{\pi}{M}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Whereas, the relationship between erfc and Q is given by

$$Q(X) = \frac{1}{2}\, erfc\left[\frac{X}{\sqrt{2}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

For M-ary QAM the Pe is given by [10];

$$P_e \cong 4\left(1 - \frac{1}{\sqrt{M}}\right) Q\left[\sqrt{\frac{3E_{av}}{(M-1)N_0}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Similarly in terms of erfc, the Pe of M-ary QAM is given by [14];

$$P_e \cong 2\left(1 - \frac{1}{\sqrt{M}}\right) erfc\left[\sqrt{\frac{3E_{av}}{2(M-1)N_0}}\right] \ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

3.7 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 [6].

In our simulation, we use a Matlab function spectrum that is used to estimate the spectrum characteristics of a signal, along with PSD (describes power characteristics of a signal). The average power of a signal in a given frequency band is determined by the integral of PSD over that frequency band. There are different types of spectral estimation methods used with PSD. In ours simulation we use period gram spectrum estimation method which is a valid approach for discrete sinusoidal signals.

In our case, we analyse the average power distribution in OFDMA and SC-FDMA symbols over a 5 MHz bandwidth. This 5 MHz bandwidth may exist in any LTE carrier frequency band (900 MHz, 1800 MHz, and 2600 MHz). For baseband modulation, we estimate the power characteristics of OFDMA and SC-FDMA symbols over a sampling frequency that is equal to twice of bandwidth (10 MHz). The total power in the frequency band for the periodic signal with N period would be [13].

$$P_{xx}(m) = \frac{1}{f_s}\frac{1}{N}\left[DFT_N\{x(n)\}\right]^2 \quad \text{……………………..……(3.7)}$$

Where,

f_s= Sampling Frequency (10 MHz)

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

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

Chapter Four

Simulation Results and Discussion

4.1 BER vs. SNR for OFDMA and SCFDMA

Figure 4-1 and figure 4-2 showed the results of BER vs. SNR for OFDMA. The observations are taken for a specific value of SNR (8 dB), for OFDMA, the BPSK (black curve) and QPSK (green curve) are performed similarly, but a change occur in 16-QAM (blue curve) and 64-QAM (red curve). The 64-QAM has highest value of BER which shows that 16-QAM give better BER results is more efficient in terms BER than 64-QAM. In the other hand BPSK and QPSK are outperform both 16-QAM and 64-QAM.

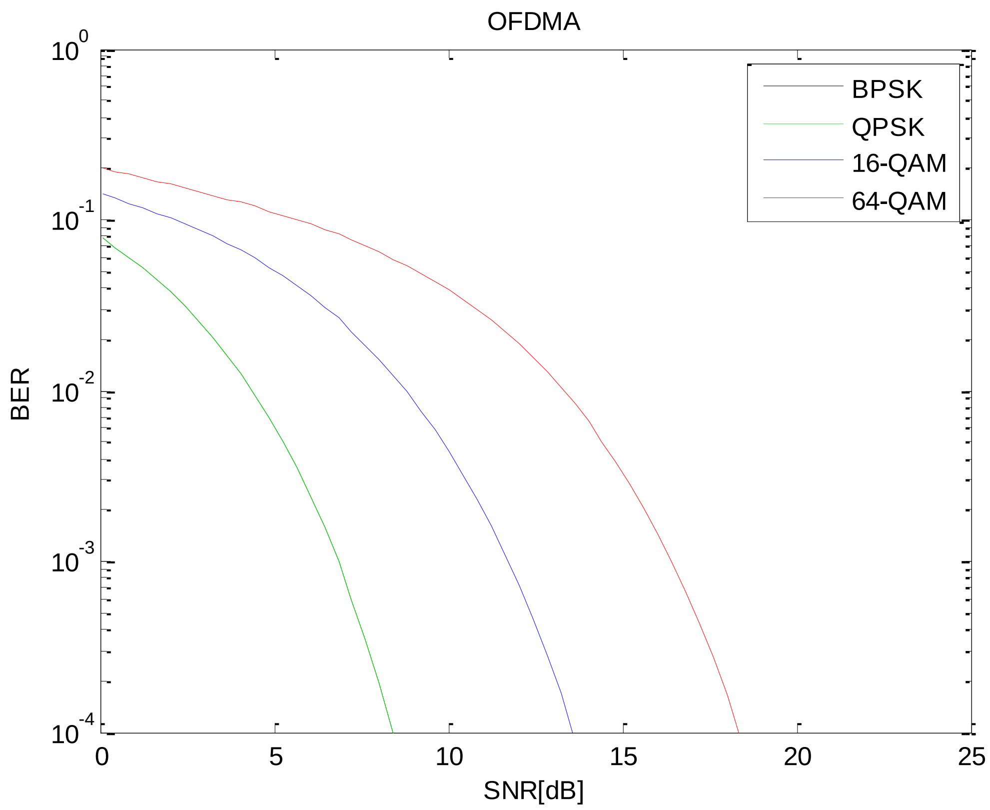

Figure 4-1: BER vs. SNR of OFDMA with Different Modulation

Figure 4-2 showed the results of BER vs SNR for OFDMA. The observations are taken for a specific value of SNR (8 dB), for SC-FDMA, the BPSK (black curve) and QPSK (red curve) are performed similarly, but a change occur in 16-QAM (blue curve) and 64-QAM (green curve). The 64-QAM has highest value of BER which shows that 16-QAM give better BER results is more efficient in terms BER than 64-QAM. In the other hand BPSK and QPSK are outperform both 16-QAM and 64-QAM.

