Comparative Analysis of OFDMA and SC-FDMA

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***Abstract*— *A communication system is considered good enough if it is showing lower error and lesser noise addition with a high speed of operation. For an LTE system available multiple accessing techniques are OFDMA and SC-FDMA and digital modulation techniques such as BPSK, QPSK, QAM etc. Noise that adds to the signal while traveling through wireless media is Additive White Gaussian noise. An LTE system is supposed to provide data transmission with high rate of transmission and lesser error in the received signal. For that a comparison of the techniques is required. Performance comparison depends on the parameters chosen. These parameters include PAPR, BER, SNR etc. In this paper, work is done on comparison of OFDMA and SC-FDMA for different kinds of modulation techniques with the help of parameters PAPR and BER.*

Keywords— LTE, OFDMA, SC-FDMA, PAPR, BER

I. INTRODUCTION

Designing an efficient wireless communication system is always a challenge. With increase in demand for high data rate this task has become even more challenging. To achieve this challenging goal next generation system came in to existence. Recent standard introduced by 3GPP group which promises high-speed data, multimedia uncast and multimedia broadcast services for next generation cellular concept. Long Term Evolution (LTE) improves the susceptibility and speed of wireless data networks. Long Term Evolution (LTE) 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 Single Carrier Frequency Division Multiple Access (SC-FDMA). 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[1].

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. 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. 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 [2] [3].

OFDM is referred as multicarrier modulation. It uses multiple RF carrier signals at different frequencies which send some of 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. 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. 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].

SC-FDMA is a multiple access method. 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. Its structure is same as OFDMA with an addition of Fast Fourier Transform (FFT) block; because of this the SC-FDMA is also called DFT-Precoded OFDMA. 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 [4][5]. SC-FDMA system is less sensitive to frequency offset compare to OFDM system.

The Long Term Evolution (LTE) is an evolution of the third generation technology based on Wideband Code Division Multiple Access (WCDMA). LTE uses OFDM for downlink, i.e. from base station to the terminal. There are three physical channels such as Physical Downlink Shared Channel (PDSCH), Physical Multicast Channel (PMCH), Physical Broadcast Channel (PBCH) in the downlink used for data transmission, broadcast transmission and system information within a cell. Physical Broadcast Channel (PBCH) in the downlink used for data transmission. LTE uses a Precoded version of Orthogonal Frequency Division Multiplexing (OFDM) using a single carrier for uplink called Single Carrier Frequency Division Multiplexing (SC-FDMA). SC-FDMA is used to minimize Peak-to-Average

Power Ratio (PAPR) caused by OFDMA. PAPR is the ratio of peak signal power to the average signal power. There are two physical channels, Physical Random Access Channel (PRACH) and Physical Uplink Synchronization Channel (PUSCH), used in the LTE uplink. For initial access PRACH is used whereas when the User Equipment (UE) is not synchronized the data is send on PUSCH. The modulations schemes used for LTE uplink are BPSK. Link level simulations of the LTE uplink correspond to the main part of our thesis. Link level simulation of OFDM by using equalization schemes as Minimum Mean Square Error (MMSE) and Zero Forcing (ZF) in ITU Pedestrian A, ITU vehicular A and AWGN channels in comparison with SC-FDE and SCFDMA is also included in our thesis. The comparison is taken in terms of Symbol Error Rates (SER) and Signal-to-Noise Ratio (SNR). In addition, the Peak-to-Average Power Ratio (PAPR) is calculated for both the SC-FDMA and the OFDMA systems. The objective of this thesis work is to analysis the performance of OFDMA (Downlink transmission) and SC-FDMA (Uplink Transmission) in different types of LTE Frame structures with adaptive modulation techniques as BPSK. 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. We have considered BER 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. LTE PHYSICAL LAYER

The physical layer of LTE conveys data and control information between E-UTRAN NodeB (eNodeB) and user equipment (UE) in an efficient way. It employs advanced technologies such as OFDM and MIMO for data transmission. In addition, LTE uses OFDMA and SC-FDMA for downlink and uplink data transmissions. The use of SC-FDMA in the uplink reduces PAPR. A detail description of LTE physical layer is provided below.

A. Generic frame structure

The generic frame of LTE has a length of 10ms and is subdivided into ten sub-frames of 1ms length. Each sub-frame is further divided into two slots of 0.5ms having six or seven OFDM symbols depending upon the length of CP. Each slot uses 7 OFDM symbols in case of normal CP whereas 6 OFDM symbols in case of extended CP. Sub-frames can be assigned for either uplink or downlink. The generic frame structure of LTE downlink and uplink is shown in Figure 1.

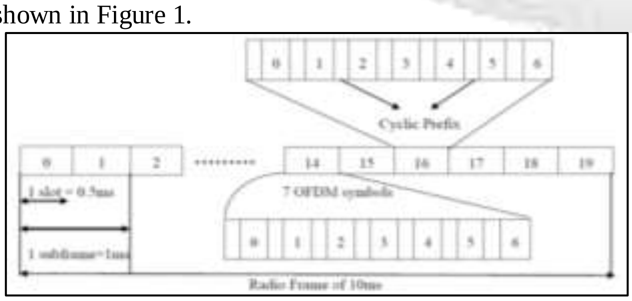

Fig. 1: Generic Frame Structure for Downlink and Uplink of LTE

B. LTE Frame Type

In LTE, Downlink and uplink transmission are organized into radio frame with Tf = 307200 * Ts=10 millisecond long where Ts = 1/ (30.72 x 106) s ≈32.255 ns per clock period [8].Two types of Frame structure i.e. (i) Frame structure type 1 that endorses FDD duplexing scheme (LTE FDD) and (ii) Frame structure type 2 which supports TDD duplexing Scheme (LTE TDD) in LTE. In both LTE FDD and LTE TDD, the transmitted signal is organized into subframes of 1 millisecond (ms) duration and 10 subframes constitute a radio frame [9]. Each frame is 10 ms in duration. Each subframe is further divided into two slots, each of 0.5 ms duration. Each slot consists of either 6 or 7 ODFM symbols, depending on whether the normal or extended cyclic prefix is employed [10]. Dynamic scheduling of the uplink and downlink resources is used in both LTE FDD and LTE TDD.

