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# Effects of Different modulation schemes in PAPR reduction of SC-FDMA System for Uplink Communication

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**ABSTRACT**: This paper presents the work done on different modulation schemes for Single carrier frequency division multiple access (SC-FDMA).SC-FDMA has turned out to be a suitable solution for high data rate uplink communication systems. It has become the choice for uplink transmission in Long Term Evolution (LTE).OFDM was an excellent choice for a multipath fading channel. But it suffers from the major limitation of Peak to average power ratio problem. PAPR is highly detrimental to battery powered devices like mobile phones. SC-FDMA can overcome the PAPR limitation of OFDMA signals. In this paper we are finding out the best modulation scheme for PAPR reduction in SC-FDMA. Here we are using QPSK, QAM and CPM modulations for studying PAPR reduction. SC-FDMA uses 2 schemes for sub-carrier mapping. They are Interleaved (IFDMA) and localized (LFDMA) mapping. In this paper we are comparing PAPR of IFDMA, LFDMA and OFDMA. Similarly BER performance of the system will also be studied. The effect of pulse shaping on the signal will also be analyzed in the paper.

**KEYWORDS:** Single carrier frequency division multiple access (SC-FDMA), Interleaved frequency division multiplexing (IFDMA), Localized frequency division multiplexing (LFDMA) and peak to average power ratio (PAPR).

## I. INTRODUCTION

Cellular communication has grown rapidly through a sequence of generations which began with the progress in technology with each new decade. The demand for higher data rate and throughput has been increasing tremendously in recent years. To support these requirements of users third generation partnership project (3GPP) has developed a new radio access technology called long term Evolution (LTE).The high data rate of LTE not only requires a wider bandwidth but also an advanced modulation technique. OFDM has developed into a popular scheme for wideband digital communication [1]. But this modulation scheme has a major limitation of high PAPR which can increase complexity and power of transmitter (mobile) in uplink. The PAPR of a signal x (t) is given by,

$$PAPR = \frac{\max |x(t)|^2}{E\{|x(t)|^2\}}$$

PAPR becomes a major constraint in uplink communication because high PAPR of signal will degrade BER performance of the system. For signals with large PAPR, the average input power must be reduced. If the input power is not reduced then signal distortion will occur which can result in out-of-band spectral re-growth of signal as the signal will be amplified in the non-linear region of high power amplifier. High power amplifiers are most efficient when they are driven into saturation. So input power back off will reduce the efficiency of the power amplifiers. In order to avoid distortion of the transmitted waveform, the power-amplifier at the transmitter front end must have a wide linear range to include the peaks in the transmitted waveform. Building power amplifiers with wide linear ranges is a costly affair [2]. So an uplink scheme should be designed with trade-off between low computation complexity and system performance. The other limitations of OFDM signal includes high sensitivity to carrier frequency offsets and spectral

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null. So a solution to these limitations of OFDM was to use SC-FDMA which is similar to OFDM but has an additional DFT pre-coding prior to OFDM modulation

The following sections are organized as follows. Section 2 provide an overview on SC-FDMA system. Section 3 highlights the modulation techniques used in the paper. Section 4 discuss the simulation results of BER and PAPR obtained from SC-FDMA system for different modulation. Finally the work is concluded in Section 5.

## II. RELATED WORKS

A number of techniques were developed to overcome PAPR limitation of OFDM signal. These techniques can be classified into two. They are distortion based and non-distortion based techniques. Distortion based technique can cause spectral re-growth of signals. Clipping is a distortion based technique in which input OFDM signal is compared with a set threshold value. If amplitude of signal exceeds the threshold then clipper will limit the signal. But it was a non-linear operation and had resulted in out-of band radiation of signals and degradation in bit error rate performance of system.

The PAPR reduction techniques which do not distort shape and cause spectral re-growth of signals are called non-distortion technique . It includes tone reservation and selected mapping .In tone reservation[3] a set of reserved tones are selected to design a peak cancelling signal. But it had slower convergence toward optimal solution and has resulted in bandwidth sacrifice as tones have to be reserved. Selected mapping multiplies the input data with a random series and resultant series having lowest PAPR is chosen for transmission. This method has the advantage that it will not eliminate peaks and can handle any number of subcarriers. But limitation of this technique was that it required additional side information that has to be transmitted to the receiver to recover the information. This technique can provide better PAPR reduction but is iterative in nature [4] .So transmitter complexity will increase with increase in number of iterations.

