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Comparative Analysis and Performance Assessment of PAPR Reduction Schemes in OFDM System

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***Abstract*— Orthogonal Frequency Division Multiplexing (OFDM) is a promising technique for next generation wireless systems. But performance of OFDM system is degraded by inter-carrier-interference (ICI) and Peak to Average Power ratio (PAPR). This paper provides a comparative analysis of some PAPR reduction schemes and performance assessment is made by simulating their performance metrics CCDF, SNR and bit-error rate (BER).**

Keywords—Orthogonal Frequency Division Multiplexing, PAPR, Clipping, Selective mapping

I. INTRODUCTION

OFDM is a prominent technology for next generation high data rate communication systems. But there are several problem associated with design of OFDM system which needs to be addressed. High Peak to Average Power Ratio (PAPR) of OFDM system is one of the most important issues, which needs to be addressed. In OFDM there is an IFFT used at the transmitter, which adds the N sinusoids through superposition. When the instantaneous amplitude of two or more signals have high peak at the same time then their sum creates high peak. Due to large peaks of the resulted signal, it put pressure on design components of OFDM system. There are lots of non-linear component used in OFDM system which is sensitive towards large peaks of the signal like as word length of IFFT/FFT pair, ADC and DAC, mixture stages, and the power amplifier. These components need to be handling the irregularly occurring large peak. So there is requirement to design all above components to have large dynamic range to handle the large peaks of the signals. If fail to design such large dynamic range of power amplifier saturates the signal, which distorted the signal and there is in-band distortion occurs which increases the BER and out-of-band distortion which causes the inter-carrier interference.

The most feasible way to eliminate the problem is yet improvised, is the number of techniques that can reduce PAPR of the OFDM signal to some acceptable limit before transmitted. These techniques allow the OFDM signal to higher range as required and also do not add much cost to the transmitter as these processing is done in baseband but there is required some extra set of computational complexity.

II. PAPR REDUCTION SCHEMES

The complementary cumulative distributive function (CCDF) is the most important metric used for calculating the PAPR. So CCDF is measured the PAPR reduction capability. It provides the probability of the OFDM signal's envelope more than the specified threshold of PAPR within the OFDM symbol. $CCDF\ [PAPR\ (x^n\ (t))] = \text{prob}\ [PAPR\ (x^n\ (t) > \delta)]$, Where PAPR ($x^n$ (t)) is the Peak to Average power Ratio of the n^{th} OFDM symbol and δ is some threshold value of peak to Average power Ratio. According to the CLT, the OFDM signal's envelope follows the Rayleigh distribution and its energy follows the exponential distribution or equivalently central chi-square distribution. There is two degree of freedom and zero mean. The CDF is given by,

$$CDF(\delta) = (1 - e^{-\delta})$$

In OFDM, samples are mutually independent to each other, if the probability of Peak to Average Power Ratio of N subcarriers is below the threshold value δ then probability of all the samples are below the threshold value. Thus probability is given as $prob(PAPR < \delta) = CDF[PAPR(x^n(t))] = (1 - e^{-\delta})^N$. The above approximation result is valid for the peak of the OFDM samples but in continuous OFDM signal, it is not necessarily for the maximum peak. Some more approximation is required to predict the accurate peak of continuous OFDM. Oversampling can be used to predict the accurate peak. But due to oversampling the OFDM symbols are not mutually independent to each other. So there's required some empirical approximation. One of way to predict this, without oversampling the distribution of oversampled OFDM signal with N subcarriers is approximated by αN subcarriers. So CDF of the PAPR is written as $CDF[PAPR(x^n(t))] = (1 - e^{-\delta})^{\alpha N}$