As wireless multimedia applications become more widespread, demand for higher data rate is leading to utilization of a wider transmission bandwidth. With a wider transmission bandwidth, frequency selectivity of the channel becomes more severe and thus the problem of inter-symbol interference (ISI) becomes more serious. In a conventional single carrier communication system, time domain equalization in the form of tap delay line filtering is performed to eliminate ISI. However, in case of a wide band channel, the length of the time domain filter to perform equalization becomes prohibitively large since it linearly increases with the channel response length. One way to mitigate the frequency-selective fading seen in a wide band channel is to use a multicarrier technique which subdivides the entire channel into smaller sub-bands, or subcarriers. Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique which uses orthogonal subcarriers to convey information. In the frequency domain, since the bandwidth of a subcarrier is designed to be smaller than the coherence bandwidth, each subchannel is seen as a flat fading channel which simplifies the channel equalization process. In the time domain, by splitting a high-rate data stream into a number of lower-rate data stream that are transmitted in parallel, OFDM resolves the problem of ISI in wide band communications [1]. But OFDM has its disadvantages: High peak-to-average power ratio (PAPR), high sensitivity to frequency offset, and a need for an adaptive or coded scheme to overcome spectral nulls in the channel [2], [3].

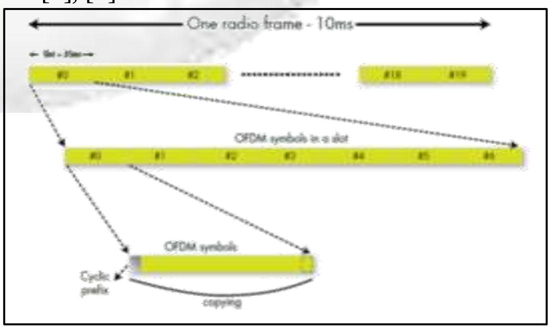

Figure 2: LTE Frame Format

In this correspondence, we give an in-depth overview of a single carrier FDMA (SC-FDMA) system, which is a newly developed multiple access scheme adopted in the uplink of 3GPP Long Term Evolution (LTE), and show some research results on its PAPR characteristics and resource scheduling In case of FDD, all sub frames are used either for downlink or for uplink data transmissions. For TDD, sub frame 1 and 6 are used for downlink transmission whereas the rest of the frames are used either for uplink or downlink.

Sub frames 1 and 6 contain synchronization signals for downlink. Figure 3 shows downlink and uplink sub frame assignments for FDD.

Fig. 3: Downlink and Uplink Sub frame Assignment for FDD

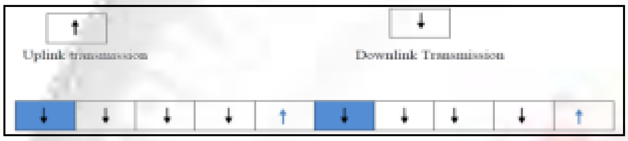

Fig. 3(a): Downlink Sub frame Assignment for TDD

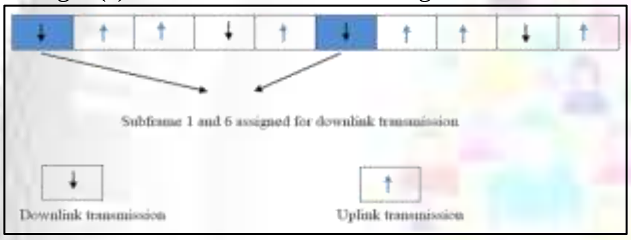

Fig. 3(b): Uplink Sub frame Assignment for TDD

C. Downlink Transmission

OFDMA is an extension of OFDM and is used in the downlink of LTE. OFDMA distributes subcarriers to different users at the same time so that multiple users can receive data simultaneously while in OFDM, a single user can receive data on all subcarriers at any given time. Subcarriers are allocated in contiguous groups with subcarrier spacing of 15 kHz in order to reduce the overhead of indicating which subcarriers have been allocated to each user.

OFDMA is based on Discrete Fourier Transform (DFT) and Inverse Discrete Fourier Transform (IDFT) to switch between time and frequency domain. The time domain representation of various inputs applied to FFT are shown in Figure 4:

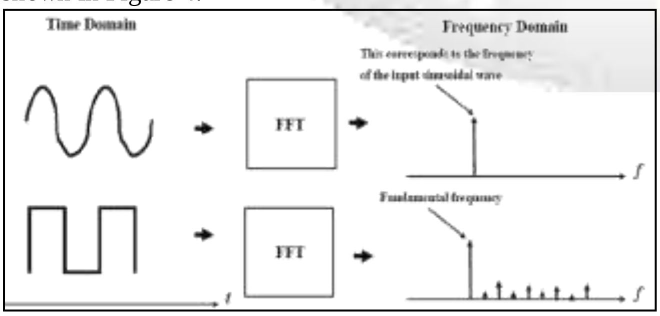

Fig. 4: FFT Operation Applied to Various Inputs in Time Domain

OFDMA arranges the subcarrier on the basis of resource blocks instead of individual subcarriers. A resource block is comprised of 12 consecutive subcarriers with 15 kHz frequency spacing in the frequency domain for duration of 0.5ms in time domain. The size of RB is 180 kHz in the frequency domain while having 84 OFDM symbols (12 x 7 = 84) in the time domain as in the case of normal CP. One OFDM symbol corresponds to a Resource Element (RE). The advantage of adding cyclic prefix is to avoid the ISI. The length of CP should be larger than the channel delay spread or channel impulse response in order to avoid the ISI at the receiver.

