Performance Analysis of LTE System in term of SC-FDMA & OFDMA

Monika Sehrawat[1], Priyanka Sharma[2]
[1]M.Tech Scholar, SPGOI Rohtak
[2]Assistant Professor, ECE Deptt. SPGOI Rohtak

Abstract - To meet the increasing demands on the mobile radio systems and data traffic, a successor of UMTS, which runs on an evolution of the existing infrastructure used by over 80 percent of mobile subscribers globally, has been worked on by 3GPP, called Long Term Evolution (LTE). This will permit more powerful and better spectral efficiency of the transmission. The major parts of LTE are Single Carrier Frequency Division Multiple Access (SC-FDMA) & Orthogonal Division Multiple Access (OFDMA). OFDMA is used in the LTE downlink as a multiple access method as it provides good bandwidth efficiency, immunity to multi-path and frequency selective fading, and less complex equalization at the receiver. SC-FDMA is introduced recently and it became handy candidate for uplink multiple access scheme in LTE system as it has the advantage of lower PAPR as compared to that of OFDMA.

In our paper, we analyzed the performance of SCFDMA and OFDMA of LTE using different modulation schemes (BPSK) on the basis of BER by simulating the model of SCFDMA & OFDMA in MATLAB. We used Additive White Gaussian Noise (AWGN) channel and introduced frequency flat fading in the channel by using Rayleigh fading model to evaluate the performance in presence of noise and fading. We also found PAPR for both the accessing methods using the same model developed for BPSK modulation.

Keywords - *SCFDMA, OFDMA, PAPR, Rayleigh fading model*

I. INTRODUCTION

Long Term Evolution (LTE) enhances the susceptibility and speed of wireless data networks using various types of modulations (BPSK). LTE redesigns and modifies the network architecture with substantially diluted transfer latent period. It depicts a wireless communication system which endorses downlink transmission using Orthogonal Frequency Division Multiple Access (OFDMA) scheme up to 300 mbps of data transmission and 75 mbps throughput for uplink data transmission using Carrier Frequency Division Multiple Access (Sc-FDMA). OFDMA transmits data over a large number of subcarriers [1]. These signals are spaced in reciprocally perpendicular axis assembling at right angles to each another and their summation will be zero which removes mutual interference. SC-FDMA aggregates multipath interference abjuration and flexible subcarrier frequency assignment which provides only one carrier at a time instead of multiple carriers in transmission. Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are the two most common Frame Structure that are used in LTE where both transmitter and receiver operate on same frequency band and same time in FDD, but in TDD both transmitter and receiver works on same frequency at different time [2]. The purpose of this paper is to analysis the performance of OFDMA (Downlink transmission) and SC-FDMA (Uplink Transmission) in different types of LTE Frame structures with different modulation techniques. We analytically derive the OFDMA and SC-FDMA signals in FDD and TDD mode and also numerically compare PAPR characteristics using the complementary cumulative distribution function (CCDF) of PAPR. The rest of this paper is organized as follows: Section 2 and Section 3 provide the brief idea about the OFDMA system model and SC-FDMA System Model.

Like other cellular technologies LTE uses OFDM as multiplexing technique. LTE uses OFDMA as downlink and Single Carrier FDMA (SC FDMA) as uplink transmission technique. The use of SC FDMA in LTE reduces the Peak to Average Power Ratio (PAPR) which is the main drawback of OFDM. LTE uses wider spectrum, up to 20 MHz, to provide compatibility with existing cellular technologies such as UMTS and HSPA+, and increases the capacity of the system. LTE uses flexible spectrum which makes it possible to be deployed in any bandwidth combinations. This makes LTE suitable for various sizes of spectrum resources. LTE uses both FDD and TDD as duplexing techniques to accommodate all types of spectrum resources. e bits on each of the assigned channels. This seems to be similar to FDM but in the case of OFDM, total subcarriers are divided into sub channels and these sub channels are mapped to one single data/traffic source [4]. SC-FDMA is a multiple access method. Its structure is same as OFDMA with an addition of Fast Fourier Transform (FFT) block. The parallel data streams are first passed through FFT block then are modulated on subcarriers because of this the SC-FDMA is also called DFT-Precoded OFDM. The main difference between OFDMA and SC-FDMA is, in OFDMA, each data symbol is carried on a separate subcarrier while, in SC-FDMA, multiple subcarriers carry each data symbol due to mapping of the symbols' frequency domain samples to subcarriers. As SC-FDMA is derived from OFDMA it has same basic advantages as OFDMA but the spreading of each data symbol over multiple subcarriers gives it the profound advantage of lower PAPR value as compare to that of OFDMA.