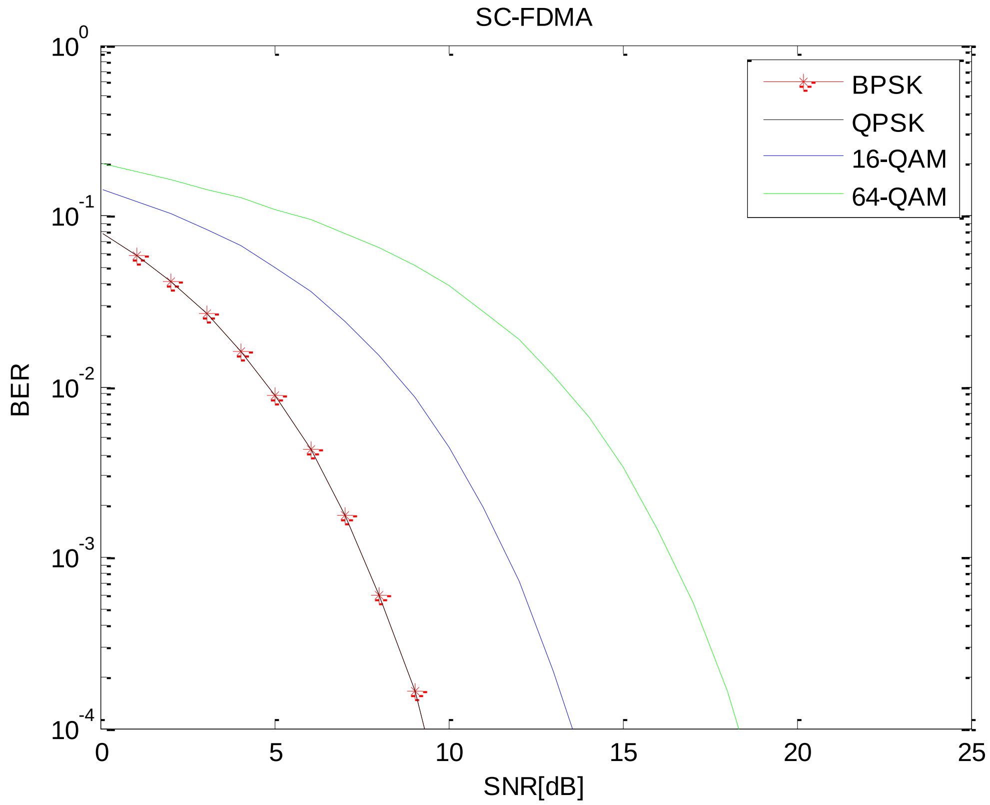

Figure 4-2: BER vs SNR of SC-FDMA with Different Modulation

4.2 Error Probability for SC-FDMA and OFDMA

Figure 4-3 showed the results of Probability of Error vs SNR for OFDMA. The observations are taken for a specific value of SNR (4 dB) , the BPSK (black curve), QPSK (red curve), 16-QAM (blue curve) and 64-QAM (green curve) are performed as different values. The 64-QAM has highest value of Probability of Error which shows that 16-QAM give better Probability of Error results is more efficient in terms Probability of Error than 64-QAM and QPSK is outperform both 16-QAM and 64-

QAM In the other hand BPSK outperform of QPSK, 16-QAM and 64-QAM.