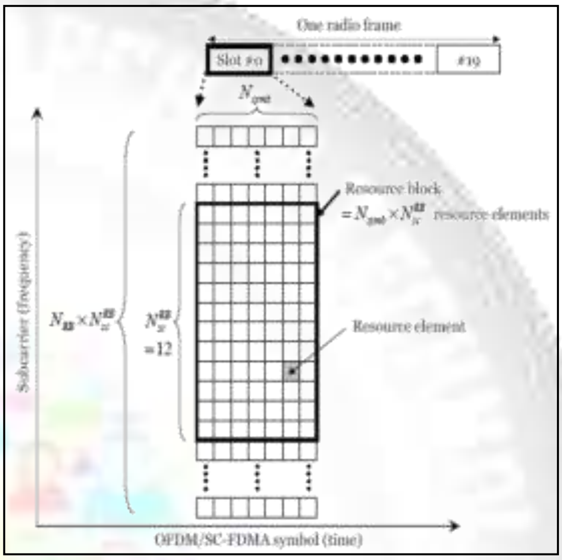

Fig. 5: Structure of OFDMA Resource Blocks

D. Uplink Transmission

Single Carrier-FDMA (SC-FDMA) is an extension of OFDMA and is used in the uplink of LTE. Unlike OFDMA, SC-FDMA reduces the PAPR by adding additional blocks of DFT and IDFT at transmitter and receiver.

1) SC-FDMA resources

SC-FDMA arranges subcarriers in RBs similar to the downlink OFDMA. A RB is comprised of 12 consecutive subcarriers for the duration of one time slot of LTE frame (1slot = 0.5 ms). Two types of CP are used in uplink, the normal and extended CP having 7 and 6 SC-FDMA symbols respectively. Due to the fixed size of RB's, uplink supports flexible transmission bandwidths similar to downlink.

The SC-FDMA Resource Grid for LTE is shown in Figure 6.

Where NRB = number of Resource Blocks

N_{sc}^{RB}= Number of subcarriers in a resource block

NRB x NscRB = Total transmission bandwidth (LTE supports bandwidth ranges from 1.4 MHz to 20 MHz).

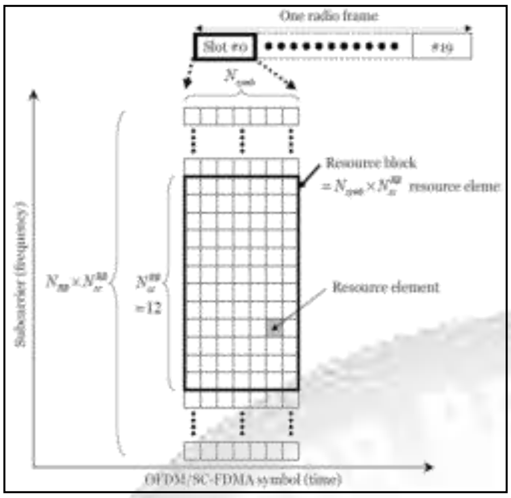

Fig. 6: LTE Resource Grid for SC-FDMA
Nsymb= Number of SC-FDMA symbols in one slot.
Nsymb x NscRB= Number of REs in one RB.

E. Frequency spread OFDMA

Each data symbol is DFT transformed before mapping to subcarriers, hence the SC-FDMA is called DFT-Precoded OFDMA. In a standard OFDMA, each data symbol is carried on a separate subcarrier. In SC-FDMA, multiple subcarriers carry each data symbol due to mapping of the symbols' frequency domain samples to subcarriers. As each data symbol is spread over multiple subcarriers, SC-FDMA offers spreading gain or frequency diversity gain in a frequency selective channel. Thus, SC-FDMA can be viewed as frequency-spread OFDMA or DFT-spread OFDMA.

1) Subcarrier Mapping

DFT output of the data symbols is mapped to a subset of subcarriers, a process called subcarrier mapping. The subcarrier mapping assigns DFT output complex values as the amplitudes of some of the selected subcarriers. Subcarrier mapping can be classified into two types: *localized mapping* and *distributed mapping*. In *localized mapping*, the DFT outputs are mapped to a subset of consecutive sub-carriers thereby confining them to only a fraction of the system bandwidth. In *distributed mapping*, the DFT outputs of the input data are assigned to subcarriers over the entire bandwidth non-continuously, resulting in zero amplitude for the remaining subcarriers. A special case of *distributed SC-FDMA* is called *interleaved SC-FDMA*, where the occupied subcarriers are equally spaced over the entire bandwidth. Figure 7 is a general picture of *localized* and *distributed* mapping.