Hence PAPR is a useful parameter for uplink it is used in uplink transmission. Our objective of this work is to analyze the performance of LTE by considering two multiple access techniques (SC-FDMA and OFDMA) with adaptive modulation techniques BPSK. We have considered BER and PAPR parameters to evaluate the performance of LTE. 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.

II. ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS (OFDMA) MODEL

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

In OFDMA transmitter, the high speed serial data from each user is first converted in to low speed parallel data streams. This increases the symbol duration which reduce the Intersymbol Interference (ISI) at the receiver. Then the parallel data streams are passed through modulator, where adaptive modulation schemes such as (BPSK, QPSK, 16-QAM, 64-QAM) is applied. These modulated data streams are then mapped to orthogonal subcarriers by dividing the available spectrum into number of orthogonal frequency subcarriers. This makes the time domain data stream from user a frequency domain data stream or signal as at different frequency different low speed data stream will be present. The IFFT stage converts these complex data streams into time domain and generates OFDM symbols. A guard band or cyclic prefix (CP) is inserted between OFDMA symbols in order to cancel the ISI at the receiver. The CP is inserted by taking some part from end of the OFDM symbol and putting it at the start of the symbol as shown in figure 2.3. The duration of these CP should be greater than the channel impulse response or delay spread. After appending CP the data streams are converted to a serial data stream to be transmitted in the channel.

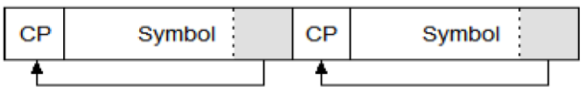

Fig.1: Inserting Cyclic prefix (CP)

At the receiver, the inverse processes of the transmitter occur. The serial data is converted to parallel data streams, CP is removed from each symbol and FFT stage converts the OFDM symbols in to frequency domain followed by subcarrier de-mapping and demodulation. Finally parallel data streams are converted to high speed serial data stream.

Figure 1 shows the block diagram of the model we used to simulate OFDMA system. We write a MATLAB program to simulate the model shown

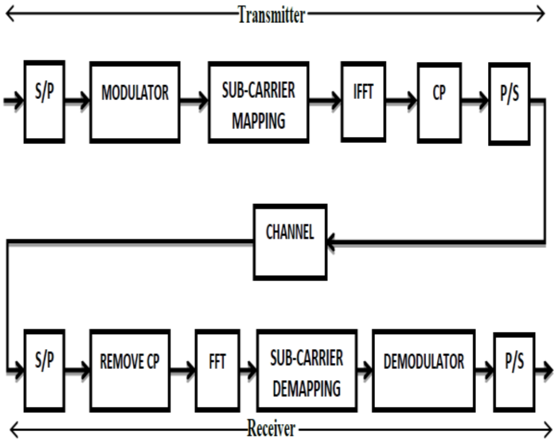

Fig.2: Block diagram of the OFDMA system model

Following are the steps or algorithm we followed while writing the program to simulate the model.

- First we generated binary stream of data.
- We converted this stream of data in to number of parallel streams of data.
- We modulated these streams of data using modulation schemes BPSK,
- Then these modulated streams of data are mapped to different sub-carriers.
- Then we took the IFFT of these mapped streams of data.

CP was appended by taking some portion from end of each symbol and adding it at the beginning of the symbol.

- Then the resultant parallel streams were converted to long serial data stream.
- Then we created an AWGN channel by using a built in function in MATLAB in which the noise level is described by SNR per sample, which is one input parameter to the function.
- We passed serial data stream through this channel (function).
- For Rayleigh fading channel simulation we introduced fading using a built in function in MATLAB for Rayleigh frequency flat fading.
- Corrupted data from channel were then converted to parallel data streams.
- From each symbol CP were removed.
- Then FFT of the streams were taken.
- Data streams were de-mapped from the subcarriers.