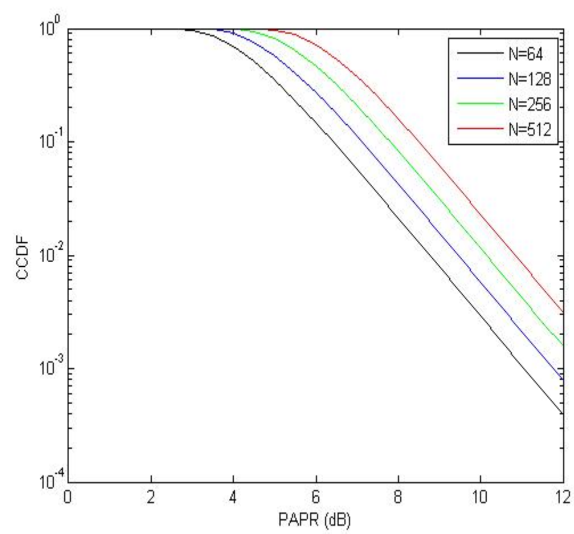

Fig 1: CCDF versus PAPR for different value of subcarriers for α=1

Some reference suggested that α = 2.8 is practical value for OFDM signal and some other suggested that α = 4 is more good choice for OFDM signal. Now probability of PAPR of the OFDM system of the n^{th} symbol with N subcarriers more than the threshold value α is expressed by CCDF and is written as $CCDF\left[PAPR\left(x^{n}(t)\right)\right] = 1 - (1 - e^{-\delta})^{\alpha N}$

In CCDF versus PAPR plot which is shown in figure 1, where PAPR is increases with the number of subcarrier. Ideally PAPR should be at 0dB, but at the 0 dB CCDF equal to 1 means probability of the entire signal have greater amplitude than threshold value.

In literature there are large numbers of PAPR reduction schemes have been reported. The major reduction schemes are classified into three categories: - Signal distortion schemes, Multiple signaling & probabilistic schemes and Coding schemes.

A. Signal distortion schemes

In these schemes distorting the OFDM signal for reducing the PAPR before it passes through the power amplifier. It reduces the PAPR at the cost of creating the both out-of-band and in-band distortion. This leads to increase the BER. In OFDM signal, there is high PAPR but there is rarely occurs the high peak of the signal. Most of the signal power depends upon the low amplitude samples only. So, there is possibility to eliminate the high peak of the signal without much distorting the signal. Hence, in these scheme PAPR is reduced at the cost of some tolerable increase in BER. The following schemes come under this category: - Clipping and filtering, Peak windowing, Companding and Peak cancellation.

B. Multiple signaling and probabilistic schemes

In these schemes, one way is to reduce PAPR is generate multiple of OFDM signal and then calculate the each permutation of OFDM signal and transmit the one which has minimum PAPR. Another way to reduce the PAPR of OFDM signal by modifying the OFDM signal using changing constellation points, phase shifts or adding peak reduction carrier. Then these parameters of modification of OFDM signal is optimize to minimize the PAPR. The following schemes come under this category: - Selective mappings, Partial transmit sequence, Interleaved OFDM, Tone injection, Tone reservation, Active constellation shaping and Constrained constellation shaping

C. Coding schemes

Some coding scheme has capability to error detection and correction. This property makes them ideal choice for reducing the PAPR in OFDM system. By modifying the coding scheme some coding techniques reduce the PAPR. The following coding techniques come under this category:- Linear block coding, Golay sequences and Turbo coding

III. SELECTION OF SCHEMES

For selection of PAPR reduction schemes, there are a number of factors is considered. Not all factors can be fully satisfied by the any existing schemes of PAPR reduction. So there is tradeoff for selection of reduction schemes between these factors.

The selection of most appropriate scheme depends upon the system under consideration. The factors are following:

A. PAPR Reduction capability

PAPR reduction capability is measured through the amount of CCDF is reduced. After reduction technique is applied, amount of PAPR is reduced with respect to the CCDF is measured in dB. More is reduction of PAPR better the technique.

B. Power increase in transmit signals

The transmitted power level of the signal must not increase by the reduction scheme. If reduction scheme increases the power level then it must be in permissible limit.