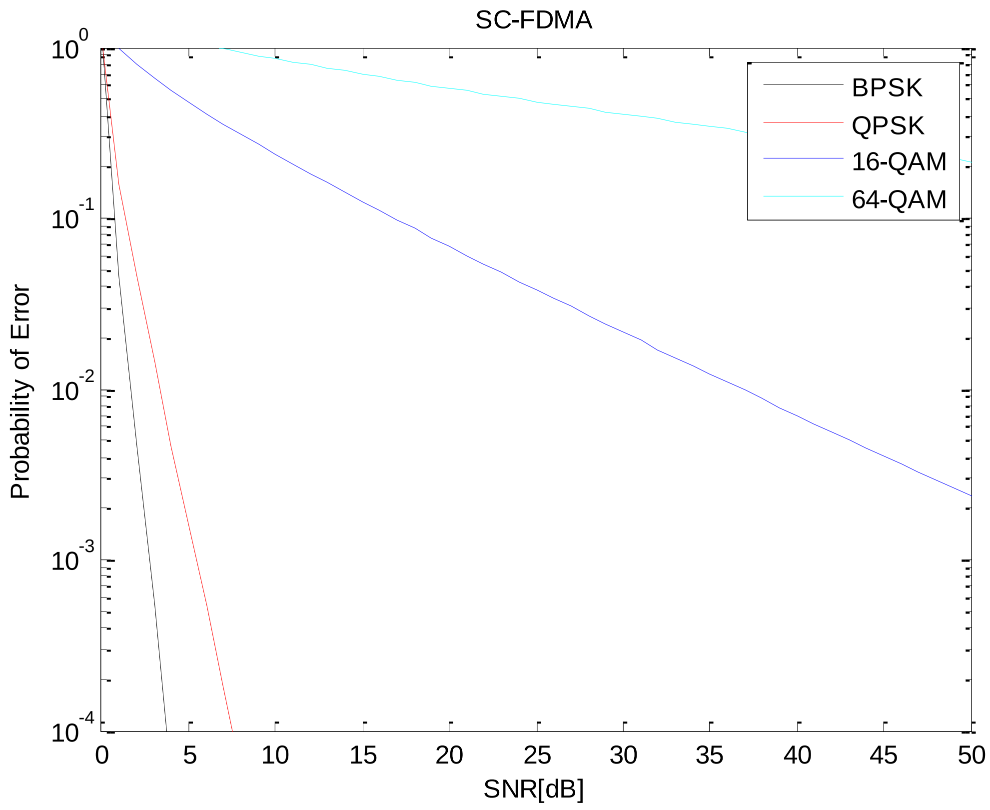

Figure 4-3: Error Probability of SC-FDMA with Different Modulation

Figure 4-4 showed the results of Probability of Error vs SNR for SC-FDMA. The observations are taken for a specific value of SNR (4 dB), the BPSK (black curve), QPSK (red curve), 16-QAM (blue curve) and 64-QAM (green curve) are performed as different values. The 64-QAM has highest value of Probability of Error which shows that 16-QAM give better Probability of Error results is more efficient in terms Probability of Error than 64-QAM and QPSK is outperform both 16-QAM and 64-QAM In the other hand BPSK outperform of QPSK, 16-QAM and 64-QAM.

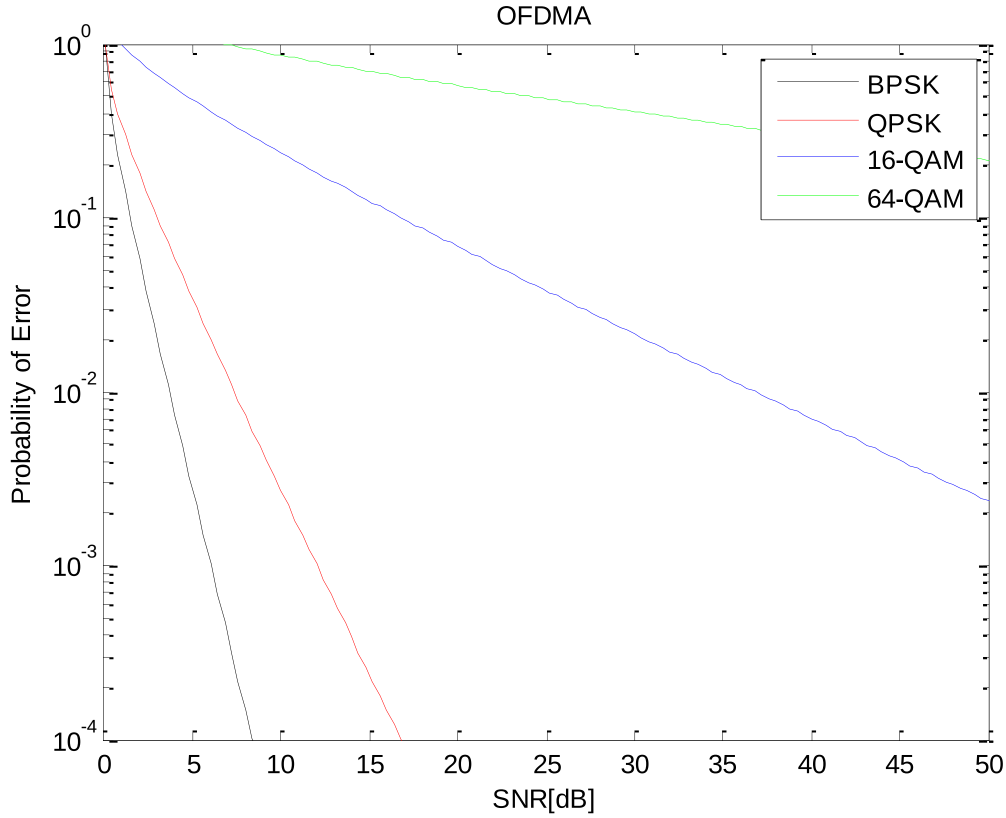

Figure 4-4: Error Probability of OFDMA With Different Modulation

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.