Another method to overcome PAPR problem is based on signal transformation. The conversion of OFDM signal into a constant envelope by phase modulation can ensure a very low PAPR level of 0dB [5]. It provides faster side-lobe roll-off than OFDM. But orthogonality of subcarriers was not maintained in this method.

## III. SC-FDMA

The major reason for PAPR in OFDM is its multi-carrier structure. So conversion of multi-carrier OFDM signal into single carrier can effectively reduce PAPR of the signals. Pre-coding of OFDMA signal with Discrete Fourier transformation (DFT) can convert it into single carrier frequency division multiple access signal (SC-FDMA). SC-FDMA has similar performance and essentially the same overall complexity as that of an OFDMA system. It can provide flexible bandwidth assignment for different users and was chosen for uplink in 3GPP Long Term Evolution (LTE) due to its low PAPR property. SC-FDMA transmitter and receiver are given below

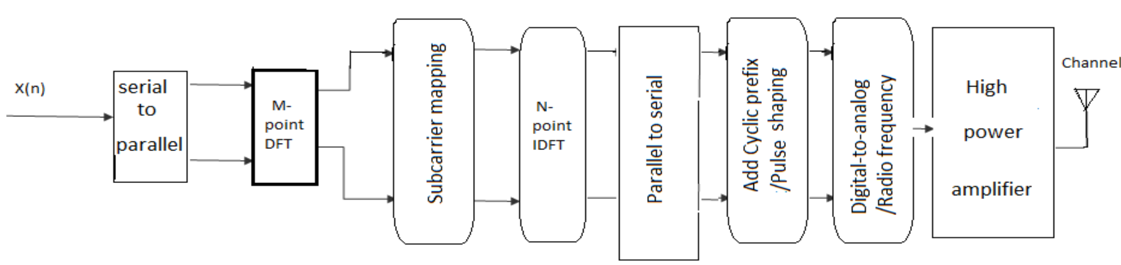


Fig.1 SC-FDMA Transmitter

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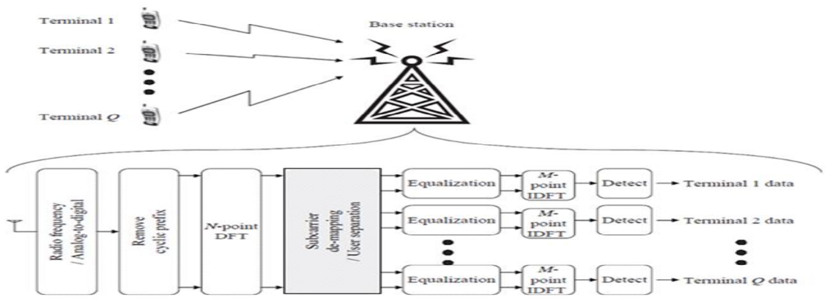


Fig.2 SC-FDMA Reciever [6]

The information bits can be modulated using any of the modulation techniques like QPSK, QAM or CPM. The complex modulated signal undergoes discrete time Fourier transformation. The number of DFT points (M) is defined by the number of symbols to be transmitted [8].The DFT output are then mapped on to different sub-carrier using two mapping schemes. The number of sub-carriers (N) allocated for the entire users is given by the following equation

$$N = M.Q$$

Where, M represents the number of DFT points and Q represents number of users. Sub-carrier mapping can be classified into two. They are
1) Localized Mapping (LFDMA) and
2) Distributed Mapping.

In localized mapping each user is given a set of adjacent sub-carriers [10]. This scheme can provide multi-user diversity even in the presence of frequency selective fading by assigning each user to subcarriers in the portion of the signal band where that user has favourable transmission characteristics (high channel gain).This requires channel-dependent scheduling (CDS) of subcarriers. CDS requires the system (base station) to monitor the channel quality as a function of frequency for each terminal, and adapt assignment of subcarriers according to changes in channel frequency responses of all other user terminals. In distributed mapping each user is provided a set of sub-carriers that are distributed over the entire signal bandwidth. This can ensure high frequency diversity. Interleaved sub-carrier mapping (IFDMA) is a special case of distributed mapping where sub-carriers allocated for user will be equidistant to one another. It was found that IFDMA was suitable for users transmitting at a moderate bit while LFDMA can work better in a system using high-bit-rate. LFDMA can provide better BER performance than IFDMA. LFDMA are usually used in LTE uplink applications.

