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Performance Analysis of the Physical Layer of Long-Term Evolution (LTE)

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ABSTRACT

This research starts with a brief introduction to generations of mobile communications along with their standards, the modulation technique multiple access schemes and the basics of wireless communication, including noise and fading. It contains an introduction to LTE physical layer for both downlink and uplink transmission. It also describes in detail the two multiple access schemes (OFDMA & SC-FDMA) used in LTE on the physical layer. After that, it illustrates the design analysis of both multiple access techniques i.e., SCFDMA and OFDMA with block diagrams. It also contains the description of performance parameters used for performance evolution i.e., equations, and formulas of PAPR, SNR and probability of error. In the end, it contains a result analysis of the graphs based on MATLAB simulation of above described parameters. These graphs are taken for different modulation schemes i.e., BPSK, QPSK, 16-QAM and 64-QAM. Finally, it shows the set of conclusions of our research work based on result analysis.

Keywords: Mobile communication, Performance analysis, Physical resource block, and Modulation schemes.

INTRODUCTION:

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. It is always a challenge to design an efficient wireless communication system (Zawawi Zati *et al.,* 2015). 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 etc. Our objective of this thesis is to evaluate the performance of LTE physical layer by considering two multiple access techniques (SC-FDMA and OFDMA) with adaptive modulation techniques BPSK, QPSK, 16-QAM and 64-QAM.

We have considered Signal to Noise Ratio (SNR), BER, Power Spectral Density (PSD), bit error probability and PAPR parameters to evaluate the performance of LTE physical layer. We have considered these parameters because they are vital in communication systems and we have achieved our results by simulating the OFDMA and SC-FDMA models in MATLAB (Sami *et al*., 2021).

Literature Review

History of Wireless Communication and Generation of Mobile Phones

In 1895, a few decades after the telephone was invented, Guglielmo Marconi demonstrated the first radio transmission from the Isle of Wight to a tugboat 18 miles away, and radio communications was born. The concept of wireless communication was first introduced in 1897 by Guglielmo Marconi. (V. Vij, 2010). 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. Wireless communication was effectively used in military and satellite purposes for quite longtime, 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 were based on analogue communication and were categorized as a first generation (1G) of wireless phones. After that more generations came with strong change in their characteristics. 1st generation is used analog technology; later generations are used digital communication. Here a comparison among the mobile phone generation. Details are described below in **Table 1**.

Table 1: Generation of Mobile Phones.

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

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. So transfer of information between two or more points that are not connected by an electrical conductor is knows as wireless communication. The information can be data, voice and video.

Basic Structure of Communication System

The basic communication model consists of three parts, transmitter, channel and receiver, as shown in **Fig.1**.

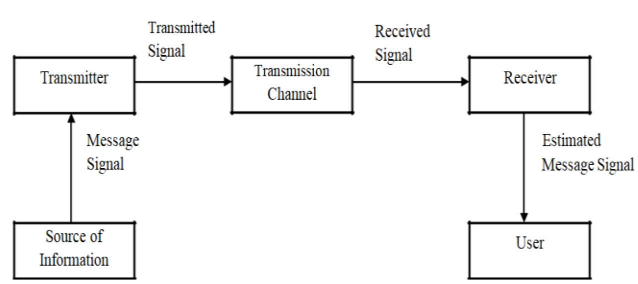

Fig. 1: General Communication Model.

Each part in the above model has a particular role to transmit the signal successfully, (S. Haykin, 2001) which is described as -

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

A suitable and more detailed communication model is given below.

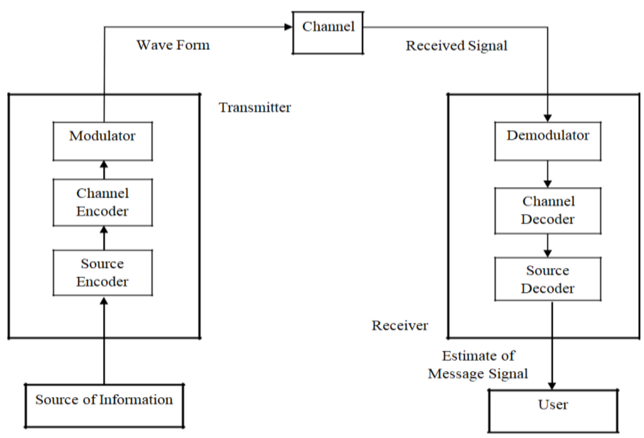

Fig. 2: Communication Systems.

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.

Forms of Communication

Point-to-Point Communication

In telecommunications, a point-to-point connection refers to a communications connection between two nodes or endpoints.

Point to Multipoint Communication

Point-to-multipoint communication is communication which is accomplished via a distinct type of one-to-many connection, providing multiple paths from a single location to multiple locations.

Simplex

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

Half Duplex

A half-duplex system provides communication in both directions, but only one direction at a time (not simultaneously). Typically, once a party begins receiving a signal, it must wait for the transmitter to stop transmitting, before replying. An example of a half-duplex system is a two-party system such as a walkie-talkie.

Full Duplex

A cell phone is a full-duplex device. That means that you use one frequency for talking and a second, separate frequency for listening. Both people on the call can talk at once.

Transmission Impairments

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received.

Attenuation

Attenuation means a loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium. That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifiers are used to amplify the signal (Behrouz A. *et al.,* 2012).

Noise

Unwanted energy from different sources other than the transmitter is called noise. Four categories of Noise:

1) Cross Talk
2) Thermal Noise
3) Impulse Noise
4) Intermodulation Noise

Cross Talk

A foreign signal enters the path of the transmitted signal. Unwanted coupling between signals on neighbouring transmission paths. Here coupling means connecting without touching. Coupling can occur between cables in close proximity or between radio signals close to the same frequency.

Amplitude Shift Keying (ASK)

Amplitude Shift-Keying commonly known as ASK works by assigning unique pattern binary digits to different amplitudes. ASK is a structure of modulation that represents digital data as variations in the amplitude of a carrier wave. The amplitude of a carrier is shifted between two states to represent zeroes and ones. ASK has low bandwidth requirements and very susceptible to interference.

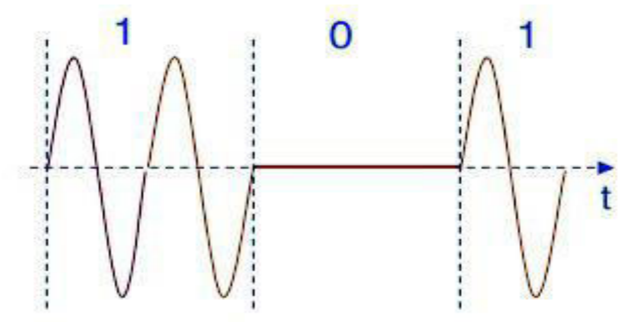

Fig. 3: Amplitude Shift Keying.

Frequency Shift Keying (FSK)

Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier wave. FSK uses two frequencies, one for 1s and the other for 0s, alternating rapidly between the two to send digital information between the cell tower and the phone. Information is transmitted by shifting between two frequencies to represent zeroes and ones.

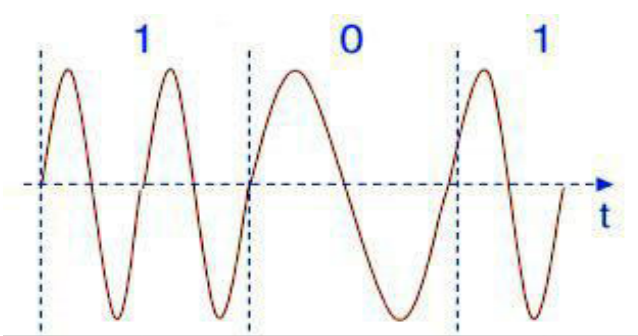

Fig. 4: Frequency Shift Keying.

Thermal Noise

Thermal noise is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter. It is a function of temperature i.e. increased temperature leads to increase in thermal noise.

Impulse Noise

Irregular disturbances, such as lightning, and flawed communication elements. Irregular pulses or noise spikes of short duration and high amplitude. Analogue signals are less affected by this type of noise. E.g. a voice transmission, whilst affected by impulse noise, it can still be received intelligibly. Digital signals are very susceptible to impulse noise. It is a primary source of error in digital data. Impulse noise can lead to corruption of data i.e. changing one to zero and vice-versa.

Intermodulation Noise

Multiple signals can be carried across a single transmission medium. Resulting from interference of different frequencies sharing the same medium. It is caused by a component malfunction or a signal with excessive strength is used. For example, the mixing of signals at frequencies f1 and f2 might produce energy at the frequency f1 + f2. This derived signal could interfere with an intended signal at frequency f1 + f2.