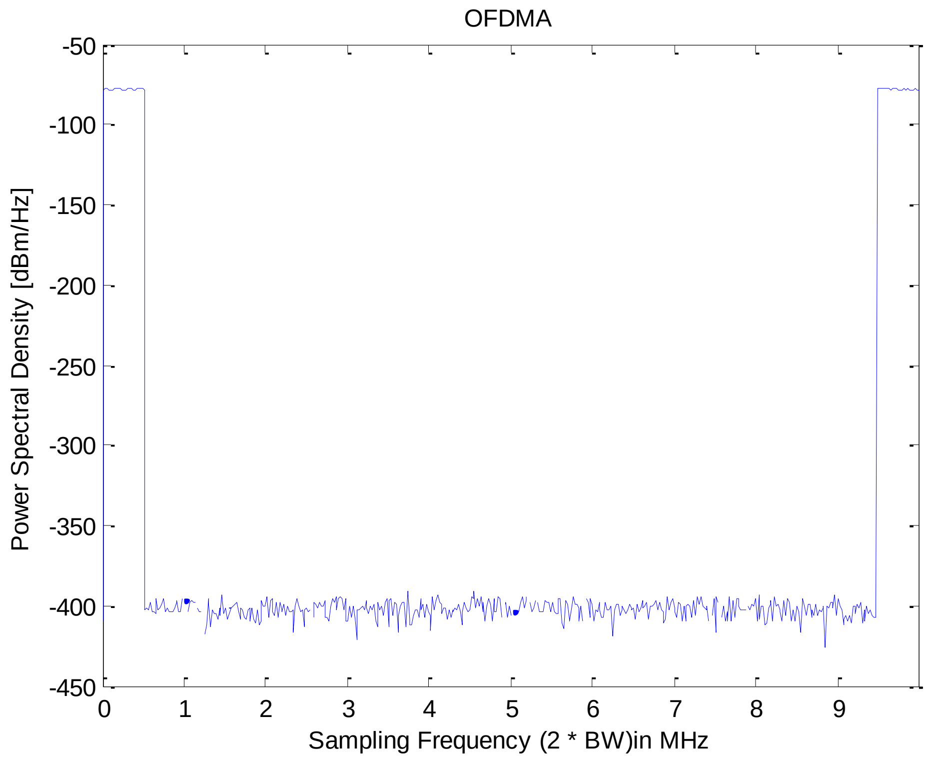

figure 4-5: Power Spectral Density of OFDMA

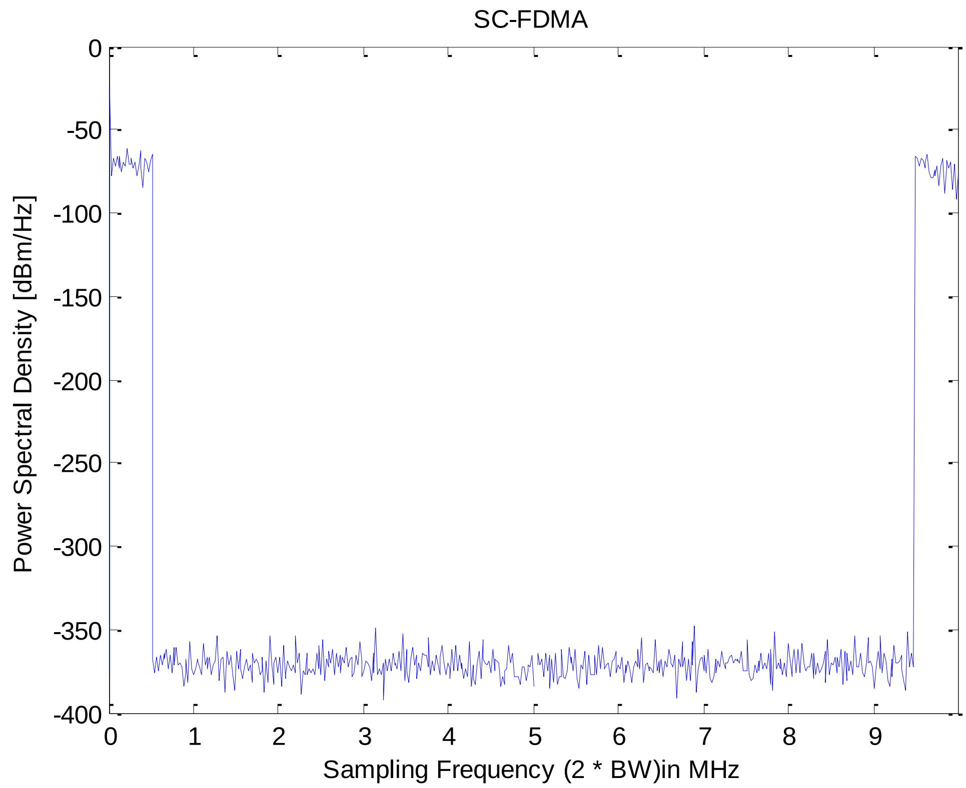

Figure4-6: Power Spectral Density of SC-FDMA

Figure 4-5 and Figure 4-6 shows the power spectral density of the OFDMA and SC-FDMA respectively. We can observe that the average power of all SC-FDMA symbols (512) is nearly -75dB, whereas, in case of OFDMA the average power of all symbols is nearly -80dB. 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.

4.4 PAPR of OFDMA and SC-FDMA for BPSK Modulation

The PAPR of OFDMA and SC-FDMA for BPSK modulation are shown in figure 4-7respectively.

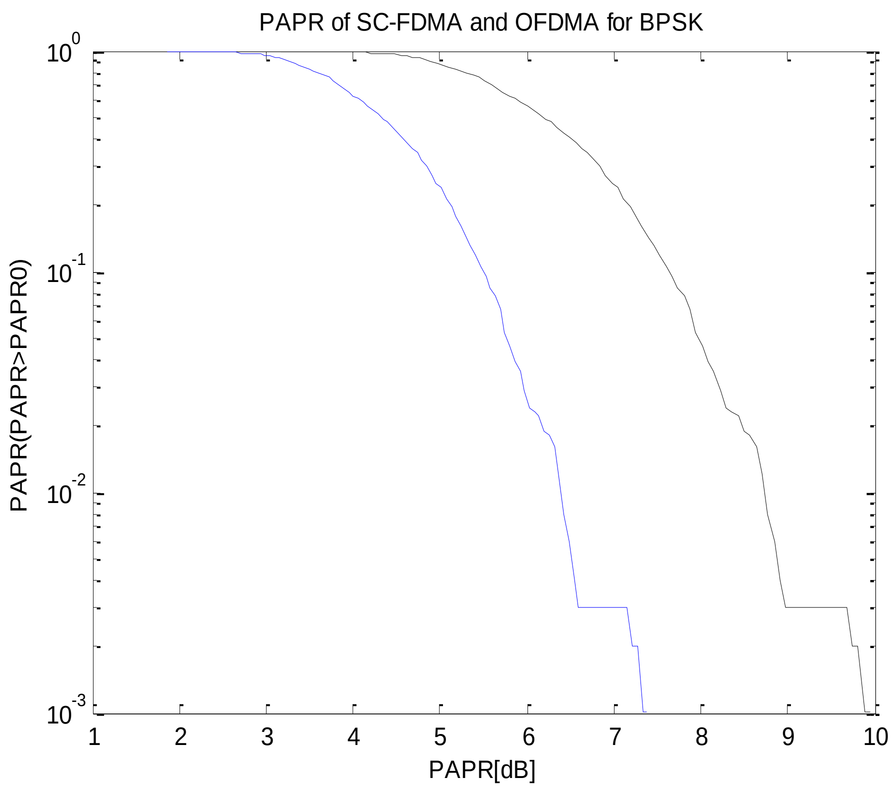

Figure4-7: PAPR of OFDMA and SC-FDMA for BPSK

figure 4-7 showed the results of PAPR 0f OFDMA and SC-FDMA for BPSK modulation .we can observe that the PAPR value (black curve) of OFDMA is 9.9 dB and the PAPR value (blue curve) of SC-FDMA is 7.3 dB, that mean the PAPR of SC-FDMA in BPSK modulation is more efficient than OFDMA.

Chapter Five

Conclusion and Recommendation

For Future Work

5.1 Conclusion

BER is one of important parameters to evaluate system performance , so we found the BER value in SC-FDMA is less and more efficient than OFDMA .Because in SC-FDMA is divided all data over only one single subcarrier ,not like OFDMA which it divided data over many subcarrier.

In SNR the OFDMA is more efficient than SC-FDMA in all modulation types Cause it uses multi frequency (subcarrier) it increase in high order modulation.

Probability of Error the SC-FDMA value is less than OFDMA, so SC-FDMA is more efficient than OFDMA (in all modulation schemes).

In power spectral density the average power for OFDMA symbols (512) is greater than SC-FDMA symbols in all frequencies, so OFDMA is more efficient than SC-FDMA.

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 our result we conclude to adopt low order modulation scheme i.e. BPSK, QPSK, 16-QAM and 64QAM for uplink in order to have less PAPR at user end.

5.2 Recommendations

Here are some recommendations that can improve the performance of the SC-FDMA system:

1- Multi Input Multi Output (MIMO) because it important for improve system performance in (diversity and spatial multiplexing) So, it is recommended to go on a further and deep studies on it..