C. BER increases at the receiver

When distortion occurs in the transmitter, then there is error occurs at receiver. Due to this error BER increases. So the reduction must not increase the BER beyond the permissible limit.

D. Loss in data rates

Some schemes use some extra bit for side information about the reduction mechanism and this may loss of data rate. So reduction scheme should be low loss of data rate is preferable.

E. Computational Complexity

For implementation of any scheme, there is required their computational complexity is less. If reduction technique is more complex then there is required more hardware to implement also their processing time is increases and this makes system slow. Hence there is required less complex reduction technique in OFDM system.

The Table 1 presents the comparison of all these schemes based on the factors presented above.

Table 1 Performance Assessment of PAPR Reduction schemes in OFDM system

PAPR Reduction Method	BER increases	Bit Rate Loss	Computational Complexity	Power Increases
Clipping	Yes	NO	Low	NO
Companding	Yes	NO	Low	NO
SLM	NO	Yes	High	NO
PTS	NO	Yes	High	NO
Interleaving	NO	Yes	High	NO
TI	NO	NO	High	Yes
TR	NO	Yes	High	Yes
ACE	NO	NO	High	Yes
CCS	Yes	NO	High	NO
LBC	NO	Yes	Low	NO
GCS	NO	Yes	High	NO

IV. IMPLEMENTATION OF REDUCTION SCHEMES

A. Clipping and filtering

Clipping and filtering scheme is one of the simplest methods of signal distortion technique. In this technique, clip the high peak of the OFDM signal before it passing through the power amplifier. So there is required a clipper which limits the signal envelope to predefined clipping level (CL). If the transmitted signal power has more than the clipping level then their peak is clipped to clipping level, otherwise clipper passes the signal without any change.

$$T(x[n]) = \begin{cases} x[n] & if \ |x[n]| \leq CL \\ CL & if \ |x[n]| > CL \end{cases}$$

Where x[n] represents the OFDM signal and CL is predefined clipping level and T(x[n]) is transmitted signal.

As clipping is nonlinear process, so it creates distortion. Both in-band and out-of-band distortion occurs in this technique. Out-of-band distortion causes spectral spreading which can be removed by the filtering which is employed after clipper. In-band distortion causes degrade the BER, which cannot be eliminated by filtering. BER performance of OFDM signal can be reduced in this technique by the oversampling. Some part of noise is reshaped out-side of the signal band if we take longer IFFT and these out-side noise is removed by the filtering. Hence, BER performance is improved through oversampling by using longer IFFT.

The filtering preserve the spectral efficiency of clipped the OFDM signal by removing the out of band distortion and due to this their BER performance is improves but it leads to power re-growth. Clipping Ratio (CR) defines the amount of clipping level in this technique. It is ratio of clipping level to the average value of the OFDM signal.

$$CR = 20log_{10}\left(\frac{CL}{E[x[n]]}\right)$$

Where CL is clipping level and E[x[n]] is average power of the OFDM signal.

The FFT based simulation model of OFDM system is shown in figure 2.

