Comparative Analysis of Clipping-filtering, SLM and PTS for PAPR Reduction Technique in OFDM System

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Abstract

Modulation scheme, orthogonal frequency division multiplexing (OFDM) uses multiple carriers to communicate and transmit data. It is used widely in wireless communication due to its numerous advantages. OFDM modulation is very advantageous as it reduces inter symbol interference, provides high data rate and it is not affected by narrow band effect. To operate OFDM effectively, its high value of peak to average power ratio should be reduced. In OFDM, power amplifier should be linear and accommodate amplitude variations to work efficiently. The high peak to average power ratio affects the performance of power amplifier.

Keywords: orthogonal frequency division multiplexing (OFDM), peak average power ratio (PAPR), complementary cumulative distribution function (CCDF), Amplitude Clipping & Filtering, SLM, PTS.

1 Introduction

Communication is an important aspect of life. Orthogonal frequency division multiplexing is a transmitting method to transmit data and information simultaneously over multiple subcarrier frequencies that are spaced equally. For modulation and demodulation of data, Fourier transform is used [1]. Multicarrier data transition method is proposed for various types of radio and wireless communication system such as local-area networks, digital audio and video broadcasting [2]. In OFDM system, multiple carriers are modulated separately and independently maintaining the orthogonal interface. When numbers of subcarriers are increased to the certain extent, it will result in high peak to average power in comparison to single-carrier system. Thus, it requires power amplifier system, digital and analog converters that are linear and has large dynamic range. High peak to average power of the system leads to interference between subcarrier frequencies and it can also destroy the orthogonal behavior of the carrier. Therefore, it is important to maintain the high peak to average power.

1.1 OFDM principal

Orthogonal Frequency Division Multiplexing is one of the forms of multiple carrier modulation; it is well suited for transmitting data over a channel having dispersive behavior. Here the principal is that diverse carriers are orthogonal to each other. These different carriers are independent to one another, and to achieve this phenomenon the carriers are placed exactly at the null space in spectrum of modulation. In multiple subcarrier transmission technology to achieve high data rate transmission, no inter symbol interference, and high spectrum efficiency, the carrier signal is added through IFFT process in OFDM system. OFDM is immune to selective fading. OFDM is also used for multimedia applications because of its characteristic's [1].

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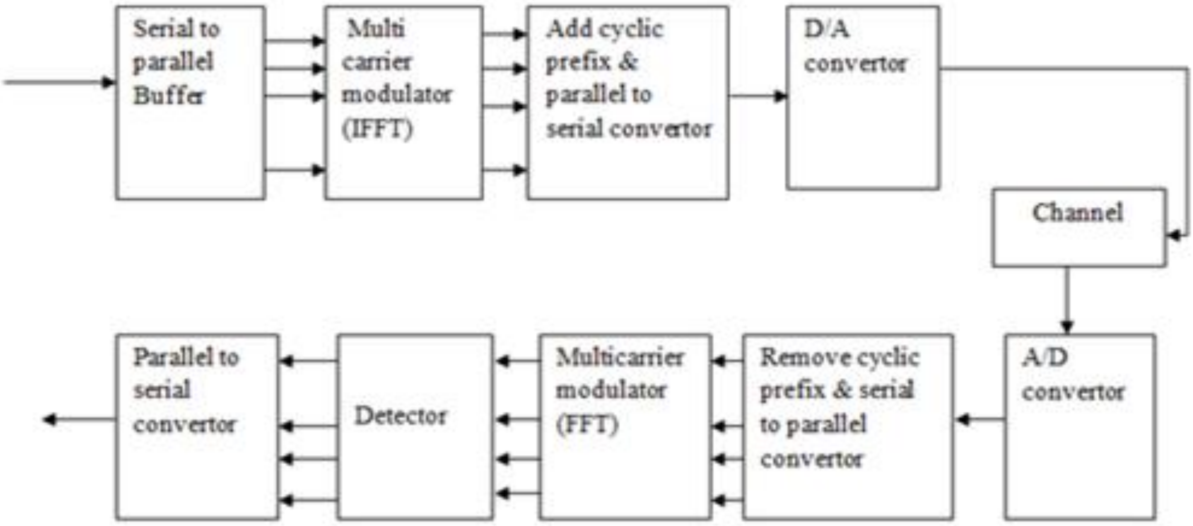

Figure 1 Basic OFDM block diagram [1].