Digital Modulation

A sine wave is defined by three characteristics:

1) Amplitude
2) Frequency
3) Phase

When we vary one of these characteristics, we create a different version of that wave. So, by changing one characteristic of a simple electrical signal, we can use it to represent digital data. Any of the three characteristics can be altered in this way, giving us at least three mechanisms for modulating digital data into an analog signal. There are three basic types of digital modulation:

1) Amplitude Shift Keying (ASK)
2) Frequency Shift Keying (FSK)
3) Phase Shift Keying (PSK)

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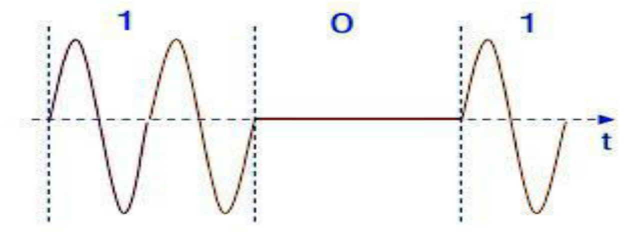

Fig. 5: Amplitude Shift Keying.

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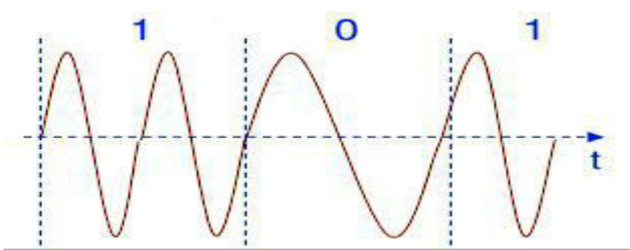

Fig. 6: Frequency Shift Keying.

Phase Shift Keying (PSK)

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). Phase shift keying enables data to be carried on a radio communications signal in a more efficient manner than Frequency Shift Keying, FSK, and some other forms of modulation. The phase of a carrier is varied between two states to represent zeroes and ones.

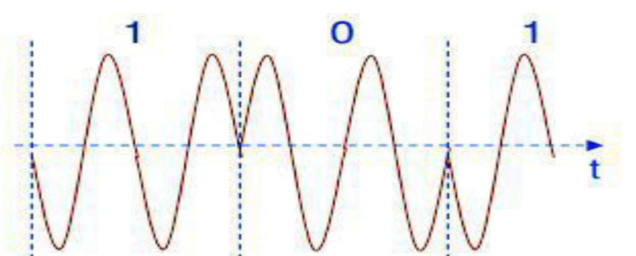

Fig. 7: Phase Shift Keying.

Binary Phase Shift Keying (BPSK)

The simplest Phase shift keying is BPSK, in which we have only two signal elements, one with a phase of 0°, and the other with a phase of 180° (Behrouz A. *et al.,* 2012).

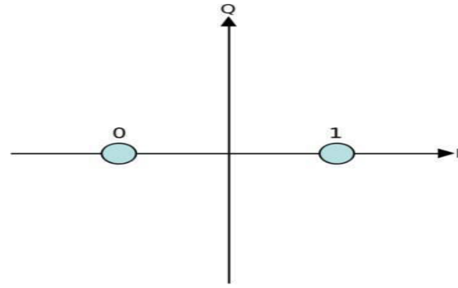

Fig. 8: Binary Phase Shift Keying.

It does not particularly matter exactly where the constellation points are positioned, and in this figure they are shown on the real axis, at 0° and 180°. This modulation is the most robust of all the PSKs since it takes the highest level of noise or distortion to make the demodulator reach an incorrect decision. It is, however, only able to modulate at 1 bit/symbol (as seen in the figure) and so is unsuitable for high data-rate applications.

Quadrature Phase Shift Keying (QPSK)

QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol, shown in the diagram with gray coding to minimize the bit error rate (BER).

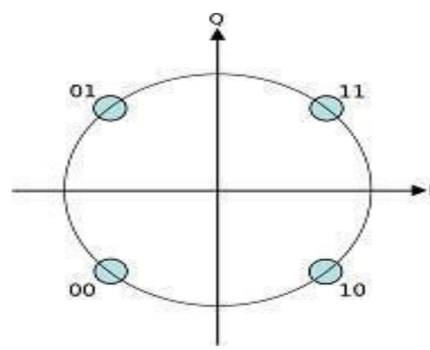

Fig. 9: Quadrature Phase Shift Keying (QPSK).

The mathematical analysis shows that QPSK can be used either to double the data rate compared with a BPSK system while maintaining the same bandwidth of the signal, or to maintain the data-rate of BPSK but halving the bandwidth needed.

Quadrature Amplitude Modulation (QAM)

Quadrature amplitude modulation is a combination of Amplitude Shift Keying (ASK) and Phase Shift Keying (PSK). Quadrature amplitude modulation is widely used in many digital data radio communications and data communications applications. A variety of forms of QAM are available and some of the more common forms include 16 QAM, 32 QAM, 64 QAM, 128 QAM, and 256 QAM. The advantage of using QAM is that it is a higher order form of modulation and as a result it is able to carry more bits of information per symbol. By selecting a higher order format of QAM, the data rate of a link can be increased.

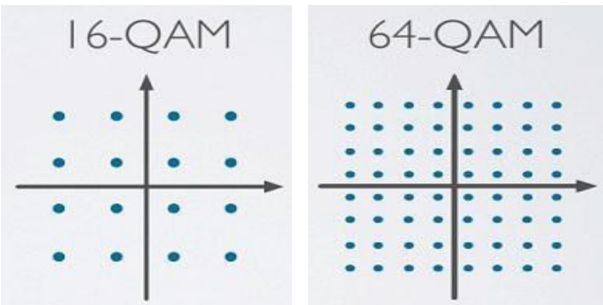

Fig. 10: 16-QAM and 64-QAM.

As the order of the modulation increases, so does the number of points on the QAM constellation diagram. The constellation diagrams show the different positions for the states within different forms.

Adaptive Modulation

Link adaptation, or adaptive modulation and coding (AMC), is a term used in wireless communications to denote the matching of the modulation, coding and other signal and protocol parameters to the conditions on the radio link (e.g. the pathloss, the interference due to signals coming from other transmitters, the sensitivity of the receiver, the available transmitter power margin, etc.). Adaptive Modulation optimizes spectrum utilization by enabling transmission in temporal situations when no meaningful transmission would be possible.

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. Adaptive modulation systems improve rate of trans-mission, and/or bit error rates, by exploiting the channel state information that is present at the transmitter.

Multiple Access Schemes

There are many types of multiple access schemes. They are:

1) Time Division Multiple Access (TDMA)
2) Frequency Division Multiple Access (FDMA)
3) Code Division Multiple Access (CDMA)
4) Space Division Multiple Access (SDMA)
5) Orthogonal Frequency Division Multiple Access (OFDMA)
6) Single Carrier Frequency Division Multiple Access (SC-FDMA)
7) Interleaved Frequency-Division Multiple-Access (IFDMA)
8) Localized Frequency-Division Multiple-Access (LFDMA)

Time Division Multiple Access (TDMA)

Time Division Multiple Access (TDMA) came about with the transition to digital schemes for cellular technology. Here digital data could be split up in time and sent as bursts when required. As speech was digitized it could be sent in short data bursts, any small delay caused by sending the data in bursts would be short and not noticed. In this way it became possible to organize the system so that a given number of slots were available on a give transmission. Each subscriber would then be allocated a different time slot in which they could transmit or receive data. As different time slots are used for each subscriber to gain access to the system, it is known as time division multiple access. Obviously this only allows a certain number of users access to the system.

Frequency Division Multiple Access (FDMA)

FDMA is the most straightforward of the multiple access schemes that have been used. As a subscriber comes onto the system, or swaps from one cell to the next, the network allocates a channel or frequency to each one. In this way the different subscribers are allocated a different slot and access to the network. As different frequencies are used, the system is naturally termed Frequency Division Multiple Access. This scheme was used by all analogue systems.

Code Division Multiple Access (CDMA)

CDMA is a scheme based on spread-spectrum technology invented and developed many years ago principally for military communication systems. In CDMA, everyone talks at once by using a code. For example, a user u1 uses code c1, u2 uses c2, etc. In this case, the listener has to know the code of the sender; otherwise it gets a background noise signal. In CDMA all terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel.

Space Division Multiple Access (SDMA)

Space division multiple access (SDMA) is a channel access method used in mobile communication systems which reuses the same set of cell phone frequencies in a given service area. Two cells or two small regions can make use of the same set of frequencies if they are separated by an allowable distance (called the reuse distance). SDMA increases the capacity of the system and transmission quality by focusing the signal into narrow transmission beams. Through the use of smart antennas with beams pointed at the direction of the mobile station, SDMA serves different users within the same region. The main advantage of SDMA is frequency reuse.

Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA is a multiple-access scheme which provides multiple channels for different users. The data symbols of each user are spread over the entire frequency band. Each subcarrier is orthogonal to the others and carries the data symbol of one user. Since the time domain transmit symbols of each user are not transmitted in serial as for time domain multiple access (TDMA) but in parallel, each user has not the entire frequency band but some portion and the symbol duration is longer. Therefore, an OFDMA system is robust to time delays caused by multipath fading i.e. frequency selectivity of the radio channel.