2- In this thesis, carrier frequency offset was not considered, which a common impairment at the receiver is. Its impact on the link level performance and capacity is an important issue for a practical implementation. So, it is recommended to go on further and deep studies on it.

3- In this thesis, the simulated OFDMA and SC-FDMA systems applied the MMSE and ZERO forcing equalization techniques. It is recommended to apply the other types of equalization techniques such as DFE and Turbo equalization.

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Appendix A

OFDMA CODE

```
function LTE()
    close all
    %% OFDMA Section
    % Number of Subcarriers
    NS=512;
    % Input Generation
    x=rand(1,NS)>0.5;
    fftlength=512;
    nd=6;
    BW=5e6;
    FS=2*BW;%Sampling Frequency
    % Conversion of data from serial to parallel
    p=series2parallel(x,NS);
    % M-ary Modulaton of PSK & QAM
    M=2;
    X=0;
    for count1=2:1:7;
        if(M==2||M==4||M==16||M==64)
            M=M+X;
            %M-ary modulation for producing y
            if(M<=8)
                %Modulation for PSK
                y = modulate(modem.pskmod(M),p);
            else
                %Moodulation for QAM
                y = modulate(modem.qammod(M),p);
            end
            ylen=length(y);
            %Applying Mapping
            q_out=ofdma_mapping(y,ylen);
            %Apply IFFT operation
            outifft=ifft(q_out);
            %Cyclic Prefix Addition
            cp(count1,:)=cyclicpad(outifft,64);
            %Length of CP
            cplength=length(cp);
            %Conversion of data from parallel to serial
            out=reshape(cp(count1,:),1,cplength);
            %Signal transmits through AWGN channel
            ynoisy=awgn(out,100,'measured');
            %Addition of relay fading
            c=rayleighchan(1/1000,100,[0 2e-5],[0 -9]);
            rf=filter(c,ynoisy);
            %Conversion of data from serial to parallel
            p2=series2parallel(rf,cplength);
            re_par=real(p2);
            %Remove cyclic prefix
            rcp(count1,:)=decyclicpad(p2,64);
```

```
            rcplength=length(rcp);
            %FFT
            zzfft=fft(rcp(count1,:),fftlength);
            %Apply Demapping
            qq_out=ofdma_demapping(zzfft);
            outfft=qq_out;
            %% Applung IFFT
            %zfft=ifft(qq_out);
            if(M<=8)
                %Demodulation of PSK at Reciever
                z=demodulate(modem.pskdemod(M),outfft);
            else
                %Demodulation of QAM at reciever
                z=demodulate(modem.qamdemod(M),outfft);
            end
            %conversion of data from parallel to serial
            xdash=reshape(z,1,NS);
            berr=0;
            for a=1:1:NS;
                if(xdash(:,a)==x(:,a))
                    berr=0;
                else
                    berr=berr+1;
                end
            end
            tberr(count1,:)=berr;
            Eb_No=0:1:NS-1;
            Eb_No=0.4*Eb_No;
            if(M<=8)

ber(count1,:)=berawgn(Eb_No,'psk',M,'nondiff');
                Pe(count1,:)=erfc(sqrt(0.9*Eb_No)*sin(pi/M));
            else
                ber1(count1,:)=berawgn(0.9*Eb_No,'qam',M);
                Pe(count1,:)=2*((1-
(1/sqrt(M)))*erfc(sqrt((1.5*Eb_No)/(M-1))));
            end
            for init=1:1:32
                switch M
                end
            end
        end
        M=2^count1;
    end
     figure()
     %Plot SNR and BER

semilogy(Eb_No,ber(2,:),'k',Eb_No,ber(3,:),'g',Eb_No,ber1(5,:)
,'b',Eb_No,ber1(7,:),'r');
     axis([0 25 0.0001 1]);
     xlabel('SNR[dB]')
     ylabel('BER')
     legend('BPSK','QPSK','16-QAM','64-QAM')
     title('OFDMA')
     figure()
     %Plot Error Probability
```

```
semilogy(Eb_No,Pe(2,:),'k',Eb_No,Pe(3,:),'r',Eb_No,Pe(5,:),'b'
,Eb_No,Pe(7,:),'g');
      axis([0 50 0.0001 1]);
      xlabel('SNR[dB]')
      ylabel('Probability of Error')
      legend('BPSK','QPSK','16-QAM','64-QAM')
      title('OFDMA')
      h=spectrum.periodogram;
      figure()

HS=psd(h,outifft,'SpectrumType','twosided','NFFT',512,'FS',FS)
;
      plot(HS)
      xlabel('Sampling Frequency (2 * BW)in MHz')
      ylabel('Power Spectral Density [dBm/Hz]')
      title('OFDMA')
      grid off;
```