- Demodulations of data streams were done.
- Finally parallel data streams were converted to serial data stream

LTE (Long Term Evolution) uses OFDMA and SC-FDMA at downstream and upstream for downlink and uplink transmission. The OFDMA system model is shown in Figure 1. A brief description of the model is provided below. At first, S symbols/second data are transmitted to the transmitter and the data symbols are pass through a serial to parallel converter and the data rate on every X line is S/X symbols [3].The input data stream on each carrier is then mapped by using different types of modulation scheme such as QPSK, 16-QAM, 64QAM etc. Then Inverse fast Fourier Transform is used to find the corresponding Time wave form, which means that M symbols are sent to an Inverse Fast Fourier Transform that performs N-point IFFT operation. The output is N time sample [4]. The Guard interval is then introduced at the start of each sample which is known as addition of cyclic extension in the prefix. Then the length of the output sample is N+LP. The cyclically extended symbols are passed through a parallel to serial converter and then transmitted through a channel [5]. A channel model is then applied to the transmitted signal. The model allows for the signal to noise ratio, multipath to be controlled. The signal to noise ratio is set by adding a known amount of white noise to the transmitted signal which is known as AWGN Additive white Gaussian noise [16].The Receiver basically does the reverse operation of the transmitter. The transmitted signals which pass through the channel are then converted by using Serial to parallel converter and cyclic extension is also removed. The signals pass through an N-point Fast Fourier Transform which converted time domain signal into frequency domain. Then the signal is demapped and performs parallel to serial conversion using Parallel to serial convert block and the resultant signal is an M sample output

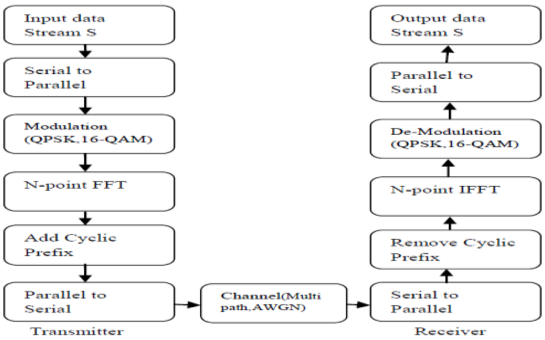

Fig.3: Transmitter Receiver system for OFDM

III. SC-FDMA SYSTEM MODEL

SC-FDMA is a multiple access method. Its structure is same as OFDMA with an addition of Fast Fourier Transform (FFT) block. The parallel data streams are first passed through FFT block then are modulated on subcarriers because of this the SC-FDMA is also called DFT-precoded OFDM. The main difference between OFDMA and SC-FDMA is, in OFDMA, each data symbol is carried on a separate subcarrier while, in SC-FDMA, multiple subcarriers carry each data symbol due to mapping of the symbols' frequency domain samples to subcarriers. As SC-FDMA is derived from OFDMA it has same basic advantages as OFDMA but the spreading of each data symbol over multiple subcarriers gives it the profound advantage of lower PAPR value as compare to that of OFDMA. Hence PAPR is a useful parameter for uplink it is used in uplink transmission of LTE system.

Figure 4 shows the block diagram of the model we used to simulate SC-FDMA system. The model is same as that of OFDMA except an FFT block is inserted before sub-carrier mapping at the transmitter while an IFFT block is placed after sub-carrier demapping at the receiver. The steps for creating the program to simulate the model are same as that of OFDMA except we took FFT before sub-carrier mapping and IFFT after sub-carrier demapping. The SC-FDMA system model is shown in Figure 4. A brief description of the model is provided below. The main difference between SCFDMA and OFDMA is that SC-FDMA has more discrete Fourier transform (DFT) processing, so we can regarded as SCFDMA as a DFT-spread OFDMA where time domain data signals are transformed to frequency domain by a DFT before going through OFDMA modulation [6].