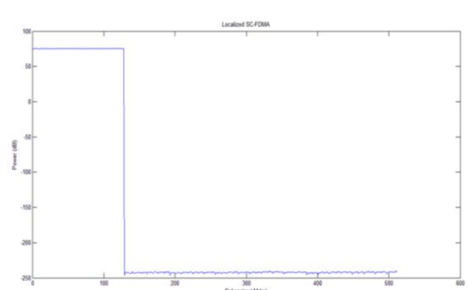

Fig.3 Localized SC-FDMA Signal

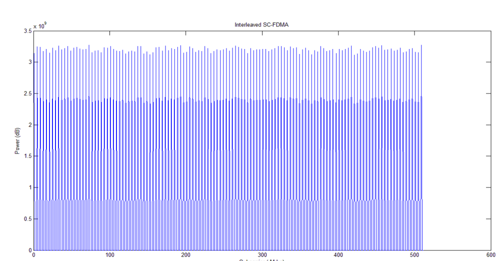

Fig.4 Interleaved SC-FDMA Signal

The figures 3 and 4 shows localized and interleaved subcarrier mapping of 128 point DFT output on to

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512subcarriers.We can observe that in localized mapping the signal have significant power level only over 128 sub-carriers and it reduces greatly after $128^{th}$ sub-carrier. In interleaved mapping the signal is spread over the entire 512 sub-carriers.

The transmitter performs two important signal processing operation prior to transmission [11]. It inserts a set of symbols referred to as a cyclic prefix (CP) to provide guard time against inter-block interference (IBI) arising from multipath propagation. If CP length is greater than the maximum delay spread of the channel or is equal to length of channel impulse response, there will be no IBI. It can convert discrete time linear convolution into discrete time circular convolution. So the data transmitted through the channel can be modelled as a circular convolution between channel impulse response and transmitted data block, which in frequency domain is a point-wise multiplication of the same. Thus complexity of equalizer at the receiver can be reduced. The next operation done by transmitter includes a linear filtering process referred to as pulse shaping for transmission of signal through a band limited channel [12]. Raised-cosine filters (RC) is one of the widely used pulse shaping filter in wireless communication systems. The increase in roll off factor of filter will cause significant reduction in PAPR. But a trade-off between PAPR and out of-band radiation is required because out-of-band radiation can increase with increase in roll-off.

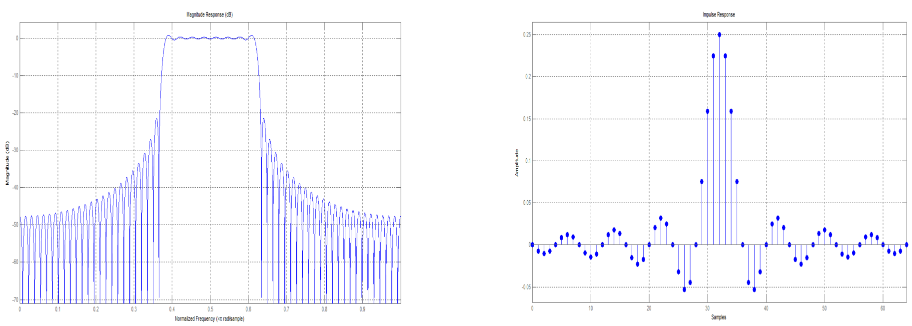

Fig.5 Frequency and Impulse response of Raised cosine filter for 0 roll-off Factor

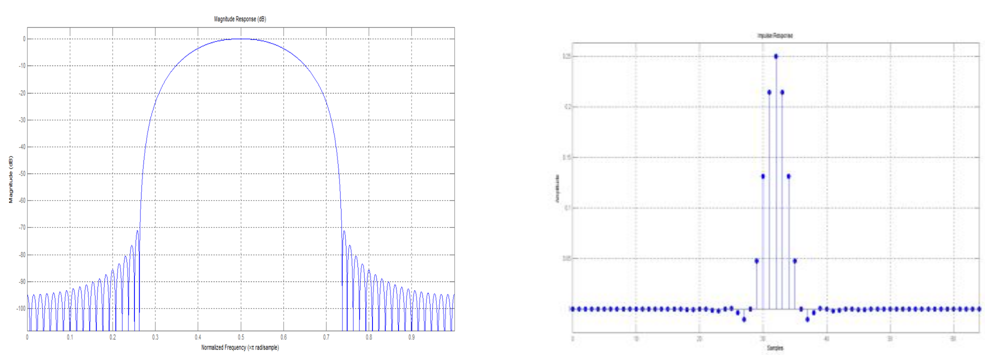

Fig.6 Frequency and Impulse response of Raised cosine filter for 0.9 roll-off Factor

The figures 5 and 6 shows frequency and impulse response of Raised cosine filter for roll-off factors of 0 and 0.9. We can observe that as roll-off factor increases spreading of main-lobe will increase with reduction in power level of side lobes.