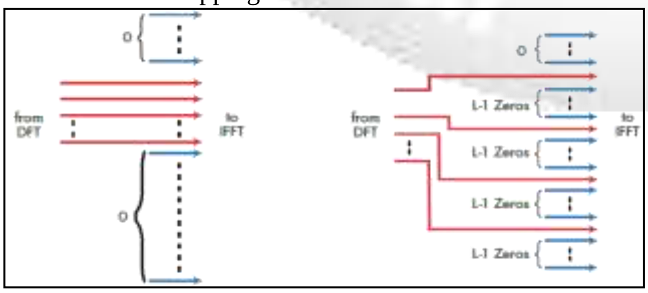

Fig. 7: Localized mapping vs. Distributed mapping

An example of subcarrier mapping is shown in Figure 3.33. This example assumes three users sharing 12 subcarriers. Each user has a block of four data symbols to transmit at a time. The DFT output of the data block has four complex frequency domain samples, which are mapped over 12 subcarriers using different mapping schemes.

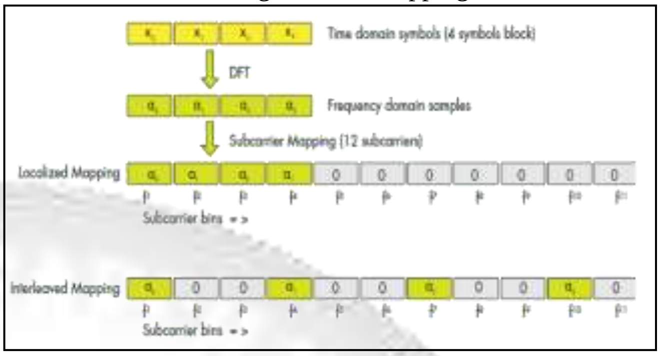

Fig. 8: Subcarrier Mapping Example

SC-FDMA inherently offers frequency diversity gain over the standard OFDMA, as all information data is spread over multiple subcarriers by the DFT mapper. However, the distributed SC-FDMA is more robust with respect to frequency selective fading and offers additional frequency diversity gain, since the information is spread across the entire system bandwidth. Localized SC-FDMA in combination with channel-dependent scheduling can potentially offer multi-user diversity in frequency selective channel conditions.

III. OFDMA SYSTEM MODEL

Figure 9 shows the block diagram of the model we used to simulate OFDMA system.

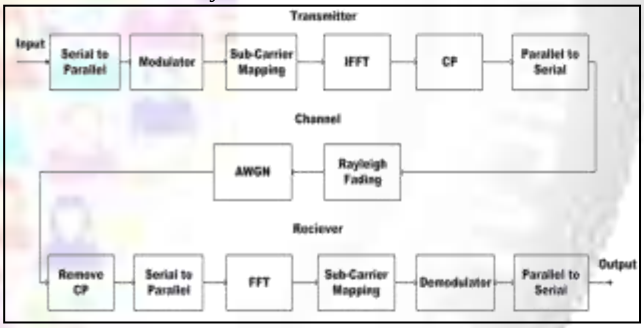

Fig. 9: OFDMA Transmission Model

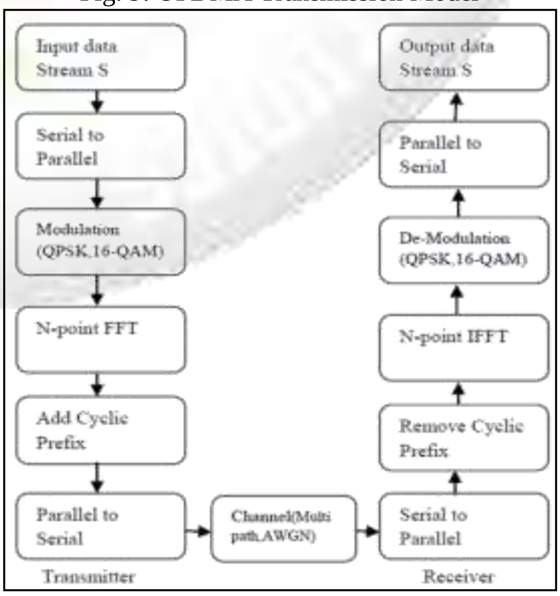

Fig. 10: Transmitter Receiver system for OFDMA

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 different modulation schemes.(as 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 using a built in function in MATLAB in which noise level is described by SNR per sample, which is one input parameter.
- 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.

A. Orthogonal Frequency Division Multiple Access (OFDMA)

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. 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.

B. Working principle of OFDMA

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 Inter symbol 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. 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 1.3. 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.

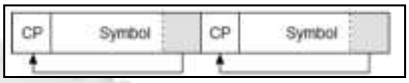

Fig. 11: Inserting Cyclic prefix (CP)

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.

IV. SC-FDMA SYSTEM MODEL

Figure 12 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.

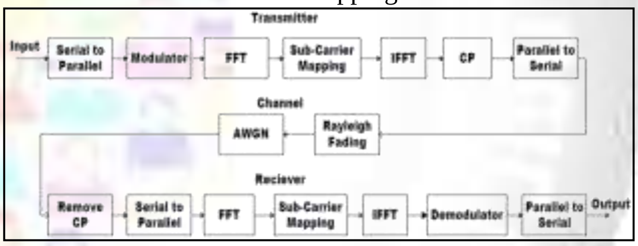

Fig. 12: SC-FDMA Transmission Model

A. Single carrier Frequency Division Multiple Access (SC-FDMA)

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.

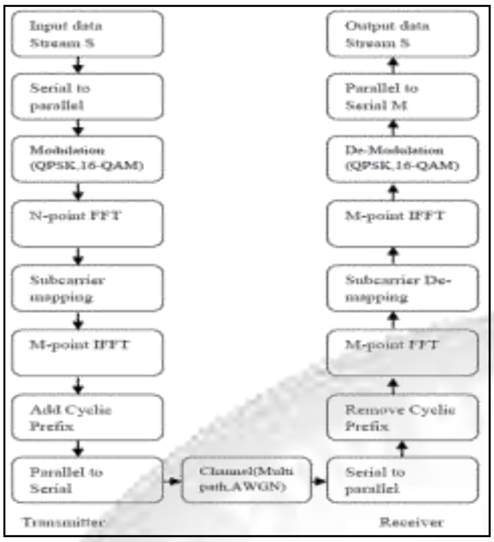

Fig. 13: Transmitter Receiver systems for SC-FDMA

B. *Working principle of 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 its 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.