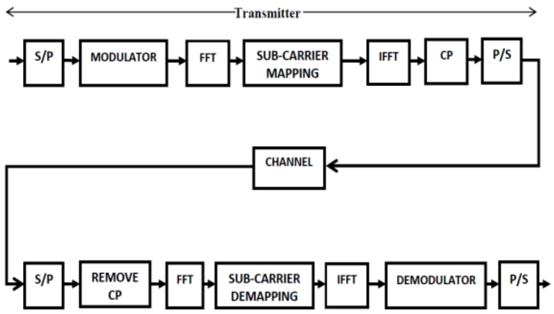

Fig.4: Block diagram of the SC-FDMA system model

At first, the input data stream is first modulated to single carrier symbols by using Quadrature Phase Shift Keying (QPSK), 16-QAM (Quadrature Amplitude Modulator) or 64-QAM. The resultant modulated symbols become the inputs of the functional blocks of SCFDMA. Then the modulated symbols are converted into parallel symbols and organized into blocks. Now N-Point DFT (Discrete Fourier Transform) Converts time domain single carrier blocks into N discrete frequency tones. Then Subcarrier Mapping, controls the frequency allocation, and maps N discrete frequency tones to subcarriers for transmission. The mapping can be localized or distributed. In localized mapping, N-discrete frequency tones are mapped on N consecutive subcarriers where as in distributed mapping; N-discrete frequency tones are mapped on uniformly spaced subcarriers. Then M-Point IDFT converts the mapped subcarriers to time domain. If M >N then unused inputs are set to zero. If they are equal (M = N), they simply cancel out and it becomes a conventional single user single carrier system with frequency domain equalization. However, if N is smaller than M and the remaining inputs to the IDFT are set to zero, the output of the IDFT will be a signal with 'single-carrier' properties, i.e. a signal with low power variations, and with a bandwidth that depends on N [7].

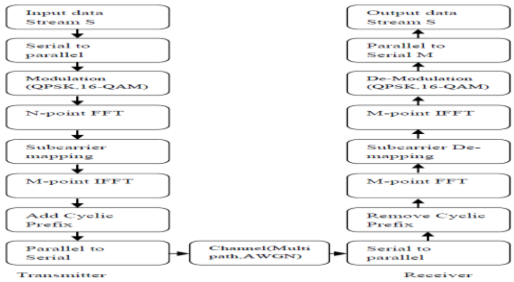

Fig.5: Transmitter Receiver systems for SC-FDMA

In SC-FDMA transmitter, after modulating parallel low speed data streams, the transmitter groups the modulated symbols into a block of *N* symbols. An *N*-point FFT block transforms these symbols in time domain into frequency domain. The frequency domain samples are then mapped to a subset of *M* subcarriers where *M* is typically greater than *N*. Similar to OFDMA, an IFFT block is used to generate the time-domain samples of these subcarriers, which is followed by appending cyclic prefix and parallel to serial conversion. At the receiver just the opposite processes take place. Serial to parallel conversion, removing CP, taking FFT to convert to frequency domain, sub-carrier demapping followed by IFFT and demodulation.

Single Carrier Frequency Division Multiple Access (SC-FDMA) is a promising technique for high data rate uplink communication and has been adopted by 3GPP for it next generation cellular system, called Long-Term Evolution (LTE). SC-FDMA is a modified form of OFDM with similar throughput performance and complexity. This is often viewed as DFT-coded OFDM where time-domain data symbols are transformed to frequency-domain by a discrete Fourier transform (DFT) before going through the standard OFDM modulation. Thus, SC-FDMA inherits all the advantages of OFDM over other well-known techniques such as TDMA and CDMA. The major problem in extending GSM TDMA and wideband CDMA to broadband systems is the increase in complexity with the multipath signal reception. The main advantage of OFDM, as is for SC-FDMA, is its robustness against multipath signal propagation, which makes it suitable for broadband systems. SC-FDMA brings additional benefit of low peak-to-average power ratio (PAPR) compared to OFDM making it suitable for uplink transmission by user-terminals.