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The SC-FDMA receiver performs reverse operation of transmitter. The receiver transforms the signal into frequency domain via DFT, de-maps the subcarriers and performs frequency domain equalization [13]. Equalization is done in frequency domain because in broadband channels time domain equalizers are impractical as they have a very long channel impulse response in time domain. For cellular systems with severe multipath propagation conditions, SC-FDMA signals will arrive base station with significant inter-symbol interference. The base station will use an adaptive frequency domain equalization to cancel this interference. Most of the well-known equalization techniques like minimum mean square error (MMSE) equalization, decision feedback equalization (DFE) and turbo equalization are used. The equalized symbols are transformed back to time domain via IDFT and detection and decoding will be done in time domain.

## IV. MODULATION SCHEMES

In this paper we are using QPSK, QAM and continuous phase modulation (CPM) modulation scheme. The PAPR value varies with the modulation schemes used. Constant envelope modulation like QPSK can ensure high power efficiency and maintains low spectral side lobes. CPM have constant envelope and continuous phase which can provide high spectral and power efficiency with better PAPR reduction. The modulation index can control spectral confinement of CPM signal, smaller the index better will be the spectral confinement [7]. When modulation index increases BER performance will be improved. But modulation and demodulation of CPM signal is complicated by the fact that initial phase of each symbol will be determined by the cumulative phase of previously transmitted symbols which demands receiver to have memory.CPM signals uses three types of pulse shaping for the signals namely rectangular, raised cosine and Gaussian. When length of the pulse shape is equal to 1 (L=1), it is called full response signal [14]. When length is greater than1 (L>1) it is called partial response signal. Full response signal will be having a better BER and PAPR reduction than partial response signal.

## V. SIMULATION REULTS

The simulation of SC-FDMA system for QPSK, QAM and CPM modulation was done using monte-carlo method for random bits of 100 (BER) and 10000 (PAPR) frames with each frame containing 128 symbols that are averaged over the entire duration of transmission. The simulation parameters are given below

| | |
|---|---|
| System Bandwidth | 5 Mhz |
| DFT Size | 128 |
| IFFT Size | 512 |
| Modulation scheme | QPSK,QAM and CPM |
| Length of cyclic prefix | 20 |
| No of users | 4 |
| Sub-carrier spacing | 15Khz |
| Channel | Urban |
| Filter | Raised Cosine |
| Roll –Off | 0.5 |
| Oversampling Factor | 8 |
| Equalization | Zero forcing |

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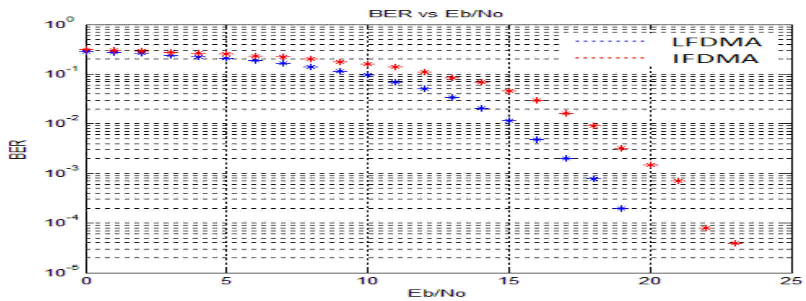


Fig.7 BER performance of SC-FDMA signal for QPSK modulation

The BER performance of LFDMA and IFDMA for QPSK SC-FDMA is done. It was observed that BER is better for LFDMA than IFDMA. BER will decrease with increase in Eb/No.