V. ADVANTAGES AND DISADVANTAGES OF OFDMA

OFDM has many advantages when compared with a single carrier modulation scheme.

A. *Advantages of OFDMA*

- OFDMA is simple to implement due to the use of FFT.
- OFDMA is spectral efficient due to overlapping spectra and orthogonality.
- It is robust in NLOS transmissions.
- OFDMA reduces the effects of ISI through the use of a cyclic prefix in a transmitted symbol.
- In OFDMA each subcarrier is modulated by different modulation techniques such as BPSK, QAM and QPSK.
- It is robust against narrow band interference.
- It is useful for coherent demodulation because pilot based channel estimations are easy to implement in OFDMA systems.

B. *Disadvantages of OFDMA*

Here are some drawbacks of OFDMA.

- OFDMA has Peak to Average Power Ratio (PAPR) that causes nonlinearities and clipping distortions.
- It is sensitive to phase noise which is acute at higher frequencies.
- It is sensitive to timing and frequency offset

C. *Difference between OFDMA&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.

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. A built-in Matlab function AWGN is used here, in which the noise level is described by SNR per sample, which is the actual input parameter to the awgn function. The frequency selective (multipath) fading is also introduced 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. A built-in Matlab function is used here, for Rayleigh fading and the parameters used for that are given below in table 1.

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

Parameter	Assumption
Number of Sub-carriers	512 (FFT Length)
CP Length	64
Range of SNR in dB	0 to 30
Modulation	BPSK
Data Block Size	16 (Number of Symbols)
Channel	AWGN (SNR = 100 dB)
System Bandwidth	5 MHz
Confidence Interval used	32 times

Table 1: Parameters used for Simulation

VI. Parameters used for LTE testing

A. Bit Error Rate (BER)

BER is the ratio of number of error bits and total number of bits transmitted. It is given by the following formula [2].

$$BER = \frac{Number\ of\ Error\ Bits}{\text{Total Number of Transmitted Bits}}$$

The BER plot is plotted for different values of BER for different SNR values versus values of SNR ratio for the simulated model. The procedure was repeated for different modulation techniques for both OFDMA and SC-FDMA for their comparison.

B. Peak to Average Power Ratio

We calculated PAPR for both OFDMA and SC-FDMA system using the following formula [2].

$$\text{PAPR} = \frac{\text{Peak power of transmitted signal}}{\text{Average power of transmitted signal}}$$

Where peak and average power of transmitted signal was calculated by:

$$\text{Peak power of transmitted signal} = \{\text{Maximum}(\text{xt} \times \text{conjugate of xt})\}$$

$$\text{Average power of transmitted signal} = \{\text{Mean}(\text{xt} \times \text{conjugate of xt})\}$$

Where, ‘xt’ represent transmitted signal.

To plot PAPR, Complementary Cumulative Distribution Function (CCDF) of calculated PAPR values is used. The CCDF of PAPR is the probability that the PAPR is higher than a certain PAPR value PAPR0 (Pr {PAPR> PAPR0}).

VII. Results and discussion

Graph for PAPR value vs CCDF of PAPR is plotted for OFDMA using different kinds of modulation techniques. For the calculation of PAPR we use Complementary Cumulative Distribution Function (CCDF). The CCDF is defined as the probability for which PAPR is greater than any PAPR value i.e. PAPR0.

Simulation results shows that 16 QAM has slightly better performance over Q-PSK.

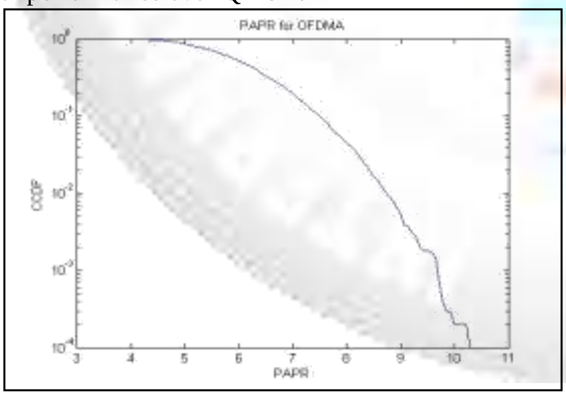

Fig. 14: PAPR vs CCDF plot for OFDMA using Q-PSK modulation technique

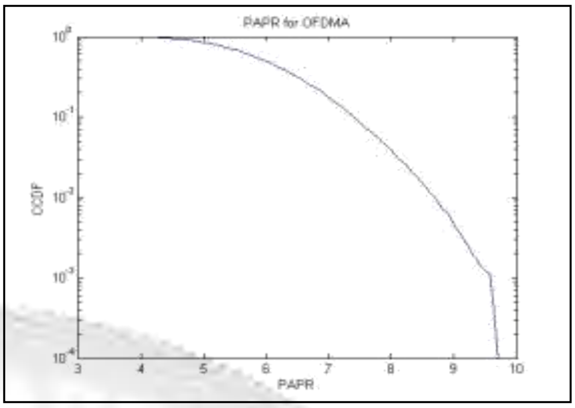

Fig. 15: PAPR vs CCDF plot for OFDMA using 16QAM modulation technique

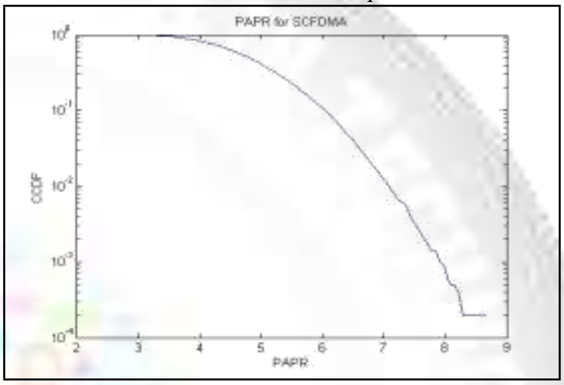

Fig. 16: PAPR vs CCDF plot for SC-FDMA using DFDMA subcarrier mapping using 16QAM modulation technique