Single Carrier Frequency Division Multiple Access (SC-FDMA)

Similar to OFDMA, SC-FDMA divides the transmission bandwidth into multiple parallel subcarriers maintaining the orthogonality of the subcarriers by the addition of the cyclic prefix (CP) as a guard interval. However, in SC-FDMA the data symbols are not directly assigned to each subcarrier independently like in OFDMA. Instead, the signal which is assigned to each subcarrier is a linear combination of all modulated data symbols transmitted at the same time instant. The difference of SC-FDMA transmission from the OFDMA transmission which is an additional DFT (Discrete Fourier Transform) block before the subcarrier mapping.

Interleaved Frequency-Division Multiple-Access (IFDMA)

IFDMA can be applied to the downlink and the uplink. However, special interest has been given to the uplink since other multi-carrier systems show some deficiencies for the uplink. IFDMA is a special kind of a multi-carrier spread spectrum scheme. The property of a repeated data sequence has been used for multiple-access. IFDMA assigns to each user a different set of orthogonal subcarriers. It is mainly used for uplink (Alexander A., 2009).

Localized Frequency-Division Multiple-Access (LFDMA)

In LFDMA a set of successive subcarriers are used for conveying the symbols of a user. The diversity gain of the IFDMA system is higher than that of the LFDMA. Mainly used for downlink. LFDMA has advantage over OFDMA in terms of spectrum mask margin when power limited users with relatively small size assignments get resources close to the edge of spectrum allocation.

Multiple Input Multiple Output (MIMO)

MIMO is used within LTE to provide better signal performance and / or higher data rates by the use of the radio path reflections that exist. One of the main problems that previous telecommunications systems have encountered is that of multiple signals arising from the many reflections that are encountered. By using MIMO, these additional signal paths can be used to advantage and are able to be used to increase the throughput. Although MIMO adds complexity to the system in terms of processing and the number of antennas required, it enables far high data rates to be achieved along with much improved spectral efficiency. As a result, MIMO has been included as an integral part of LTE. The schemes employed in LTE again vary slightly between the uplink and downlink. The reason for this is to keep the terminal cost low as there are far more terminals than base stations and as a result terminal works cost price is far more sensitive. For the downlink, a configuration of two transmit antennas at the base station and two receive antennas on the mobile terminal is used as baseline, although configurations with four antennas are also being considered. For the uplink from the mobile terminal to the base station, a scheme called MU-MIMO (Multi-User

MIMO) is to be employed. Using this, even though the base station requires multiple antennas, the mobiles only have one transmit antenna and this considerably reduces the cost of the mobile. In operation, multiple mobile terminals may transmit simultaneously on the same channel or channels, but they do not cause interference to each other because mutually orthogonal pilot patterns are used. This techniques is also referred to as spatial domain multiple access (SDMA). The basic principle of MIMO is presented in Figure 2.9, where the different data streams are fed to the precoding operation and then onwards to signal mapping and OFDMA signal generation.

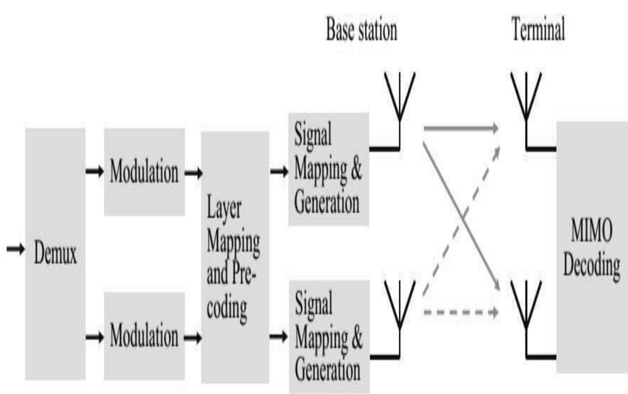

Fig. 11: MIMO principle with two-by-two antenna configuration.

The reference symbols enable the receiver to separate different antennas from each other. To avoid transmission from another antenna corrupting the channel estimation needed for separating the MIMO streams, one needs to have each reference symbol resource used by a single transmit antenna only.

LTE Physical Layer

Introduction

LTE, an acronym for Long Term Evolution, marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. (W. Stallings, 2007) LTE is launched by the 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 a 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.

Performance Requirements of LTE

For smooth performance, the main requirements for designing LTE are as follows:

Peak data rate

Instantaneous downlink peak data rate of 100 Mbps within a 20 MHz downlink spectrum allocation (5 bps/Hz). Instantaneous uplink peak data rate of 50 Mbps (2.5 bps/Hz) within a 20MHz uplink spectrum allocation

Bandwidth

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 (cH. Holma and A. Toskala, 2009).

Peak Spectrum efficiency

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

Spectral Efficiency of Cell Edge

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 10 user/cell.

Control-plane capacity

At least 200 users per cell should be supported in the active state for spectrum allocations up to 5 MHz

Average Cell Spectral Efficiency

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.

User-plane latency

Less than 5 ms in unload condition (i.e., single user with single data stream) for small IP packet

Coverage

Throughput, spectrum efficiency and mobility targets above should be met for 5 km cells, and with a slight degradation for 30 km cells. Cells range up to 100 km should not be precluded.

Latency

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. We can find significantly higher data rate (50-100Mbps) and faster connection times as most remarkable requirements relative to 3G/3.5G. In order to achieve the high data rate, 3GPP decided to use OFDMA and MIMO together for radio access technology. LTE also introduce scheduling for shared channel data, HARQ and AMC (Adaptive Modulation and Coding).

LTE Key Features

Key features of LTE are as follows:

Multiple access schemes

- DL: OFDMA with CP (Cyclic Prefix)
- UL: Single Carrier FDMA (SC-FDMA) with CP

Adaptive modulation and coding

- DL/UL modulations: QPSK, 16QAM, and 64QAM
- Convolutional code and Rel-6 turbo code Advanced MIMO spatial multiplexing techniques
- (2 or 4)x(2 or 4) downlink and uplink supported
- Multi-user MIMO also supported

Support for both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) H-ARQ, mobility support, rate control, security, and etc.

Multiple Access Techniques of LTE

Multiple access schemes are used to allow many mobile users to share simultaneously a finite amount of radio spectrum. The sharing of spectrum is required to achieve high capacity by simultaneously allocating the available bandwidth (or the available amount of channels) to multiple users. For high quality communications, this must be done without severe degradation in the performance of the system. The first major design in LTE was to adopt multicarrier approach for multiple access schemes (H. Holma and A. Toskala, 2009). 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 signals. The frequency can also be adjusted, but in LTE the frequency adjustment is not affected.

LTE Physical Layer

The physical layer of LTE for downlink and uplink is different from each other. Uplink and downlink are quite different from each other. So, it is essential to describe them separately. Therefore, we describe these accordingly.

LTE Frame Structure

The frame structures for LTE differ between the Time Division Duplex, TDD and the Frequency Division Duplex, FDD modes as there are different requirements on segregating the transmitted data. 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

Type-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. A subframe consists of two slots; therefore one radio frame has 10 sub-frames as shown in **Fig. 12**. 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. Frame structure type 1 is applicable to both full duplex and half duplex FDD. Each radio frame is Tf □ 307200 □Ts □10 ms long and consists of 20 slots of length Tslot □15360 □Ts □ 0.5 ms, numbered from 0 to 19. A subframe is defined as two consecutive slots where subframe I. Frame structure type 1 is applicable to both full duplex and half duplex FDD. Each radio frame is Tf □ 307200 □Ts □10 ms long and consists of 20 slots of length Tslot □15360 □Ts □ 0.5 ms, numbered from 0 to 19. A subframe is defined as two consecutive slots where subframe I

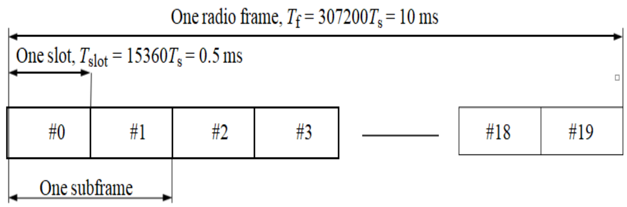

Fig. 12: Type-1 LTE Frame Structure.

Type-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 **Fig.13**.

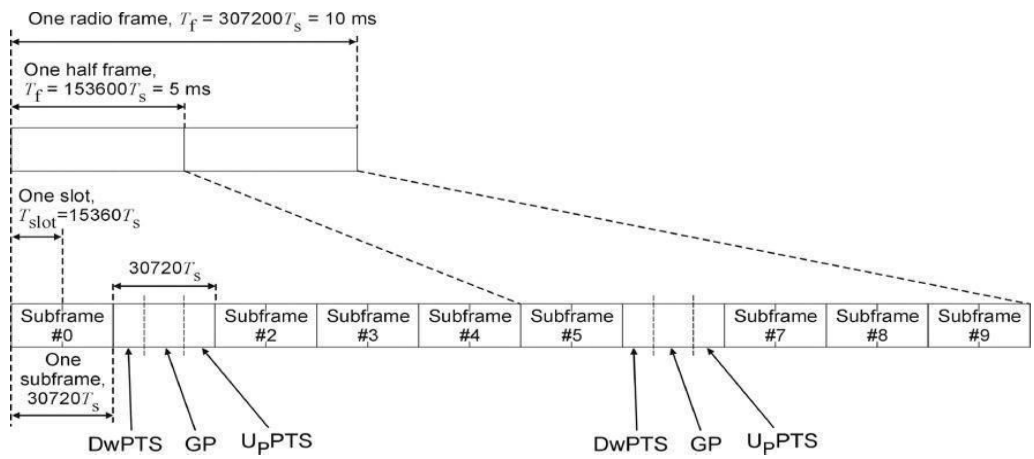

Fig. 13: Type-2 LTE Frame Structure.