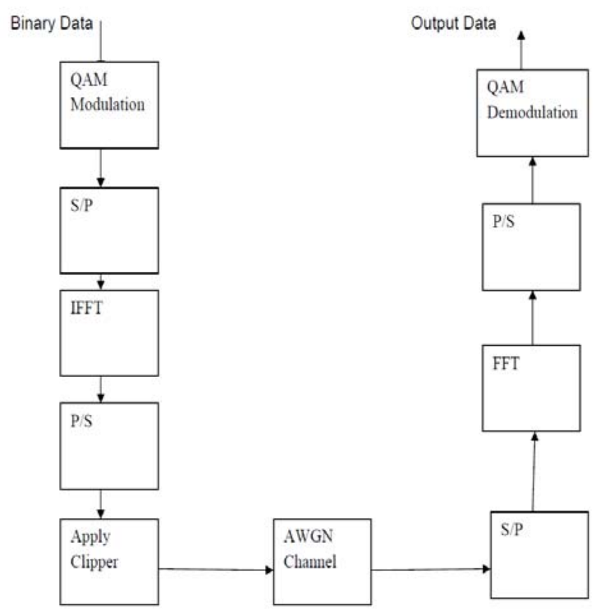

Fig. 2 FFT based simulation model of OFDM system

B. Selective mapping

The idea behind the selective mapping is to generate large number different OFDM symbols x(m), $0 \leq m \leq M\text{-}1$, where each of the OFDM symbol has length N and all the symbols carries the same information as original OFDM symbol x, after that calculate the PAPR of all different symbol and transmit the one which has minimum PAPR. Hence, transmitted OFDM symbol x can be written as

$$\tilde{x} = \arg\ min_{0 \leq m \leq M-1} [PAPR(x_m)]$$

In this technique, the original data block X = [X_1 X_2 ….X_N] is multiplying with M different phase sequences p_m and each these phase sequences has length N. The phase sequences can be written as

$$p_m = [e^{j\varphi m,1} \ e^{j\varphi m,2} \ldots\ldots\ldots e^{j\varphi m,N}], \quad 0 \leq m \leq M-1$$

Where $\varphi_{m,k}$ lies the value between 0 and 2π excluding 2π and k = 1,2,…N.

So this generated OFDM symbol set is then undergoes through IDFT operation. Hence modified OFDM symbol x(m) is generated. #

$$x(m) = IDFT[X_1\, e^{j\varphi m,1} \ X_2 e^{j\varphi m,2} \ldots\ldots\ldots X_N e^{j\varphi m,N}]$$

The simulation model for selective mapping is presented in figure 3.

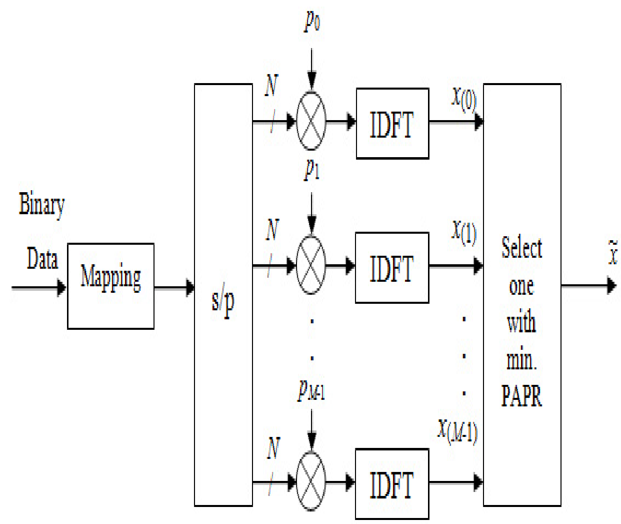

Fig. 3 Simulation model for selective mapping

C. Computational complexity of two schemes

Computational complexity of the reduction scheme depends upon the number of real addition and multiplication. Here division is considered as multiplication and subtraction is considered as addition. In OFDM, there is IFFT block used at the transmitter, so first calculate the number of addition and multiplication required for IFFT block. For radix-2 decimation in time N- point IFFT, there are required N $\log_2$ (N) complex addition and N/2 $\log_2$ (N) complex multiplication. Now for calculating the number of real addition and multiplication, we know that for each complex addition there are required 2 real additions and each complex multiplication there are required 4 real multiplication and 2 real additions. Hence for one IFFT block, there are required 3N $\log_2$ (N) real additions and 2N $\log_2$ (N) real multiplications.

In clipping scheme, first calculate the power of the OFDM signal and then compared with threshold value. So there are required N subtractions for comparison and for calculation of power of N complex samples, there are required N real additions and 2N real multiplications.