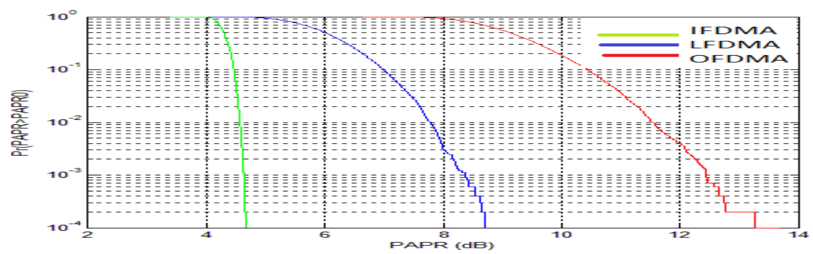


Fig.8 PAPR performance of SC-FDMA and OFDMA signal for QPSK modulation

The PAPR of QPSK signal is plotted against complementary cumulative distribution function(CCDF).The peak power of a signal x(t) will be maximum of its squared envelope $|x(t)|^2$. But for a continuous random process, max $|x(t)|^2|$ can be unbounded. For a random process with discrete values, max $|x(t)|^2|$ will be bounded but it may occur at very low probability. The distribution of $|x(t)|^2$ is a useful performance indicator and it will be better to be described with complementary cut-off probability. From the graph it can be observed that SC-FDMA will be having lower PAPR compared to OFDMA and PAPR reduction is higher in IFDMA than LFDMA.

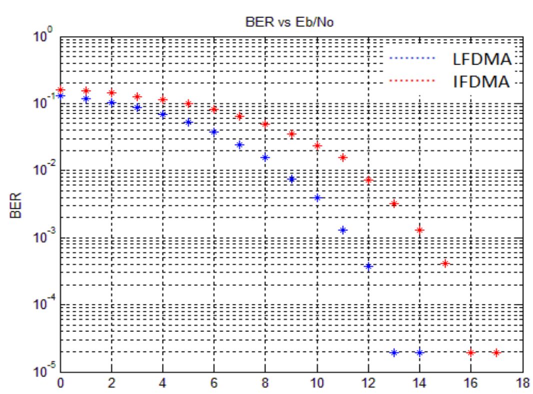


Fig .9 BER performance of SC-FDMA signal for 16 QAM modulation

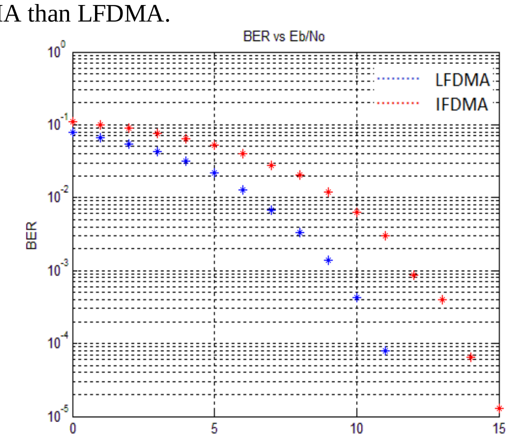


Fig.10 BER performance of SC-FDMA signal for 64QAM modulation

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The BER performance of 16 and 64 QAM modulation is given above. It was observed that as M value increases from 16 to 64 the BER performance of the system is improved.

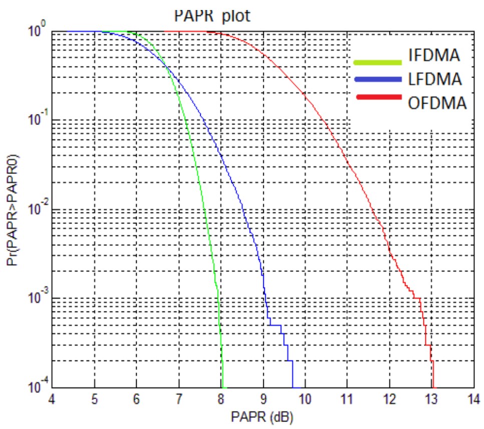


Fig.11 PAPR performance of SC-FDMA and OFDMA signal for 16-QAM modulation

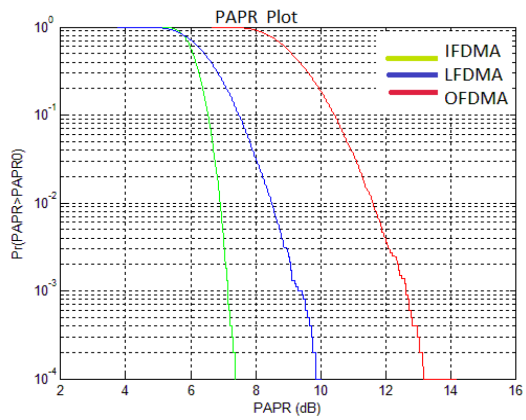


Fig.12 PAPR performance of SC-FDMA and OFDMA signal for 64-QAM modulation

The PAPR performance of 16 and 64 QAM is given above. It was observed that as alphabet size M value increases PAPR of the signal will also increases. SC-FDMA has better PAPR reduction than OFDMA.It was also observed that PAPR will be higher for QAM compared to QPSK .