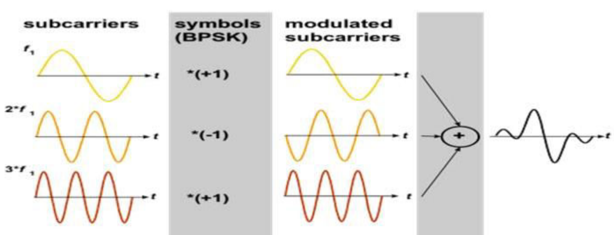

Fig. 14: Processing Steps of OFDMA.

The basic implementation of OFDMA is in digital telephony. In OFDMA, the Discrete Fourier Transform (DFT) and Inverse Discrete Fourier Transform (IDFT) are used for time and frequency domain representation. OFDMA is robust against multipath fading. Examples of different input signals and their corresponding output after passing from FFT block are shown in **Fig. 14**.

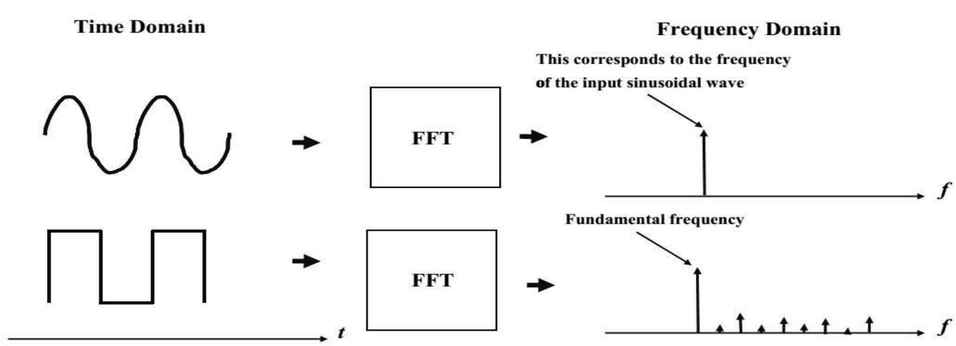

Fig. 15: Result of FFT operation with different inputs.

LTE OFDM Cyclic Prefix, CP

One of the primary reasons for using OFDM as a modulation format within LTE (and many other wireless systems for that matter) is its resilience to multipath delays and spread. However it is still necessary to implement methods of adding resilience to the system.

This helps overcome the inter-symbol interference (ISI) that results from this. In areas where inter-symbol interference is expected, it can be avoided by inserting a guard period into the timing at the beginning of each data symbol. It is then possible to copy a section from the end of the symbol to the beginning. This is known as the cyclic prefix, CP. The receiver can then sample the waveform at the optimum time and avoid any inter-symbol interference caused by reflections that are delayed by times up to the length of the cyclic prefix, CP.

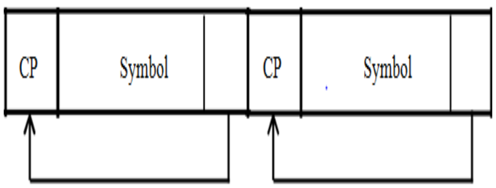

Fig. 16: Cyclic Prefix.

The length of the cyclic prefix, CP is important. If it is not long enough then it will not counteract the multi-path reflection delay spread. If it is too long, then it will reduce the data throughput capacity. For LTE, the standard length of the cyclic prefix has been chosen to be 4.69 µs. This enables the system to accommodate path variations of up to 1.4 km. With the symbol length in LTE set to 66.7 µs. The symbol length is defined by the fact that for OFDM systems the symbol length is equal to the reciprocal of the carrier spacing so that orthogonality is achieved. With a carrier spacing of 15 kHz, this gives the symbol length of 66.7 µs.

LTE OFDMA in the Downlink

The OFDM signal used in LTE comprises a maximum of 2048 different sub-carriers having a spacing of 15 kHz. Although it is mandatory for the mobiles to have capability to be able to receive all 2048 sub-carriers, not all need to be transmitted by the base station which only needs to be able to support the transmission of 72 sub-carriers. In this way all mobiles will be able to talk to any base station.

Within the OFDM signal it is possible to choose between three types of modulation:

QPSK (= 4QAM) 2 bits per symbol
16QAM 4 bits per symbol
64QAM 6 bits per symbol

The exact format is chosen depending on the prevailling conditions. The lower forms of modulation, (QPSK) do not require such a large signal-to-noise ratio but are not able to send the data as fast. Only when there is a sufficient signal-to-noise ratio can the higher-order modulation format is used.

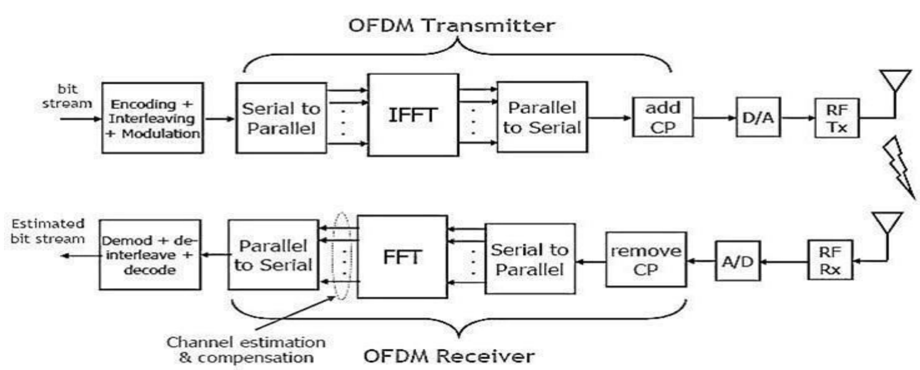

Fig. 17: Transmitter and Receiver of OFDMA.

Transmitter and Receiver of OFDMA

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), as shown in

Fig. 17. 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. 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 as shown in **Fig. 17**.

Modulation Parameters

The modulation parameters for different transmission bandwidth are shown in **Table 2** (White Paper, 2010).

Table 2: LTE Downlink Physical Layer Parameters.

Channel Bandwidth (MHz)	1.25	2.5	5	10	15	20
Frame Duration (ms)				10		
Subframe Duration (ms)				1		
Sub-carrier Spacing (kHz)				15		
Sampling Frequency (MHz)	1.92	3.84	7.68	15.36	23.04	30.72
FFT Size	128	256	512	1024	1536	2048
Occupied Sub-carriers (inc. DC sub-carrier)	76	151	301	601	901	1201
Guard Sub-carriers	52	105	211	423	635	847
Number of Resource Blocks	6	12	25	50	75	100
Occupied Channel Bandwidth (MHz)	1.140	2.265	4.515	9.015	13.515	18.015
DL Bandwidth Efficiency	77.1%	90%	90%	90%	90%	90%
OFDM Symbols/Subframe			7/6 (short/long CP)			
CP Length (Short CP) (µs)		5.2 (first symbol) / 4.69 (six following symbols)				
CP Length (Long CP) (µs)			16.67			

Downlink Physical Resource Block (PRB)

In downlink, the subcarriers are divided into resource blocks. This allows the system to split the subcarriers into small parts, without mixing the data across the total number of subcarriers for a given bandwidth. The resource block consists of 12 subcarriers for a single time slot of 0.5ms duration. The structure of PRB is given in **Fig.18**.