After clipping, there is filtering used which remove the out of band distortion. Suppose filter length is L, so there are required NL+L^2+L complex additions and multiplication. In OFDM system, usually there large number of subcarriers that is N is very-very large as compared to filter length L. so approximately there are required NL complex additions and multiplications. This required 4NL real additions and 4NL real multiplications. So total number of real addition and multiplication required in clipping and filtering is 4NL+2N.

. In selective mapping, there are M phase sequence is used where each of length N. For simplicity phase sequence {1,-1,j,-j} is considered because this phase sequence can be implemented without multiplications in hardware. Hence there are required MN additions for applying the phase sequences. Here M IFFT block is used, so there are required

3MN $\log_2$ (N) real additions and 2MN $\log_2$ (N) real multiplication. After that PAPR of M signals has been calculated, so there are required M (3N-1) real additions and M (2N+1) real multiplications. After that selecting the minimum PAPR, for this there are required (M-1) subtractions. Hence total number of real addition is 3MN (1+$\log_2$ N) + M (N-1) -1 and real multiplication is 2MN (1+$\log_2$ N) + M is required.

Table 2 presents the summary of Computational complexity of reduction schemes.

Table 2 Summary of Computational complexity

Reduction schemes	Total number of addition and multiplication
Clipping and Filtering	4NL + 2N additions 4NL + 2N multiplications
SLM	3MN (1+ $\log_2$ N) + M (N-1) -1 additions 2MN (1 + $\log_2$ N) + M multiplications

V. RESULTS

A. Simulation results for Clipping

SCCDF and BER performance of reduction schemes are compared with standard OFDM signal.

The parameter which is used in simulation is given in table 3.

Table 3 Simulation parameters for clipping

Parameter	Specifications
Number of Sub-carriers (N)	128
FFT size	128
Modulation	PSK
Channel	AWGN
OFDM symbols	1000

Figure 4 shows the standard OFDM signal envelope, where some of peaks are obtained. These peaks are responsible for high PAPR. Then applied a clipper which is clipped them to predetermined level. Figure 5 shows the clipped OFDM signal envelope with clipping ratio (CR) 6dB which limits the signal amplitude. Again decrease the clipping ratio then more limitation of the signal amplitude results which is shown in figure 6.