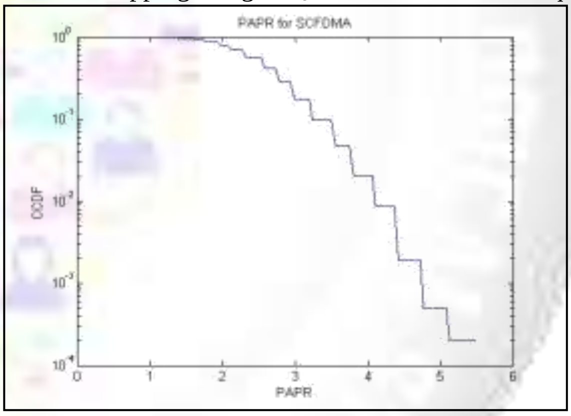

Fig. 17: PAPR vs CCDF plot for SC-FDMA using IFDMA subcarrier mapping using 16QAM modulation technique

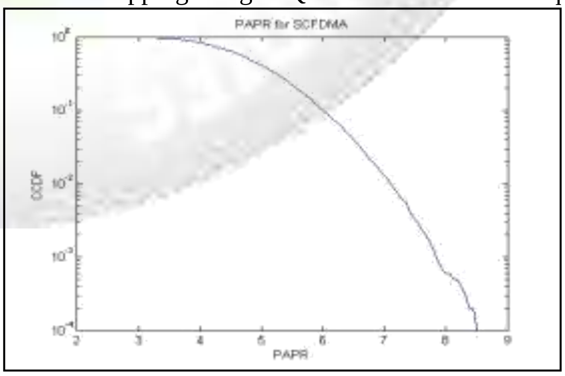

Fig. 18: PAPR vs CCDF plot for SC-FDMA using LFDMA subcarrier mapping using 16QAM modulation technique

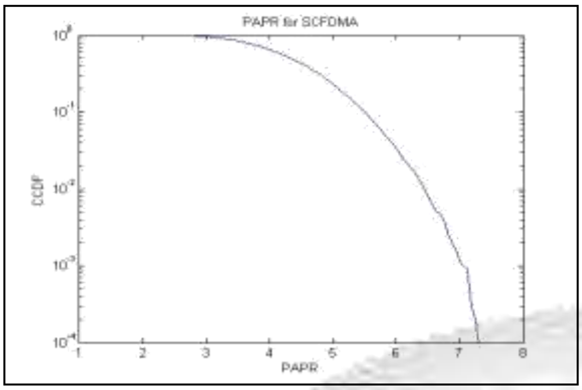

Fig. 19: PAPR vs CCDF plot for SC-FDMA using DFDMA subcarrier mapping using Q-PSK modulation technique

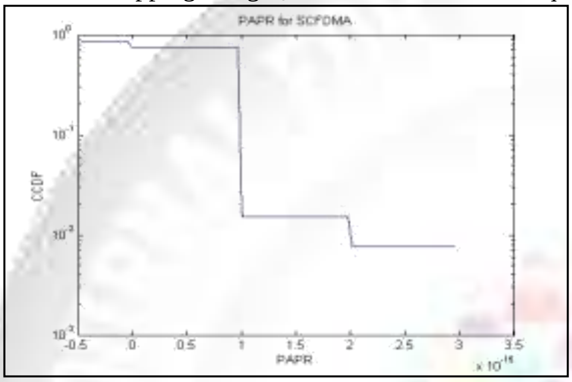

Fig. 20: PAPR vs CCDF plot for SC-FDMA using IFDMA subcarrier mapping using Q-PSK modulation technique

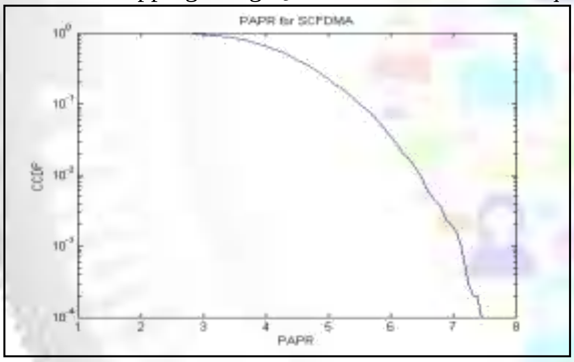

Fig. 21: PAPR vs CCDF plot for SC-FDMA using LFDMA subcarrier mapping using Q-PSK modulation technique

A. *Case 2*

For pulse shaping we used Raised Cosine (RC) and Square Root Raised Cosine (RRC) filters because they make the receiver robust against timing synchronization errors. For the calculation of PAPR we use Complementary Cumulative Distribution Function (CCDF). The CCDF is defined as the probability for which PAPR is greater than any PAPR value i.e. PAPR0.