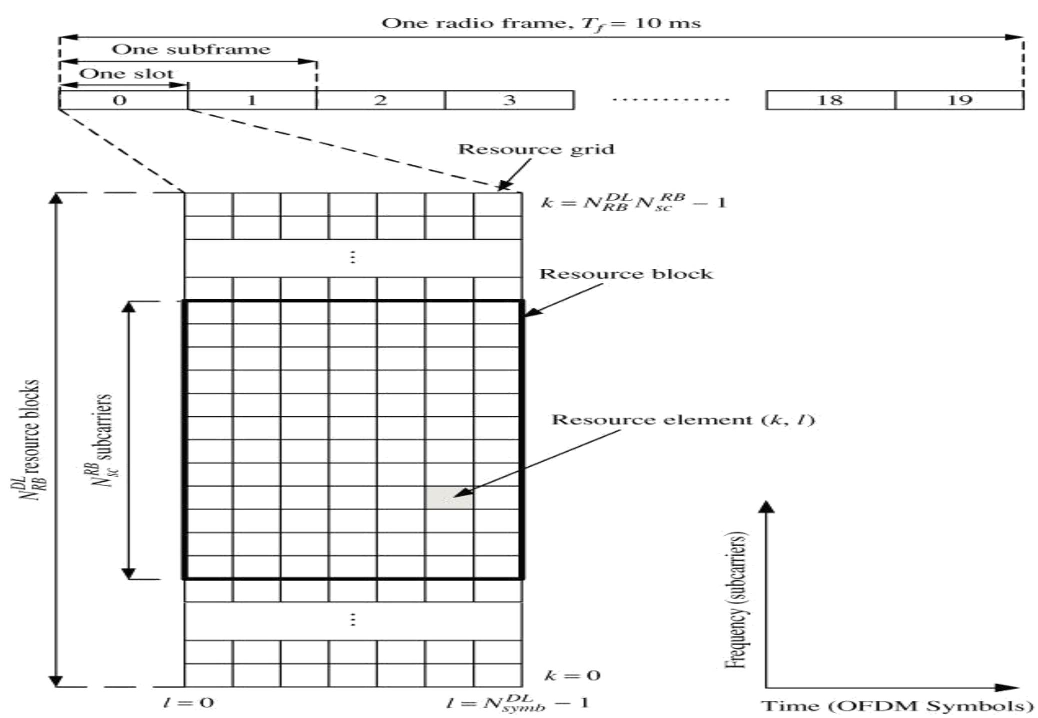

Fig. 18: Downlink Physical Resource Block.

Table 3: Physical Resource Block for different Bandwidths.

Bandwidth (MHz)	1.4	3	5		10	15	20
Physical Resource Block (PRB) Bandwidth (kHz)	180						
Subcarrier Bandwidth (kHz)				15			
Number of Resource Blocks	6	15	25		50	75	100

There are different numbers of resource blocks for different signal bandwidths in LTE as shown in **Table 3**. The structure of each resource grid is characterized by the following three parameters:

The number of downlink resource block ( )

It depends on the transmission bandwidth and shall fulfill *N N N,* where *N* = 6 and *N* = 110 are for the smallest and largest downlink channel bandwidth, respectively. The values of *N* for several current specified bandwidths are listed in **Table 3**.

The number of subcarriers in each resource block ( )

It depends on the subcarrier spacing, satisfying *N* = 180KHz that is, each resource block is of 180kHz wide in the frequency domain. The values of *N* for different subcarrier spacings are shown in **Table 4**. There are a total of *N N* subcarriers in each resource grid. For downlink transmission, the DC subcarrier is not used as it may be subject to a too high level of interference.

The number of OFDM symbols in each block

It depends on both the CP length and the subcarrier spacing, specified in **Table 4**.

Table 4: Physical Resource Block Parameters for the Downlink.

Bandwidth (MHz)	1.4	3	5		10	15	20
Physical Resource Block							
				180			
(PRB) Bandwidth (kHz)							
Subcarrier Bandwidth (kHz)				15			
Number of Resource Blocks	6	15	25		50	75	100

Physical Channels

The main purpose of physical channel is to convey information in LTE stack from higher layers (T. Zemen, 2008). Three different types of physical channels are defined for the LTE downlink. One common characteristic of physical channels is that they all convey information from higher layers in the LTE stack. This is in contrast to physical signals, which convey information that is used exclusively within the PHY layer.

LTE DL physical channels are

1) Physical Downlink Shared Channel (PDSCH)
2) Physical Downlink Control Channel (PDCCH)
3) Common Control Physical Channel (CCPCH)

Physical Downlink Shared Channel (PDSCH)

The PDSCH is designed for high data rates and is utilized for multimedia transport & data. Modulation schemes used by PDSCH are QPSK, 16-QAM & 64-QAM.

Physical Downlink Control Channel (PDCCH)

The PDCCH is basically used for control information signaling. It is mapped on the resource element in first three OFDM symbols in first slot of sub-frame. It uses only QPSK as modulation scheme and carries NACK/ ACK response to the uplink channel. In one sub-frame, multiple PDCCH can transmit.

Common Control Physical Channel (CCPCH)

The CCPCH is used to carry cell-wide control information. Like PDCCH, only QPSK modulation scheme is used for CCPCH. In addition, CCPCH is always transmitted close to the center frequency at 72 active subcarriers centered on DC sub-carrier. In CCPCH control information, signal is mapped onto resource elements (k,l), where k and l are OFDM symbols and subcarriers respectively.

Physical Signals

A channel can be considered as a medium through which some information is transmitted, where as a sign-al has a mathematical importance and it is, most of the times generated at the physical layer itself. So this article will speak about the different physical layer signals used at LTE downlink. There are two types of Physical Signals used in downlink.

Reference Signals

For channel estimation in OFDMA transmission, the reference symbols are inserted in the subcarriers. Theses reference symbols are jointly called downlink reference signals in LTE system. The reference signals are used to determine the channel impulse response (CIR). The product of a pseudo-random numerical (PRN) sequence and an orthogonal sequence generates the reference signals. There are possibly 510 unique reference signals generated of following three types;

Cell-Specific Reference Signals

They are assigned to each cell within a network and transmitted in each downlink sub-frame. They act as a cell-specific identifier.

UE-Specific Reference Signals

They are used for supporting single antenna port transmissions of PDSCH. They are only transmitted in the resource block that is assigned for PDSCH.

Mobile Broadband Single Frequency Network (MB SFN) Reference Signals

They support MBSFN transmission and transmitted on the antenna port.

Synchronization Signals

Synchronization signals are used by UE in cell search procedure and are categorized by primary and secondary synchronizations signals. Like reference signals, the same PRN and orthogonal sequence is used in synchronization signals. The primary and secondary synchronization signals are transmitted during the slot _0' and slot _10' of LTE radio frame, and occupy 72 subcarriers that are centered at the DC subcarrier.

Transport Channel

The transport channel transfers the information to upper layers and MAC, and works as an interface between physical layer and MAC. The different types of transport channels are described as;

Broadcast Channel (BCH)

The Broadcast channel is a fixed format transport channel that broadcasts the system parameters to enable the devices accessing the system. It should be broadcasted over the whole cell coverage area.

Downlink Shared Channel (DL-SCH)

This transport channel is the main channel for downlink data transfer. It is used by many logical channels.

Paging Channel

The paging channel is used to carry the paging information and to switch the device from idle state to connected state. It is also required to broadcast over the whole cell coverage area.

Multicast Channel

The multicast channel transfers multicast services to the UE and performs following functions;

1) Provides support for multicast broadcast single frequency network
2) Semi Static resource allocation

Uplink

LTE uplink requirements differ from downlink requirements in several ways. Not surprisingly, power consumption is a key consideration for UE terminals. The high peak-to-average power ratio (PAPR) and related loss of efficiency associated with OFDM signaling are major concerns. As a result, an alternative to OFDM was sought for use in the LTE uplink. The reason for the selection of SC-FDMA comes mainly from its advantage to provide low a peak-to-average power ratio (PAPR) for the transmit waveform. This result in less power consumption in the mobile station compared to an OFDMA transmission.

SC-FDMA

Single Carrier - Frequency Domain Multiple Access (SC-FDMA) is well suited to the LTE uplink requirements. The basic transmitter and receiver architecture is very similar (nearly identical) to OFDMA, and it offers the same degree of multipath protection. Importantly, because the underlying waveform is essentially single-carrier, the PAPR is lower. SC-FDMA, which is alternatively known as DFT-Spread-OFDMA (DFT-S-OFDMA), is a variant of OFDMA. The main difference from OFDMA is the addition of Discrete Fourier Transform (DFT)-spread block prior to modulating the data symbols using OFDM modulation. SC-FDMA shares almost all the characteristics as OFDMA transmission scheme, in addition to lower PAPR in comparison to OFDMA.

A UE can benefit from SC-FDMA in the uplink transmission in terms of increased transmission power efficiency along with increased data rates, which eventually translates to improved battery life on the UE.

Transmitter and Receiver

Single Carrier - Frequency Domain Multiple Access (SC-FDMA) is well suited to the LTE uplink requirements. The basic transmitter and receiver architecture is very similar (nearly identical) to OFDMA, and it offers the same degree of multipath protection. Importantly, because the underlying waveform is essentially single-carrier, the PAPR is lower. SC-FDMA and OFDMA signal chains have a high degree of functional commonality.