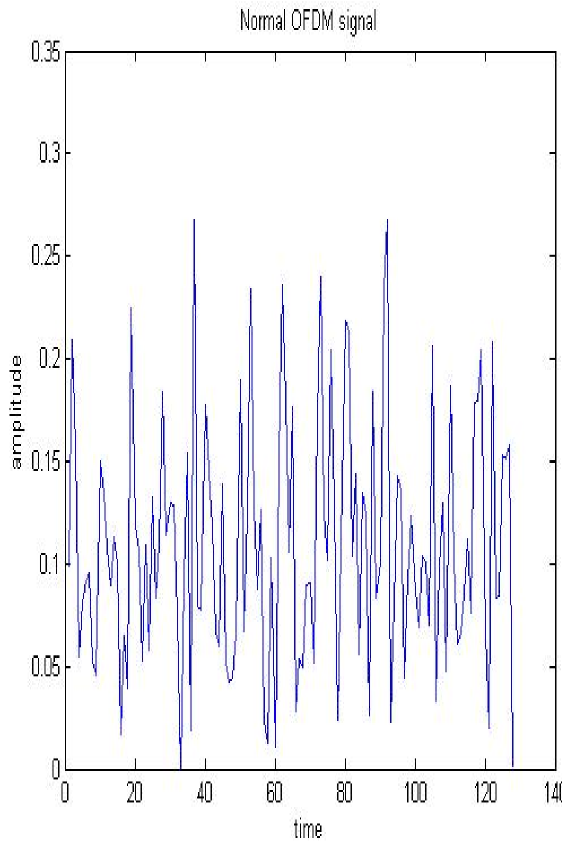

Fig. 4 Signal power envelope of standard OFDM

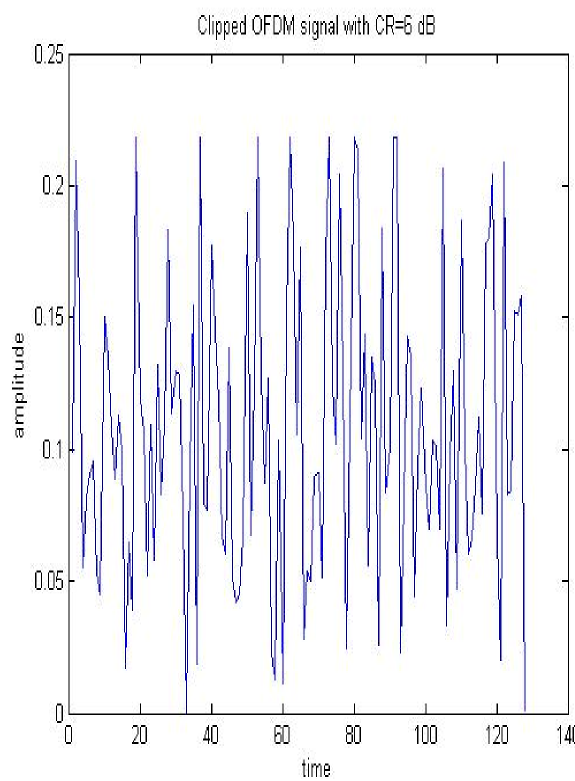

Fig. 5 Signal envelope of clipped OFDM with CR= 6dB

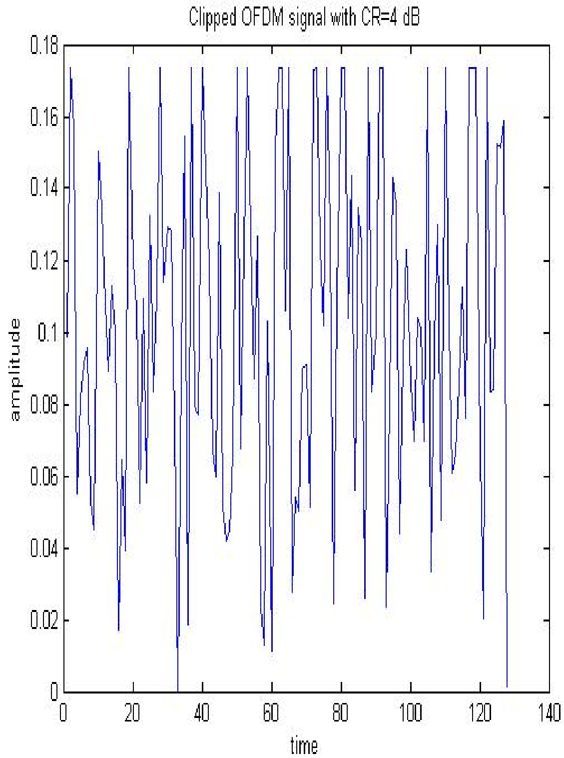

Fig. 6 Signal envelope of clipped OFDM with CR = 4dB

Now PAPR is calculated for standard OFDM and clipped OFDM signal, which is plotted against CCDF in figure 7. From the plot it is clear that PAPR is significantly reduced if clipper is applied and also if clipping ratio is decreases then PAPR is also decreases.