SC-FDMA

```
%% SC-FDMA:
% Number of Subcarriers
    NS=512;
    % Input Generation
    x=rand(1,NS)>0.5;
    fftlength=512;
    nd=6;
    BW=5e6;
    FS=2*BW;%Sampling Frequency
    % Conversion of data from serial to parallel
    p=series2parallel(x,NS);
    % M-ary Modulaton of PSK & QAM
    M=2;
    X=0;
    for count1=2:1:7;
        if(M==2||M==4||M==16||M==64)
            M=M+X;
            %M-ary modulation for producing y
            if(M<=8)
                %Modulation for PSK
                y = modulate(modem.pskmod(M),p);
            else
                %Moodulation for QAM
                y = modulate(modem.qammod(M),p);
            end
            out_fft = fft(y,fftlength);
            %ylen=length(y);
            %Applying Mapping
            q_out=ofdma_mapping(out_fft,fftlength);
            %Apply IFFT operation
```

```
            outifft=ifft(q_out);
            %Cyclic Prefix Addition
            cp(count1,:)=cyclicpad(outifft,64);
            %Length of CP
            cplength=length(cp);
            %Conversion of data from parallel to serial
            out=reshape(cp(count1,:),1,cplength);
            %Signal transmits through AWGN channel
            ynoisy=awgn(out,100,'measured');
            %Addition of relay fading
            c=rayleighchan(1/1000,100,[0 2e-5],[0 -9]);
            rf=filter(c,ynoisy);
            %Conversion of data from serial to parallel
            p2=series2parallel(rf,cplength);
            re_par=real(p2);
            %Remove cyclic prefix
            rcp(count1,:)=decyclicpad(p2,64);
            rcplength=length(rcp);
            %FFT
            zzfft=fft(rcp(count1,:),fftlength);
            %Apply Demapping
            qq_out=ofdma_demapping(zzfft);
            outfft=ifft(qq_out);
            %% Appling IFFT
            %zfft=ifft(qq_out);
            if(M<=8)
                %Demodulation of PSK at Reciever
                z=demodulate(modem.pskdemod(M),outfft);
            else
                %Demodulation of QAM at reciever
                z=demodulate(modem.qamdemod(M),outfft);
            end
            %conversion of data from parallel to serial
            xdash=reshape(z,1,NS);
            berr=0;
            for a=1:1:NS;
                if(xdash(:,a)==x(:,a))
                    berr=0;
                else
                    berr=berr+1;
                end
            end
            tberr(count1,:)=berr;
            Eb_No=0:1:NS-1;
%             Eb_No=0.4*Eb_No;
            if(M<=8)

ber(count1,:)=berawgn(0.9*Eb_No,'psk',M,'nondiff');
                Pe(count1,:)=erfc(sqrt(2*Eb_No)*sin(pi/M));
            else
                ber1(count1,:)=berawgn(0.9*Eb_No,'qam',M);
                Pe(count1,:)=2*((1-
(1/sqrt(M)))*erfc(sqrt((1.5*Eb_No)/(M-1))));
            end
            for init=1:1:32
                switch M
```

```
                end
            end
        end
        M=2^count1;
     end
      figure()
      %Plot SNR and BER
      semilogy(Eb_No,ber(2,:),'*-
r',Eb_No,ber(3,:),'k',Eb_No,ber1(5,:),'b',Eb_No,ber1(7,:),'g')
;
      axis([0 25 0.0001 1]);
      xlabel('SNR[dB]')
      ylabel('BER')
      legend('BPSK','QPSK','16-QAM','64-QAM')
      title('SC-FDMA')
      figure()
      %Plot Error Probability
      semilogy(Eb_No,Pe(2,:),'-k',Eb_No,Pe(3,:),'-
r',Eb_No,Pe(5,:),'-b',Eb_No,Pe(7,:),'-c');
      axis([0 50 0.0001 1]);
      xlabel('SNR[dB]')
      ylabel('Probability of Error')
      legend('BPSK','QPSK','16-QAM','64-QAM')
      title('SC-FDMA')
      h=spectrum.periodogram;
      figure()

HS=psd(h,outifft,'SpectrumType','twosided','NFFT',512,'FS',FS)
;
      plot(HS)
      xlabel('Sampling Frequency (2 * BW)in MHz')
      ylabel('Power Spectral Density [dBm/Hz]')
      title('SC-FDMA')
      grid off;
      paprSCFDMA();
end

%% functions section