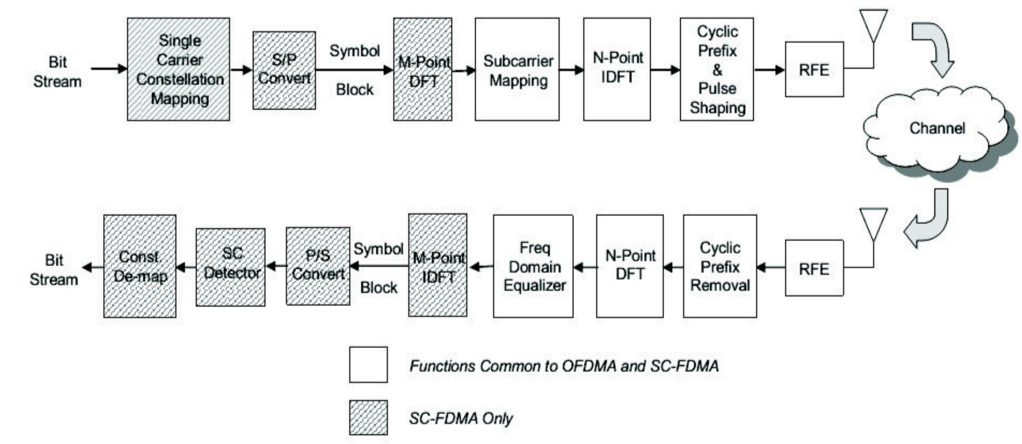

Fig. 19: A basic SC-FDMA transmitter / receiver arrangement.

The functional blocks in the transmit chain are:

Constellation mapper

Converts incoming bit stream to single carrier symbols (BPSK, QPSK, or 16QAM depending on channel conditions).

Serial/parallel converter

Formats time domain SC symbols into blocks for input to FFT engine.

M-point DFT

Converts time domain SC symbol block into M discrete tones.

Subcarrier mapping

Maps DFT output tones to specified subcarriers for transmission. SC-FDMA systems either use contiguous tones (localized) or uniformly spaced tones (distributed) as shown in **Fig. 19**. The current work-ing assumption in LTE is that localized subcarrier mapping will be used.

N-point IDFT

Converts mapped subcarriers back into time domain for transmission.

Cyclic prefix and pulse shaping

Cyclic prefix is pre-pended to the composite SC-FDMA symbol to provide multipath immunity in the same manner as described for OFDM. As in the case of OFDM, pulse shaping is employed to prevent spectral regrowth.

RFE

Converts digital signal to analog and up convert to RF for transmission. In the receiver side chain, the process is essentially reversed. Unlike OFDM, the underlying SC-FDMA signal represented by the discrete subcarriers is-not surprisingly-single carrier. This is distinctly different than OFDM because the SC-FDMA subcarriers are not independently modulated. As a result, PAPR is lower than for OFDM transmissions.

Subcarrier Allocation Methods

The allocation of the subcarriers to each user is an important issue which has an influence on the system performance of the LTE uplink data trans-mission. In **Fig. 20** the two most common techniques can be seen embedded into a transmitter scheme. These techniques are localized carrier assignment mode (localized mode) and distributed carrier assignment mode (distributed mode). In the localized mode, each terminal uses a set of adjacent subcarriers to transmit its symbols. In the distributed mode, the subcarriers used by a single terminal are distributed over the whole frequency band. **Fig. 20** shows a representation of the different modes in the frequency domain.

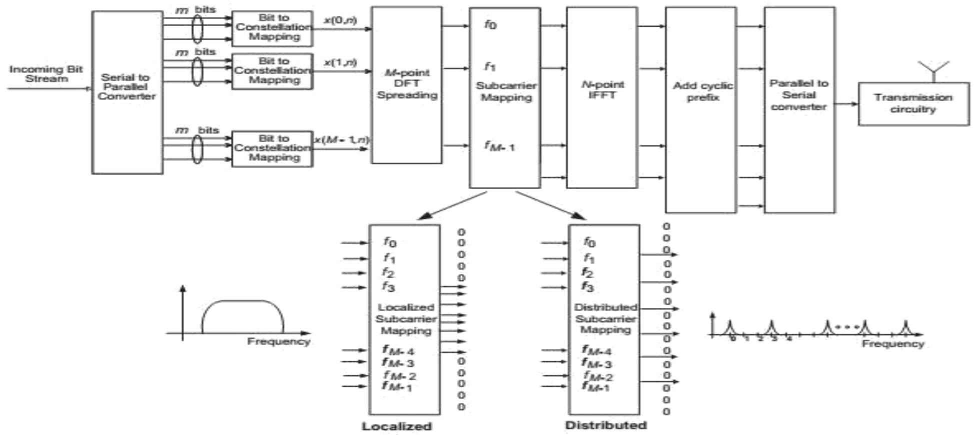

Fig. 20: SC-FDMA transmitter for localized and distributed subcarrier mappings.

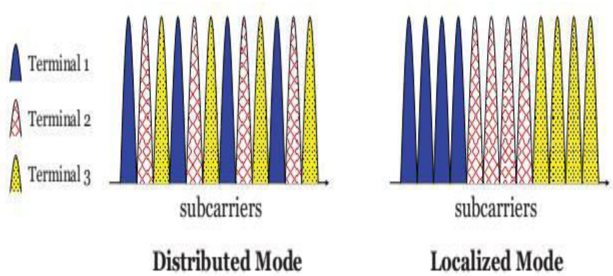

Fig. 21: Subcarrier allocation methods for multiple users (3 users, 12 subcarriers, and 4 subcarriers per user).

Although distributed mode provides high frequency diversity as the subcarriers are spread over the different parts of the frequency band and the subcarrier data transmitted over different channels are subject to different fading, with channel dependent scheduling (CDS), localized mode offers higher system throughput. LTE employs localized subcarrier mapping, which best fits the requirements and configuration of this standard. This decision was motivated by the fact that with localized mapping, it is possible to exploit frequency selective gain via channel dependent scheduling (assigning uplink frequencies to UE based on favorable propagation conditions).

Uplink Time and Frequency Structure

As depicted in **Fig. 22**, one SC-FDMA frame constitutes 20 slots, each being 0.5 mili seconds long. Two slots are called a sub frame or transmission time interval.

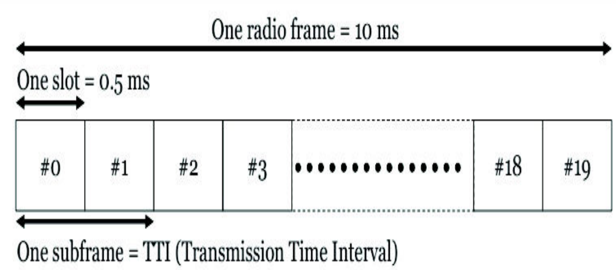

Fig. 22: Type 1 Frame structure.

The structure of one slot can be more clearly understood by looking at the resource grid structure in **Fig. 23**.

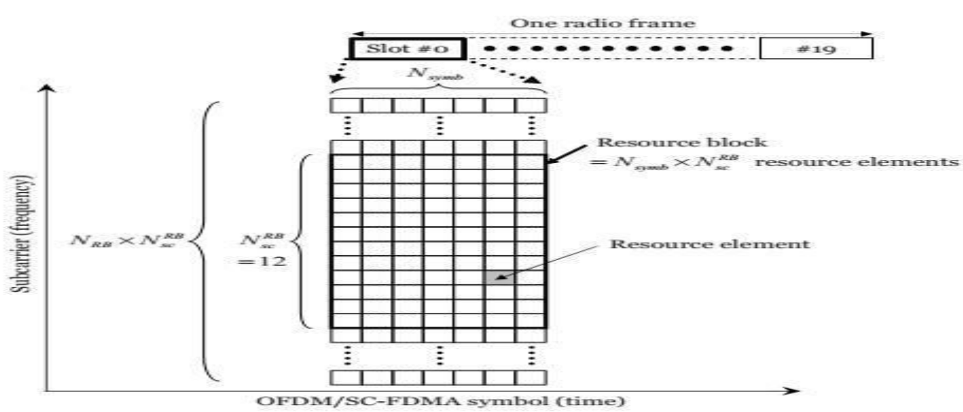

Fig. 23: Uplink resource grid for one slot.

The transmit signal in each slot is described by a resource grid with subcarriers and SC-FDMA symbols. The number of subcarriers for each resource block is standardized as 12 for the LTE uplink. N_{RB} depends on the uplink transmission bandwidth determined for that cell but should always be between 6 and 110. These numbers correspond to the smallest and largest uplink bandwidth. When the time domain is considered, the number of the SC-FDMA symbols for each slot is 7 for the normal cyclic prefix. However, when the long cyclic prefix is used, this number decreases to 6. Each resource element in the grid has two indices which stand for the time and frequency axes, respectively. The resource element corresponds to a complex value which is the linear combination of all the data symbols transmitted at that time.

Modulation Parameters

The LTE Uplink uses same generic frame structure as the downlink, in FDD applications. The width of PRB and subcarrier spacing is similar as in downlink.

Uplink Physical Channels

There are three types of LTE Uplink Physical Channels;

Physical Uplink Shared Channel (PUSCH)

It uses QPSK, 16-QAM and 64-QAM modulations. This channel carries user data. It supports QPSK and 16 QAM modulation with 64QAM being optional. Information bits are first channel-coded with a turbo code of mother rate of 1/3 before being adapted by a rate matching process for a final suitable code rate. Adjacent data symbols are mapped to adjacent SC-FDMA symbols in the time domain before being mapped across sub-carriers. After this interleaving process, bits are scrambled before modulation mapping, DFT-spreading, sub-carrier mapping and OFDM modulation. Channel coding is similar to that of the downlink. The PUSCH carries in addition to user data any control information necessary to decode the information such as transport format indicators and MIMO parameters. Control data is multiplexed with information data prior to DFT spreading.