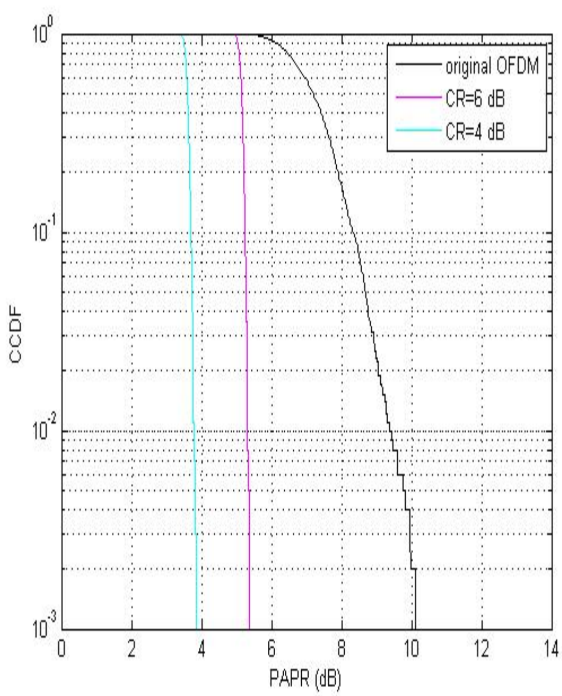

Fig. 7 CCDF vs PAPR without clipping and with clipping for different values of CR

From figure 7, it is clear that standard OFDM has PAPR about to 10 dB for 128 numbers of subcarriers. But when clipping is applied then their PAPR reduces to about 5 dB, hence there is about 5 dB reduction from standard OFDM system when clipping ratio is 6dB. Again decreases the clipping ratio to 4 dB then their PAPR is about 4dB, hence there is about 6dB reduction of PAPR from original OFDM System.

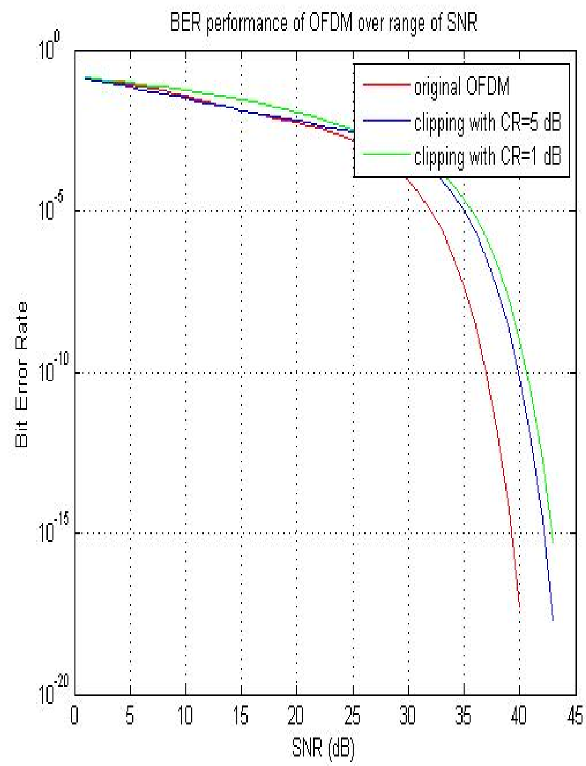

Fig. 8 BER vs SNR for different value of CR

Figure 8 shows the performance of clipping on OFDM system. In figure, BER versus SNR is plotted, which shows that BER is increase with decrease in clipping ratio. Hence there is reduction of PAPR at the cost of increment of BER in clipping technique.

B. Simulation results for Selective mapping

The simulation parameter given in table 4.

Table 4 Simulation parameters for selective mapping

Parameter	Specifications
Number of Sub-carriers (N)	128
IFFT size	128
Modulation	PSK
No. of IFFT block(M)	2,8
OFDM symbols	1000

Figure 9 plots the CCDF versus PAPR for SLM reduction method. In figure it is clearly shows that there is about 11dB PAPR for standard OFDM. But when SLM method of reduction is applied for M=2, then their PAPR is about to 9dB, hence there is 2dB reduces the PAPR. Again when M=8, then PAPR is about to 7dB, hence there is 4dB reduction of PAPR from standard OFDM system.