IV. 3GPP LONG TERM EVOLUTION (LTE) SYSTEM

LTE is a next generation mobile system from the 3GPP with a focus on wireless broadband. LTE is based on Orthogonal Frequency Division Multiplexing (OFDM) with cyclic prefix (CP) in the downlink, and on Single-Carrier Frequency Division Multiple Access (SC-FDMA) with cyclic prefix in the uplink. It supports both FDD and TDD duplex modes for transmission on paired and unpaired spectrum. The generic radio frame has time duration of 10 ms, consisting of 20 slots of each 0.5 ms. two adjacent slots form a sub-frame of 1 ms duration, which is also one transmit-time interval (TTI). Each slot consists of seven OFDM symbols with short/normal cyclic prefix (CP) or six OFDM symbols with long/extended CP. The long term evolution (LTE) is a standard introduced by 3rd Generation Partnership Project (3GPP) as one of the recent steps in cellular 3G services. LTE provides many benefits like high-speed data, bandwidth efficiency, and latency, multimedia uncast and multimedia broadcast services to cellular networks.

In order to achieve these benefits LTE employs new accessing technologies like OFDMA and SC-FDMA. To provide benefits like high data rate, bandwidth efficiency and immunity to the multi-path fading OFDMA is used for downlink transmission while SC-FDMA is used for uplink transmission in order to save power. 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.

The 3rd Generation Partnership Project (3GPP) started working on 3G cellular system evolution in November, 2004. The 3GPP is the collaboration agreement for promotion of mobile standards in order to cope future needs (high data rates, spectral efficiencies, etc.). The 3GPP LTE (Long Term Evolution) was developed to provide higher data rates, lower latencies, wider spectrum and packet optimized radio technology. Like other cellular technologies LTE uses OFDM as multiplexing technique. LTE uses OFDMA as downlink and Single Carrier FDMA (SC FDMA) as uplink transmission technique. The use of SC FDMA in LTE reduces the Peak to Average Power Ratio (PAPR) which is the main drawback of OFDM. LTE uses wider spectrum, up to 20 MHz, to provide compatibility with existing cellular technologies such as UMTS and HSPA+, and increases the capacity of the system. LTE uses flexible spectrum which makes it possible to be deployed in any bandwidth combinations. This makes LTE suitable for various sizes of spectrum resources. LTE uses both FDD and TDD as duplexing techniques to accommodate all types of spectrum resources.

A. LTE Performance Demands

To meet the desired performance of the system LTE demands many specifications. Below is summarization of some of these demands (specifications).

Data Rate: For 20 MHz spectrum, peak data rate is 50 Mbps for uplink and 100 Mbps for downlink.

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.

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

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.

Security & Mobility: 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.

Table 1: Performance Targets for Long Term Evolution for Downlink

		Requirements	Comment
Downlink	Peak data transmission rate	> 100 Mbps	LTE Bandwidth = 20 MHz Duplexing Mode = FDD Spatial Multiplexing = 2x2
	Peak Spectral Efficiency	> 5 b/s/Hz	
	Spectral Efficiency of cell Edge	> 0.04 – 0.06 bps/Hz/user	Assumed 10 Users/Cell
	Average Cell Spectral Efficiency	> 1.6 – 2.1 bps/Hz/cell	Spatial Multiplexing = 2x2 Receiver = IRC (Interference Rejection Combining)
	Broadcost Specral Efficiency	1 bps/Hz	Carrier dedicated for Broadcast mode

Table 2: Performance Targets for Long Term Evolution for uplink

		Requirements	Comments
Uplink	Peak Data Transmission Rate	> 50 Mbps	LTE Bandwidth = 20 MHz Duplexing Mode = FDD Transmission = Single Antenna
	Peak Spectral Efficiency	> 2.5 bps/Hz	
	Spectral Efficiency of Cell Edge	> 0.02 – 0.03 Bps/Hz/user	Single Antenna transmission Receiver =IRC
	Average Spectral Efficiency	> 0.66 – 1.0 bps/Hz/cell	Assumed 10 Users/Cell
System	Operating Bandwidth	1.4 MHz to 20 MHz	Initially starts at 1.25 MHz
	User Plane Latency	< 10 ms	
	Connection set up Latency	< 100 ms	From Idle mode to Active