1) *CASE 2.1: Using rc filter*

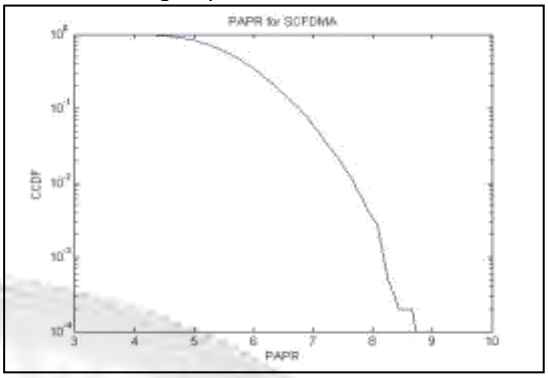

Fig. 22: PAPR vs CCDF plot for SC-FDMA using DFDMA subcarrier mapping using 16QAM modulation technique

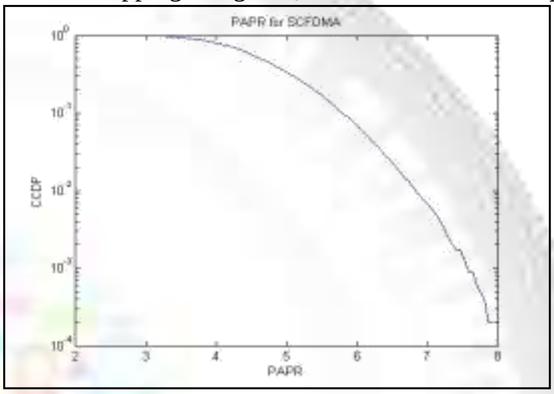

Fig. 23: PAPR vs CCDF plot for SC-FDMA using IFDMA subcarrier mapping using 16QAM modulation technique

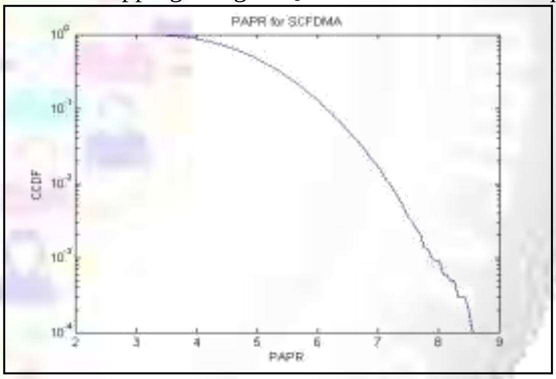

Fig. 24: PAPR vs CCDF plot for SC-FDMA using LFDMA subcarrier mapping using 16QAM modulation technique

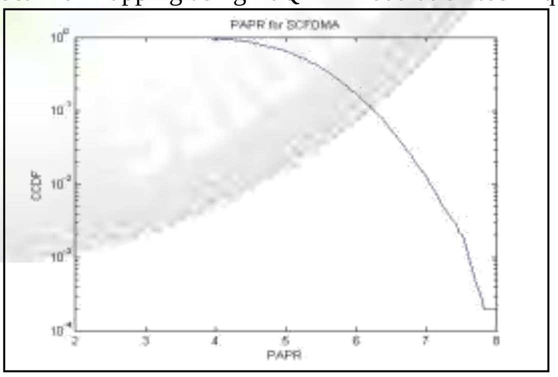

Fig. 25: PAPR vs CCDF plot for SC-FDMA using DFDMA subcarrier mapping using Q-PSK modulation technique

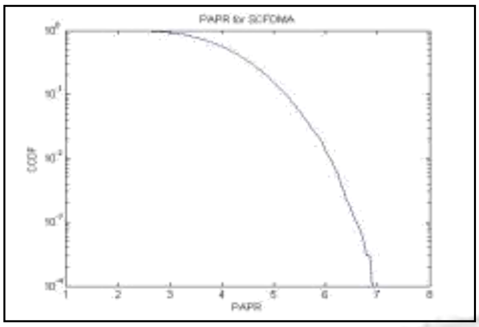

Fig. 26: PAPR vs CCDF plot for SC-FDMA using IFDMA subcarrier mapping using Q-PSK modulation technique

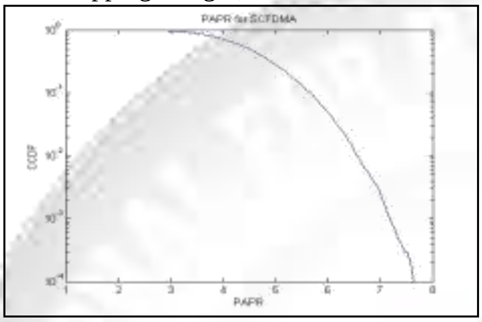

Fig. 27: PAPR vs CCDF plot for SC-FDMA using LFDMA subcarrier mapping using Q-PSK modulation technique

CASE 2.2: Using RR filter:

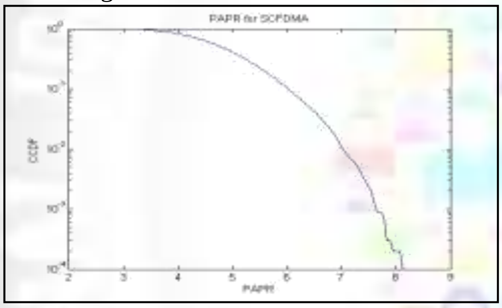

Fig. 28: PAPR vs CCDF plot for SC-FDMA using DFDMA subcarrier mapping using 16QAM modulation technique