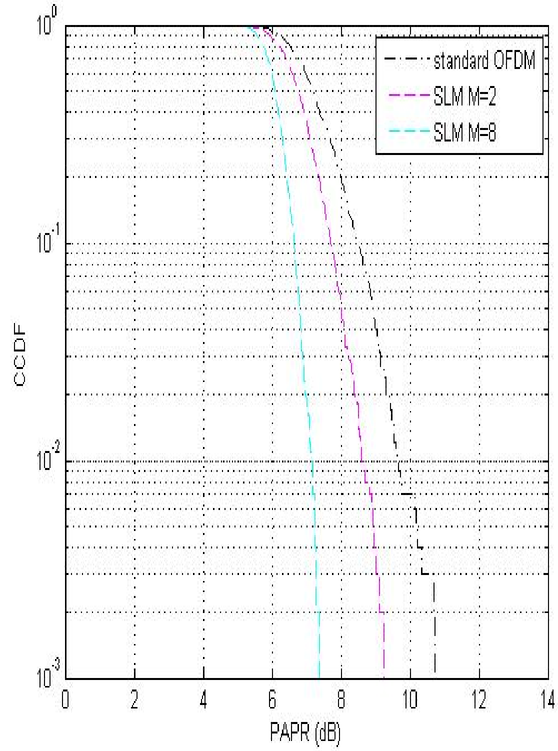

Fig. 9 CCDF vs PAPR for different value of phase sequence

C. Performance Assessment of Clipping and selective mapping

There are lots of factors on which the performance of PAPR reduction scheme depends, but mainly two factors are important:-complementary cumulative distributive function (CCDF) and bit error rate (BER). Others factors are also considered when these reduction scheme is implemented. These are transmitted signal power, computational complexity, data rate loss and spectral spreading.

Table 5 gives performance assessment between clipping and SLM.

Table 5 Performance assessment between clipping and SLM

PAPR Reduction Method	BER increases	Bit Rate Loss	Computational Complexity	Power Increases
Clipping	YES	NO	LOW	NO
SLM	NO	YES	HIGH	NO

VI. CONCLUSION

Most of the existing wireless standards are using OFDM or its variant form such as OFDMA, MIMO OFDM or MC-CDMA, because of its spectral efficiency and robustness to multipath fading. All these systems have the problem of high PAPR, which is occurred in standard OFDM system. Due to high PAPR in OFDM system, transmitter power amplifier drive's into saturation region, which distorted the signal as well as spectral spreading. Clipping and filtering and selective mapping are two reduction schemes, which reduce the PAPR significantly.

Clipping and filtering is easy to implement and also their computational complexity is low. It reduced the PAPR significantly but it also increases the BER, which undesirable for the required system. In this work, for clipping ratio 6dB, there is PAPR reduce up to 4 dB and again decreases the clipping ratio up to 4 dB, and then PAPR reduces up to 6dB from the standard OFDM PAPR of 10dB. But this reduction of PAPR at the cost of increment in BER of the system, hence there is reduction of PAPR to acceptable limit of BER in clipping and filtering technique.

Selective mapping is a reduction scheme which also reduces significantly the PAPR in OFDM system. This work is simulated for 128 subcarriers and for different number of parallel IFFT operations. It is found that if we increase the number of parallel IFFT block there is more reduction of PAPR, but this increases the computational complexity of the system. From the simulation it is found that, standard OFDM has PAPR of 11 dB but if 2 block of IFFT is used then their PAPR reduces to about 9 dB, hence there is 2dB of PAPR reduction. Again if increase the IFFT block to 8, then there is reduces the PAPR to about 7dB, hence there is about 4 dB reduction of PAPR from standard OFDM system.

VII. FUTURE SCOPE

PAPR is still a major issue in OFDM system specially for the system where minimization of dynamic range of power amplifier is required. In this work, clipping and filtering approach is applied for reduction of PAPR which reduces the PAPR but at the cost of increment of BER. This scheme can be better if there is reduction in the BER. The second approach applied in this work is SLM method, where complexity of the system has increased. So if there is reduction in the complexity then it's more desirable in implementation of the system. So following modification is required: - Minimize the BER in clipping technique, reduce the complexity of the system in SLM technique and reduce the data rate loss in SLM method.

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