V. OFDM to SC-FDMA

The main difference between OFDM and SC-FDMA transmitter is the DFT mapper. After mapping data bits into modulation symbols, the transmitter groups the modulation symbols into a block of *N* symbols. An *N-point* DFT transforms these symbols in time domain into frequency domain. The frequency domain samples are then mapped to a subset of *M* subcarriers where *M* is typically greater than *N*. Similar to OFDM, an M-point *IFFT* is used to generate the time-domain samples of these subcarriers, which is followed by cyclic prefix, parallel to serial converter, DAC and RF subsystems.

SC-FDMA offers similar performance and complexity as OFDM. However, the main advantage of SC-FDMA is the low PAPR (peak-average-power ratio) of the transmit signal. PAPR is defined as the ratio of the peak power to average power of the transmit signal. As PAPR is a major concern at the user terminals, low PAPR makes the SC-FDMA the preferred technology for the uplink transmission. PAPR relates to the power amplifier efficiency at the transmitter, and the maximum power efficiency is achieved when the amplifier operates at the saturation point. Lower PAPR allows operation of the power amplifier close to saturation resulting in higher efficiency. With higher PAPR signal, the power amplifier operating point has to be backed off to lower the signal distortion, and thereby lowering amplifier efficiency. As SC-FDMA modulated signal can be viewed as a single carrier signal, a pulse shaping filter can be applied to transmit signal to further improve PAPR. PAPR comparison between OFDM and SC-FDMA variations such as interleaved SC-FDMA and localized SC-FDMA has been done in [2]. With no pulse shaping filters, interleaved- SC-FDMA shows the best PAPR. Compared to OFDM PAPR, the PAPR of interleaved SCFDMA with QPSK is about 10 dB lower, whereas that of localized SC-FDMA is only about 3 dB lower. With 16-QAM, these levels are about 7 dB and 2 dB lower respectively. Therefore, interleaved SC-FDMA is a preferred modulation technique for lower PAPR. Pulse shape filtering of SC-FDMA in fact degrades the PAPR level of interleaved SC-FDMA whereas it shows no effect with localized SC-FDMA.