Physical Random Access Channel (PRACH)

Random access transmission is the only non-synchronized transmission in the LTE uplink. Although the terminal synchronizes to the received downlink signal before transmitting on RACH, it cannot determine its distance from the base station. Thus, timing uncertainnty caused by two-way propagation delay remains on RACH transmissions. Appropriately designed Physical Random Access Channel (PRACH) occurs reasonably frequently, provides a sufficient number of random access opportunities, supports the desired cell ranges in terms of path loss and uplink timing uncertainty, and allows for sufficiently accurate timing estimation. Additionally, PRACH should be configurable to a wide range of scenarios, both for RACH load and physical environment. The PRACH is used to carry random access preamble and it transmits a signature sequence and a CP that are received from the transport layer. In PRACH, a request for transmission resources is transmitted on other physical channels.

Physical Uplink Control Channel (PUCCH)

As the name implies, the PUCCH carries uplink control information. It is never transmitted simultaneously with PUSCH data. PUCCH conveys control information including channel quality indication (CQI), ACK/NACK, HARQ and uplink scheduling requests.

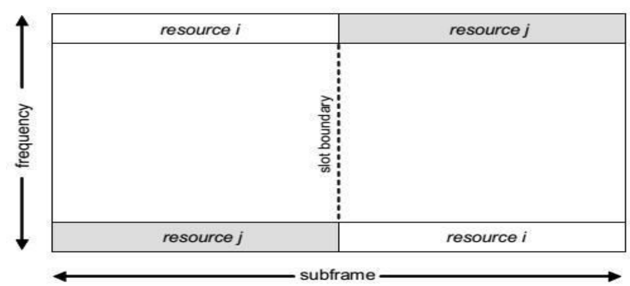

Fig. 24: PUCCH is hopped at slot boundary.

The PUCCH transmission is frequency hopped at the slot boundary as shown in **Fig. 24** for added reliability.

Uplink Physical Signals

Uplink physical signals are used within the physical layer and do not convey information from higher layers. Two types of UL physical signals are defined:

1) Uplink Reference Signal
2) Random Access Preamble

Uplink Reference Signal

There are actually two variants of the UL reference signal. The demodulation signal facilitates coherent demodulation. It is transmitted in the fourth SC-FDMA symbol of the slot and is the same size as the assigned resource. There is also a sounding reference signal used to facilitate frequency dependent scheduling. Both variants of the UL reference signal are based on Zadhoff-Chu sequences.

Random Access Preamble

The random access procedure involves the physical layer and higher layers. At the physical layer, the cell search procedure is initiated by transmission of the random access preamble by the UE. If successful, a random access response is received from the base station.

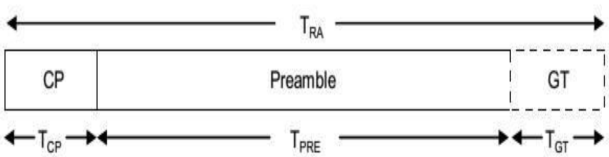

Fig. 25: Random Access Preamble Format.

The random access preamble format is shown in **Fig. 25**. It consists of a cyclic prefix, a preamble and a guard time during which there is no signal transmitted. For the generic frame structure, the timing parameters are:

T_{RA}: 30720 T_S
T_{GT}: 3152 T_S
T_{PRE}: 24576 T_S

Where T_S= period of a 30.72 MHz clock

Random access preambles are derived from Zadoff-Chu sequences. They are transmitted on blocks of 72 contiguous subcarriers allocated for random access by the base station. In FDD applications, there are 64 possible preamble sequences per cell. The exact frequency used for transmission of the random access preamble is selected from available random access channels by higher layers in the UE. Other information provided to the physical layer by higher layers includes:

1) Available random access channels
2) Preamble format (which preamble sequences)
3) Initial transmission power
4) Power ramp step size
5) Maximum number of retries

Uplink Transport Channels

As in the DL, uplink transport channels act as service access points for higher layers. Characteristics of UL transport channels are described below.

Uplink-Shared Channel (UL-SCH)

1) Support possible use of beam forming.
2) Support dynamic link adaption (varying modulation, coding and/or Tx power).
3) Support for HARQ.
4) Support for dynamic and semi-static resource allocation.

Random Access Channel (RACH)

1) Supports transmission of limited control information.
2) Possible risk of collision.

METHODOLOGY:

Transmission Model of OFDMA and SC-FDMA

In this chapter, we simulate the model of OFDMA and SC-FDMA in MATLAB. The block diagrams of OFDMA and SC-FDMA are given in **Fig. 26** and **Fig. 27** respectively.

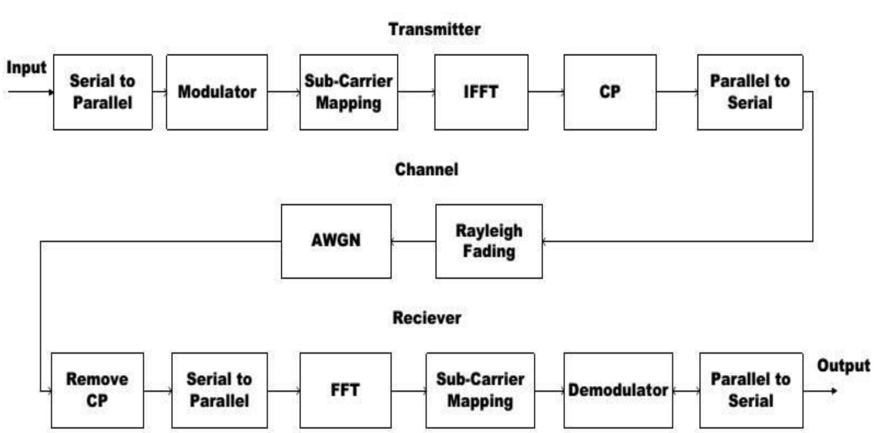

Fig. 26: OFDMA Transmission Model.

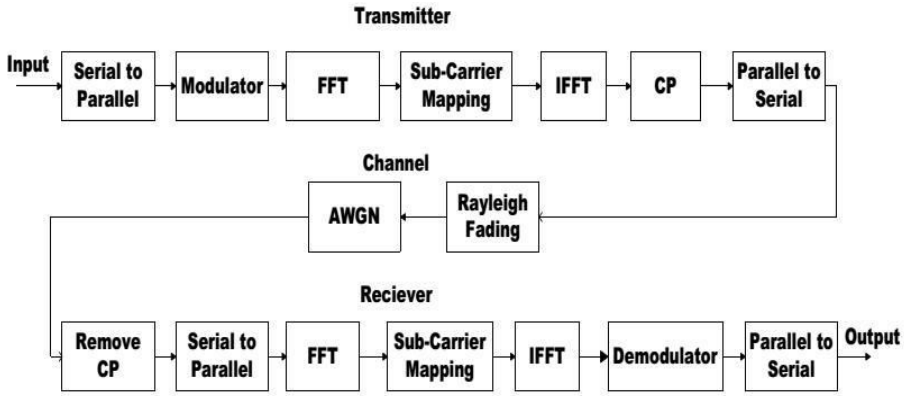

Fig. 27: SC-FDMA Transmission Model.

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 *rayleighchan* for Rayleigh fading and the parameters used for that are given below in **Table 5**. We use following adaptive modulation schemes to analysis the Peak to Average Power Ratio (PAPR), Signal to Noise Ratio (SNR), Error Probability (P_e) and for both OFDMA and SC-FDMA.

1) We use the following modulation techniques:
2) Binary Phase Shift Keying (BPSK)
3) Quadrature Phase Shift Keying (QPSK)
4) 16-Quadrature Amplitude Modulation (16-QAM)
5) 64-Quadrature Amplitude Modulation (64-QAM)

Simulation Assumptions

Table 5: Parameters of simulation model.

Parameters	Assumption
System bandwidth	5 MHz
Sampling rate	5 Mega-samples per second
Data modulation format	BPSK, QPSK, 16-QAM, 64-QAM
Channel	AWGN (SNR = 100 dB)
Cyclic prefix	20 samples (4 µs)
Transmitter IFFT size	512
Subcarrier (tone) spacing	9.765625 kHz (= 5 MHz /512
SC-FDMA input block size	16 symbols
SC-FDMA input FFT size	16
Channel estimation	Perfect
Equalization	Zero forcing or minimum mean square error (MMSE)
Channel coding	None
Number of iterations	> 10^4

Peak to Average Power Ratio (PAPR)

The Peak to Average Power Ratio (PAPR) is currently viewed as an important implementation issue in communication systems. Specifically, for wireless cellular systems the price of the mobile unit is required to remain low. This means that a limited PAPR can be supported. 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 & 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}). It is an important mea-sure that is widely used for the complete description of the power characteristics of signals.