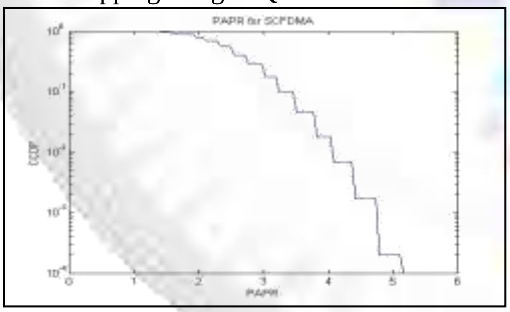

Fig. 29: PAPR vs CCDF plot for SC-FDMA using IFDMA subcarrier mapping using 16QAM modulation technique

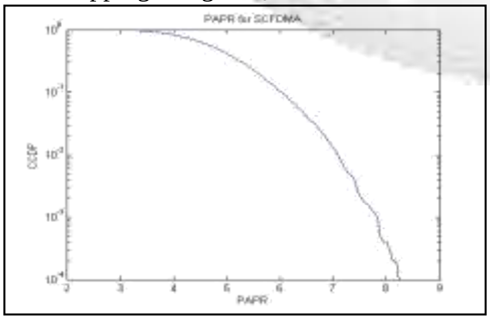

Fig. 30: PAPR vs CCDF plot for SC-FDMA using LFDMA subcarrier mapping using 16QAM modulation technique

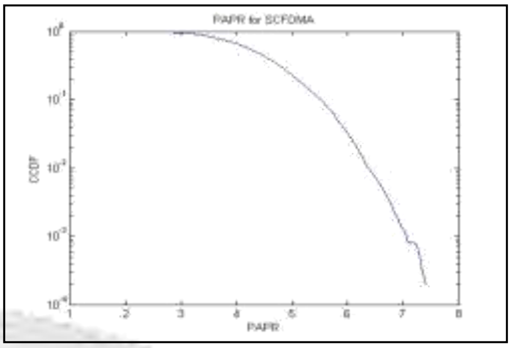

Fig. 31: PAPR vs CCDF plot for SC-FDMA using DFDMA subcarrier mapping using Q-PSK modulation technique

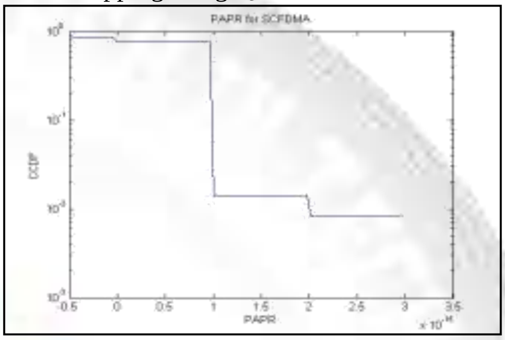

Fig. 32: PAPR vs CCDF plot for SC-FDMA using IFDMA subcarrier mapping using Q-PSK modulation technique

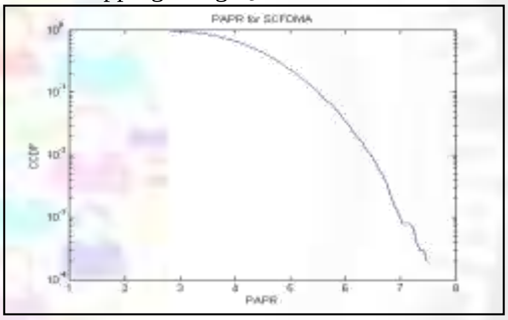

Fig. 33: PAPR vs CCDF plot for SC-FDMA using LFDMA subcarrier mapping using Q-PSK modulation technique

The PAPR calculation using various subcarrier mapping schemes for SCFDMA system is shown in the above Fig. s for different modulation schemes i.e. 16 QAM and Q-PSK. We found that 16 QAM gives better results in comparison of Q-PSK. Using plot of PAPR for different sub career mapping with both RC and RR filters we find that results with RC filter are slightly better than RR filter.

Hence we can conclude that for SC-FDMA the best results are taken by using 16 QAM modulation techniques with using root cosine filters.

B. BER Plots

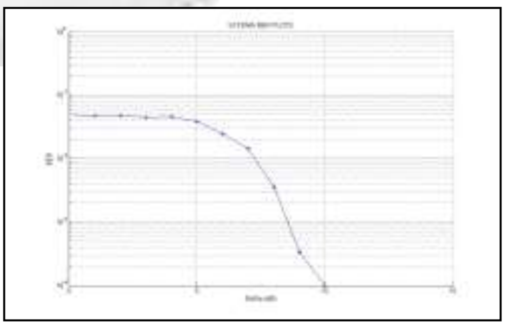

Fig. 34: BER vs SNR for SC-FDMA

Plot for BER vs SNR for SC-FDMA is plotted here for different values of BER noted down for different values of SNR (signal to noise ratio) measured in db. It is noted that SC-FDMA is having better value of BER for different SNR values.

VIII. FUTURE SCOPE

The next generation of mobile network has a long way to go before it's a reality, but tests and plans are underway to set the terms for such an upgrade. By achieving Low latency means that not only will download and upload speeds be fast, but the response times for starting those data transfers will be similarly snappy .The other benefit relates to the biggest issue with current mobile network standards - a critical lack of bandwidth. The radio frequencies that our 4G networks operate on are overcrowded to say the least. With more and more people and devices set to be connected over the next five years or so to deliver 5G, carriers will need to boost network capacity between phones and the base stations need to install every few miles. Radio waves vibrate with a frequency measured in megahertz or even faster gigahertz. Today's phones communicate at lower frequency band; 5G will require higher frequency bands. But with the presence of high buildings and walls and mountains it is harder to transmit high frequencies. To compensate this reality and requirement, carriers will rely on advanced antenna technologies.

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