function y = series2parallel(x,NS)
    L=length(x);
    q=floor(L/NS);
    newvec=zeros(NS,q);
    for i=1:q
        newvec(1:NS,i)=x((1+(i-1)*NS):i*NS);
    end
    y=newvec;
end

%Cyclic Prefix:
function y=cyclicpad(X,L)
    N=length(X(:,1));
    %N-L+1
    Y=[X(N-L+1:N,:);X];
    y=Y;
end
```

```
%Remove Cyclic Prefix:
function y=decyclicpad(X,L)
    N=length(X(:,1));
    Y=X(L+1:N,:);
    y=Y;
end

%Mapping:
%     q_out=ofdma_mapping(y,ylen);
function [qout]=ofdma_mapping(qdata,fftlength)
    qout=zeros(fftlength,1);
    qout(2:27,:) = qdata(1:26,:);
    qout(487:end,:)= qdata(27:52,:);
end

%Demapping:
function [qout]=ofdma_demapping(qdata)
    qdata = qdata';
    qout=zeros(length(qdata),1);
    qout(1:26,:)=qdata(2:27,:);
    qout(27:52,:)=qdata(487:end,:);
end

%% papr function
function paprSCFDMA()
    dataType = 'B-PSK'; % Modulation format.
    NS = 512; % Number of total subcarriers.
    Symbols = 16; % Data block size.
    Q = NS/Symbols; % Bandwidth spreading factor of SC-FDMA.
    BW = 5e6; % System bandwidth.
    Ts = 1/BW; % sampling rate.
    osf = 4; % Oversampling factor.
    Nsub = NS;
    Fsub = (0:Nsub-1)*BW/Nsub; % Subcarrier spacing of OFDMA.
    Runs = 1e3; % Number of iterations.

    papr1 = zeros(1,Runs); % Initialize the PAPR results for
sc-fdma.
    papr3 = zeros(1,Runs); % Initialize the PAPR results for
OFDMA

    for n = 1:Runs,
        % Generate random data.
        if strcmp(dataType , 'B-PSK') == 1
            tmp = round(rand(Symbols,2));
            tmp = tmp*2 - 1;
            data = (tmp(:,1) + 1i*tmp(:,2))/sqrt(2);
        elseif strcmp(dataType, '16QAM') == 1
            dataSet = [-3+3i -1+3i 1+3i 3+3i ...
                       -3+1i -1+1i 1+1i 3+1i ...
                       -3-1i -1-1i 1-1i 3-1i ...
                       -3-3i -1-3i 1-3i 3-3i];
            dataSet = dataSet / sqrt(mean(abs(dataSet).^2));
            tmp = ceil(rand(Symbols,1)*16);
            for k = 1:Symbols,
                if tmp(k) == 0
```

```
                tmp(k) = 1;
            end
            data(k) = dataSet(tmp(k));
        end
        data = data';
    end

    % Convert data to frequency domain.
    Z1 = fft(data);
    Z2 = fft(data);
    % Initialize the subcarriers.
    Y1 = zeros(NS,1);
    Y2 = zeros(NS,1);
    % Subcarrier mapping for SC-FDMA
    Y1(1:Symbols) = Z1;
    Y2(1:Symbols) = Z2;
    % Convert data back to time domain.
    y1 = ifft(Y1);
    y2 = ifft(Y2);
    % OFDMA modulation.
    % Time range of the OFDMA symbol.
    t = 0:Ts/osf:Nsub*Ts;
    y3 = 0;
    for k = 1:Symbols,
        y3= y3 + data(k)*exp(1i*2*pi*Fsub(k)*t);
    end

    % Calculate PAPR.
    papr3(n)       =       10*log10(max(abs(y3).^2)       /
mean(abs(y3).^2));
    papr1(n)       =       10*log10(max(abs(y1).^2)       /
mean(abs(y1).^2));
    papr2(n)       =       10*log10(max(abs(y2).^2)       /
mean(abs(y2).^2));
end
% Plot CCDF.
figure
[N,Z3] = hist(papr3, 100);
[N,Z1] = hist(papr1, 100);
[N,Z2] = hist(papr2, 100);
semilogy(Z1,1-cumsum(N)/max(cumsum(N)),'b')
hold on
semilogy(Z3,1-cumsum(N)/max(cumsum(N)),'black')
hold off
title ('PAPR of SC-FDMA and OFDMA for BPSK')
xlabel ('PAPR[dB]')
ylabel ('{PAPR(PAPR>PAPR0)}')
grid off;
% Save data.
% save paprSCFDMA
% QPSK:
if strcmp(dataType, 'QPSK') == 1
    tmp = round(rand(Symbols,4));
    tmp = tmp*2 - 1;
    data = (tmp(:,1) + 1i*tmp(:,2))/sqrt(2);
% 16-QAM:
```

```
    elseif strcmp(dataType , '16QAM') == 1
        dataSet = [-3+3i -1+3i 1+3i 3+3i ...
        -3+1i -1+1i 1+1i 3+1i ...
        -3-1i -1-1i 1-1i 3-1i ...
        -3-3i -1-3i 1-3i 3-3i];
    % 64-QAM:
    elseif strcmp(dataType , '64QAM') == 1
        dataSet = [-5+5i -1+5i 1+5i 5+5i ...
        -5+1i -1+1i 1+1i 5+1i ...
        -5-1i -1-1i 1-1i 5-1i ...
        -5-5i -1-5i 1-5i 5-5i];
    end
end
```