VI. RESULT & CONCLUSION

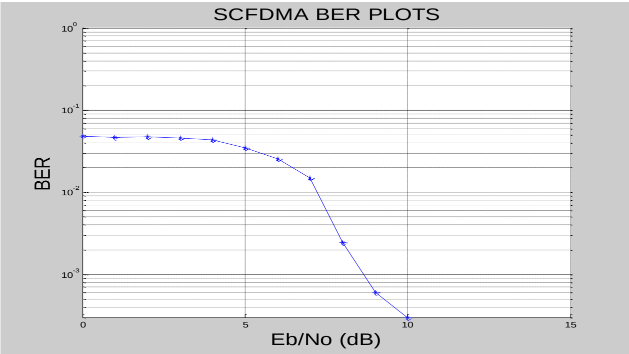

Fig.6: BER vs. SNR of SC-FDMA

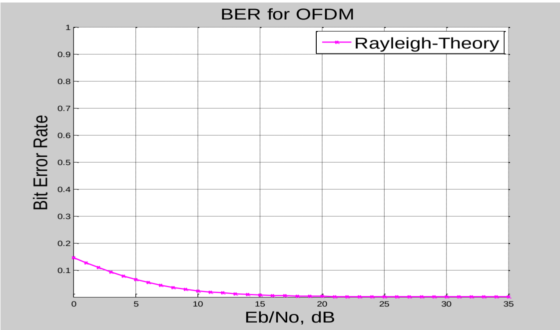

Fig.7: BER vs. SNR of OFDMA

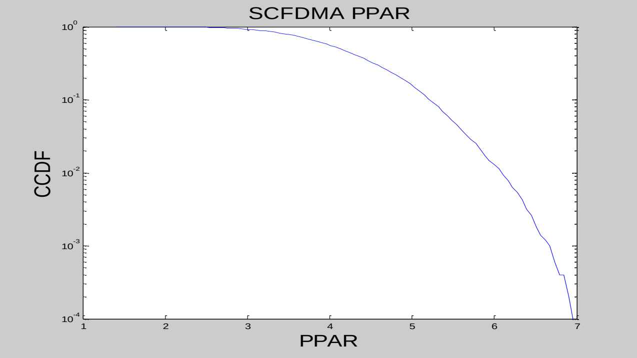

Fig.8: PAPR of SC-FDMA

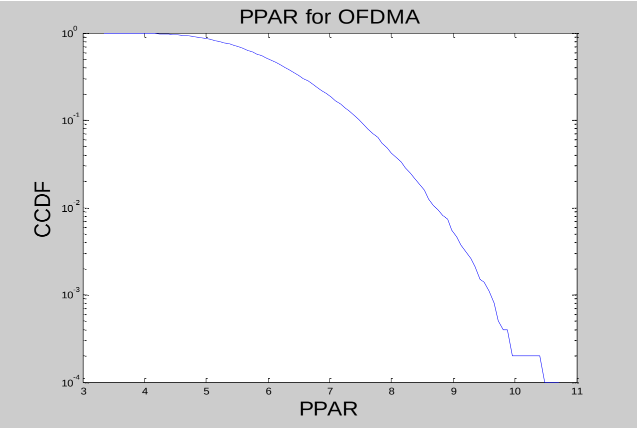

Fig.9: PAPR of OFDMA

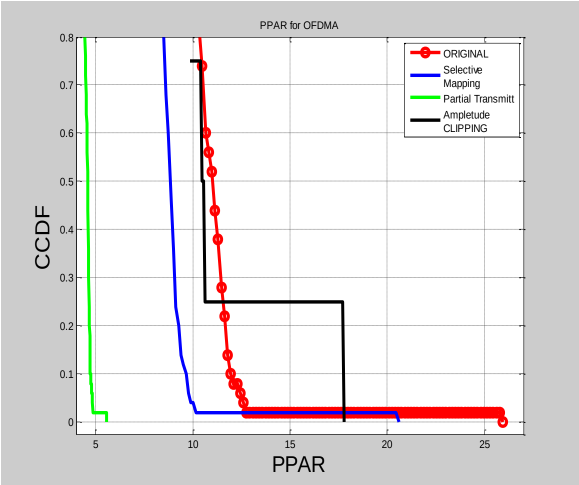

Fig.10: PAPR of OFDMA from different scheme

VII. RESULT AND CONCLUSION

BER is the key parameter for indicating the system performance of any data link. In our project we analyzed that for different values of SNR, the BER increases for high order modulation in both the multiple access techniques (OFDMA and SC-FDMA) used in LTE system. On the other hand, the lower order modulation schemes (BPSK and QPSK) experience less BER at receiver thus lower order modulations improve the system performance in terms of BER. The BER increases for high order modulation in both the techniques used in LTE system because of the fact that higher order modulation techniques use more bits per symbol. Hence it is easily affected by the noise. If we consider the bandwidth efficiency of these modulation schemes, the higher order modulation accommodates more data within a given bandwidth and is more bandwidth efficient as compare to lower order modulation. Thus there exists a trade-off between BER and bandwidth efficiency among these modulation schemes used in LTE. BER Performance of SC-FDMA and OFDMA are better in AWGN Channel as compared to that of Rayleigh Fading Channel as less distortion is introduced in the signal in AWGN channel. The BER performance of OFDMA is little bit better as compare for SC-FDMA for both the channels and all the modulation schemes. This is because in SC-FDMA symbols are spread over multiple sub-carriers.

As in SC-FDMA individual symbols are spread over multiple sub-carriers average power distributed on all frequencies is greater than OFDMA. This even reduce the peak transmits power requirements of SC-FDM as compare to OFDMA. Thus SC-FDM has low PAPR and is more power efficient.

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Monika Sehrawat pursuing **MTECH** from SPGOI Rohtak, (2013-2015) and obtained **B.Tech in Electronics and Communication Engineering from** Maharshi Dayanand University in 2012. His main research interests includes: signal Processing, image processing, signal and system & Wireless Communication