Signal to Noise Ratio (SNR)

The SNR is the ratio of bit energy (Eb) to the noise power spectral density (N0) and it is expressed in dB.

SNR = E_b / N_0

Error Probability

The probability of error or error probability (P_e) is the rate of errors occurs in the received signal. For cohe-rent 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 P_e is given by;

$$*\sqrt{\quad} \qquad Q\pm$$

Where

= (Transmitted signal energy per symbol)

= Noise density in AWGN

Q = Q-Function

Therefore

$$*\sqrt{\quad} \qquad Q\pm$$

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;

$$*\sqrt{\quad} \qquad Q\pm$$

Whereas, the relationship between erfc and Q is given by;

$$() \qquad [\sqrt{}]$$

For M-ary QAM the P_e is given by;

$$(\quad \sqrt{}) \qquad (\sqrt{(} \quad) \quad)$$

Where,

=Average value of transmitted symbol energy in M-ary QAM

Data Simulation

PAPR of OFDMA and SC-FDMA for Adaptive Modulation

In this section, we will simulate the Peak to Average Power Ratio (PAPR) for both OFDMA and SC-FDMA using different modulation schemes (BPSK, QPSK, 16-QAM and 64-QAM). We have assumed some para-meters and then we have implemented this in MAT-LAB.

PAPR using BPSK

We have compared both SC-FDMA and OFDMA PAPR using BPSK modulation technique.

The PAPR of OFDMA and SC-FDMA for BPSK modulation is shown in **Fig. 28**.

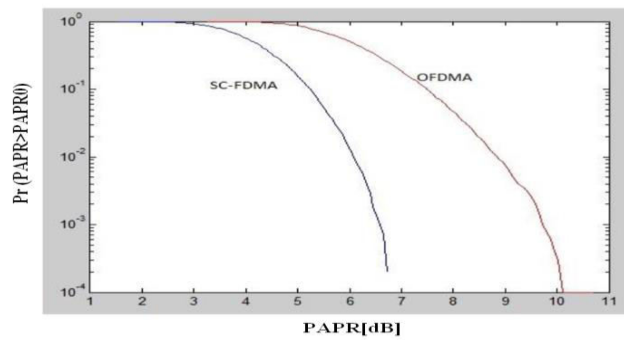

Fig. 28: PAPR of OFDMA and SC-FDMA for BPSK.

PAPR using QPSK

We have compared both SC-FDMA and OFDMA PAPR using QPSK modulation technique. The PAPR of OFDMA and SC-FDMA for QPSK modulation is shown in **Fig. 29**.

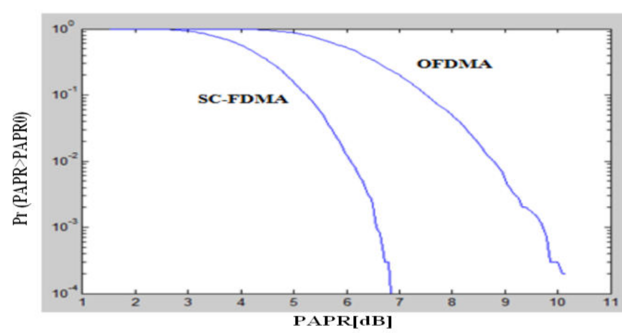

Fig. 29: PAPR of OFDMA and SC-FDMA for QPSK.

PAPR using 16-QAM

We have compared both SC-FDMA and OFDMA PAPR using 16-QAM modulation technique. The PAPR of OFDMA and SC-FDMA for 16-QAM modu-lation is shown in below **Fig. 30**.

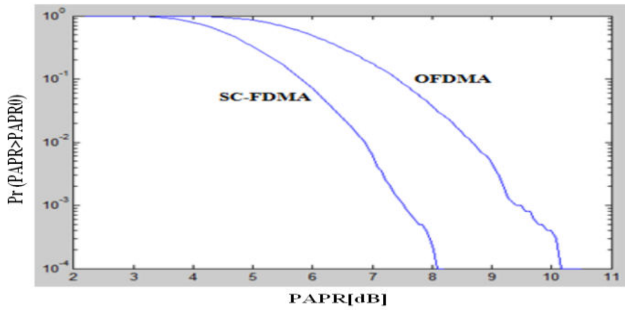

Fig. 30: PAPR of OFDMA and SC-FDMA for 16-QAM.

PAPR using 64-QAM

We have compared both SC-FDMA and OFDMA PAPR using 64-QAM modulation technique. The PAPR of OFDMA and SC-FDMA for 64-QAM modulation is shown in **Fig. 31**.

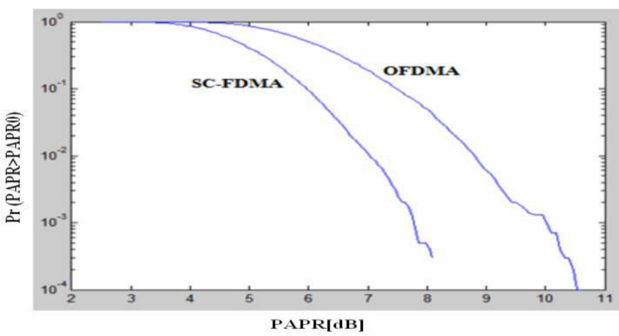

Fig. 31: PAPR of OFDMA and SC-FDMA for 64-QAM.

Decision from PAPR Simulation

From the above figures of PAPR simulation, we can observe the following things:

1) We can observe that the PAPR value of SC-FDMA is almost similar for BPSK and QPSK modulation schemes
2) PAPR value of OFDMA slightly decreases in case of QPSK modulation
3) For 16QAM and 64 QAM, the PAPR of SC-FDMA is almost same whereas the PAPR of OFDMA is slightly increased.

Error Probability of Uplink and Downlink for Adaptive Modulation

We have used Interleaved Frequency-Division Multiple-Access (IFDMA) for uplink and Localized Frequency-Division Multiple-Access (LFDMA) for downlink to check the Error Probability for adaptive modulation.

Error Probability for Uplink Simulation

The error probability for uplink is shown in **Fig. 32**.

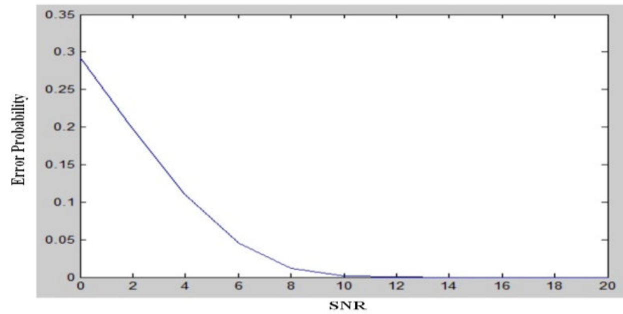

Fig. 32: Error Probability Graph for Uplink.

Error Probability for Downlink Simulation

The error probability for uplink is shown in **Fig. 33**.

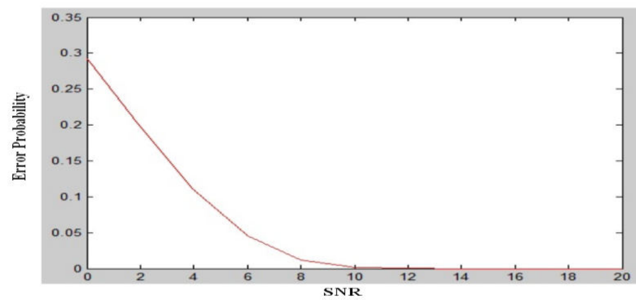

Fig. 33: Error Probability Graph for Downlink.

Decision from Error Probability Simulation

From the above figures of Error Probability simulation for uplink and downlink, we can observe the following things:

1) Error Probability graph for both uplink and downlink are almost same
2) Error Probability decreases with increase of SNR
3) Error Probability of uplink and downlink are almost same means that the received at the receiver side is same as the data is sent from the sender side.

RESULTS AND DISCUSSION:

The main purpose of our research is to measure the performance of LTE physical layer with the implementation of the structures of sender & receiver at MATLAB. The power consumption at the user end such as portable devices is again a vital issue for uplink transmission in LTE system. From our simulation results we also conclude that the higher order modulation schemes have an impact on the PAPR of both OFDMA and SC-FDMA. The PAPR of SC-FDMA is almost same and slightly increases in OFD MA 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 sys-tem. Based on our result we 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. We also simulate the error probability using SC-FDMA and we conclude that, this technique is efficient for uplink transmission in LTE system. In this thesis, our main task was to analyze the performance of the uplink physical layer of LTE. In future, we will try to find out more efficient way to improve the LTE performance which is our main & ultimate target.

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We, hereby, declare that the work presented in this report is the outcome of the investigation performed by us under the supervision of Mr. Tanvir Ahmed, Assistant Professor, Department of Computer Science and Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh.

CONFLICTS OF INTEREST:

The authors declare that there are no conflicts of interest in the current research work to publish now in this journal.

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