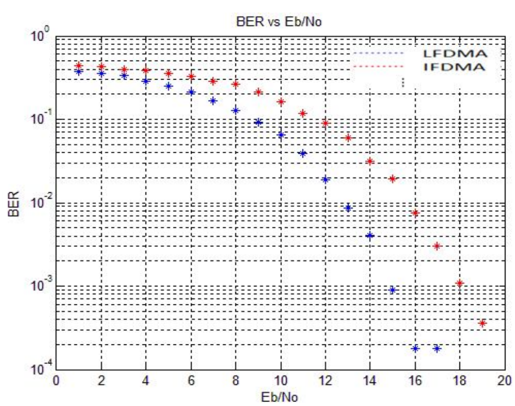


Fig.13 BER performance of SC-FDMA for 2-ary Full response CPM modulation

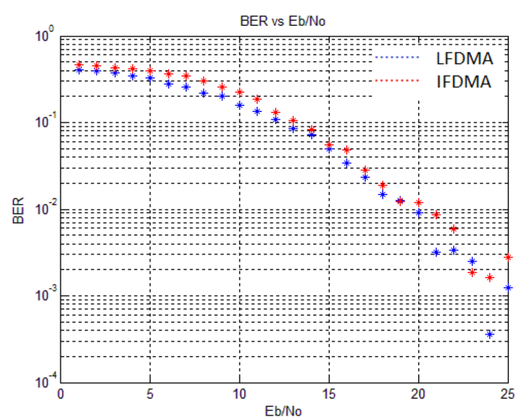


Fig.14 BER performance of SC-FDMA for 2-ary partial response CPM modulation

The above simulation shows BER performance of 2-ary CPM signal for full and partial response. It was observed that the BER performance is better for full response signal than partial response.

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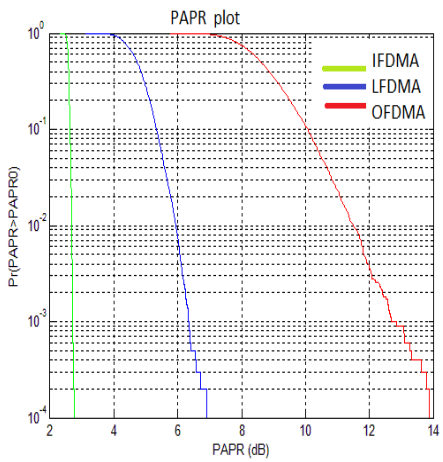


Fig.15 PAPR performance of SC-FDMA and OFDMA signal for 2-ary full response CPM

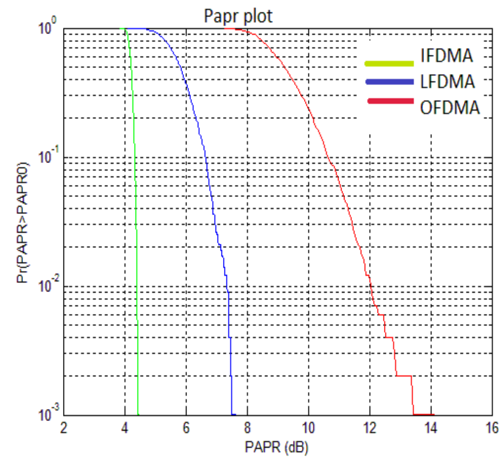


Fig.16 PAPR performance of SC-FDMA and OFDMA signal for 2-ary partial response CPM

The PAPR plot of 2-ary CPM signal was compared for full and partial response signal. It was observed that PAPR will be less for full response than partial response because pulse length (L) will increase with partial response.CPM modulation provided the best PAPR reduction than QPSK and QAM modulations.

## VI. CONCLUSION

SC-FDMA was found to be the most suitable scheme for uplink communication than OFDMA. PAPR reduction is significant in SC-FDMA system compared to OFDMA system. Among the various modulation schemes it was observed that CPM was a better modulation technique for SC-FDMA for uplink communication. Full response CPM signal has better BER and PAPR performance than partial response CPM signal. The BER performance was observed to be better for LFDMA compared to IFDMA and PAPR reduction was better in IFDMA than LFDMA. Similarly roll-off factor for pulse shaping must be chosen carefully. The PAPR reduces with roll-off factor but it can increase the out-of radiation of signal.

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