Figure1 shows the block diagram of OFDM transmitter and receiver. It depicts the steps involved in OFDM system to transmit and receive the data and information.

Mathematical representation of OFDM signal

A vector Y of length N represent the block of data and information,

$Y = [Y_0, Y_1, Y_2 \ldots\ldots\ldots\ldots Y_N]'$

Here [A]' denotes the transpose of matrix A. T is the duration of any symbol Y_K in Y block. Y_K represents the one of the subcarrier.

The data block for OFDM signal to be transmitted is represented by;

$$Y(t) = \frac{1}{\sqrt{N}} \sum_{n=o}^{N-1} Y_n e^{j2\pi n\Delta wt} \quad 0 \leq t \leq NT \qquad (1)$$

In "equation (1)" [1], Δw denotes the subcarrier spacing and NT represents the useful data block period.

1.2 Peak to average power ratio

PAPR is the result of large number of subcarrier in the OFDM system. PAPR provides a relationship between transmitted signal maximum sample power to average power.

"Peaks to average power ratio of an OFDM signal is the ratio of maximum instantaneous power to the average power." Amount of power the system utilizes in its operation is denoted by PAPR.

$$\text{PAPR} = \frac{\max\,[Y(t) * Y(t)]}{E[Y(t) * Y(t)]} \qquad (2)$$

"Equation (2)" [1, 3] is the mathematical representation of PAPR, where E [ ] represents the expectation value of signal.

2 reduction technique for papr

The high value of peak to average power ratio is due to the random leads that are sinusoidal in nature occurs during transmission. Peak envelop power reduction is required so that power amplifier unit can work effectively.

There are various methods proposed to reduce high PAPR. These methods give different outcomes and change different characteristics of the OFDM signal. PAPR reduction techniques are dependent on many

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factors such as spectral efficiency, transmit signal power, and change in data rate, BER, computation complexity. PAPR reduction techniques are generalized in to two categories: -

1. Signal scrambling techniques
2. Signal distortion techniques

Signal scrambling techniques use the side information of the signal and try to reduce the redundancy in the signal and it will improve PAPR of the system. It includes Block coding technique, Selected mapping (SLM), Interleaving, Tone reservation, Tone injection, Partial transmit sequence.

Signal distortion techniques reduce PAPR by garbling signal before amplification. It results in 'in and out' band distortions. These techniques are peak windowing, clipping and filtering and envelop scaling [3].

2.1 Clipping and filtering method

Clipping and filtering method is one of the simplest and efficient way of reducing high PAPR. In this method, unchanging amplitude level known as clip level is used. The clip level is selected and the signal to be transmitted, having peaks larger than clip level is being removed. There is no information loss in the signal by clipping as the same information is also stored at different frequency [5].

The band pass samples y having real value, are clipped at amplitude level L as follows:

$$X = \begin{cases} -L, & \text{if } y<-L \\ y, & \text{if } -L<y<L \\ L, & \text{if } y<L \end{cases}$$

Clipping is nonlinear process which results into in-band and out-band noise. In-band noise degrades the BER performance and spectral efficiency is being affected by out-band noise.

However, filtering can improve the performance of clipping method. It reduces the spectral growth. Therefore, to avoid out-band distortion; signal is passed to the filter after clipping.

Before clipping, if the interpolation is performed on a signal than it will help in reducing the out-band distortion but it will improve the chances of peak re-growth. To improve performance of clipping and filtering method, some improvements are done in this method.

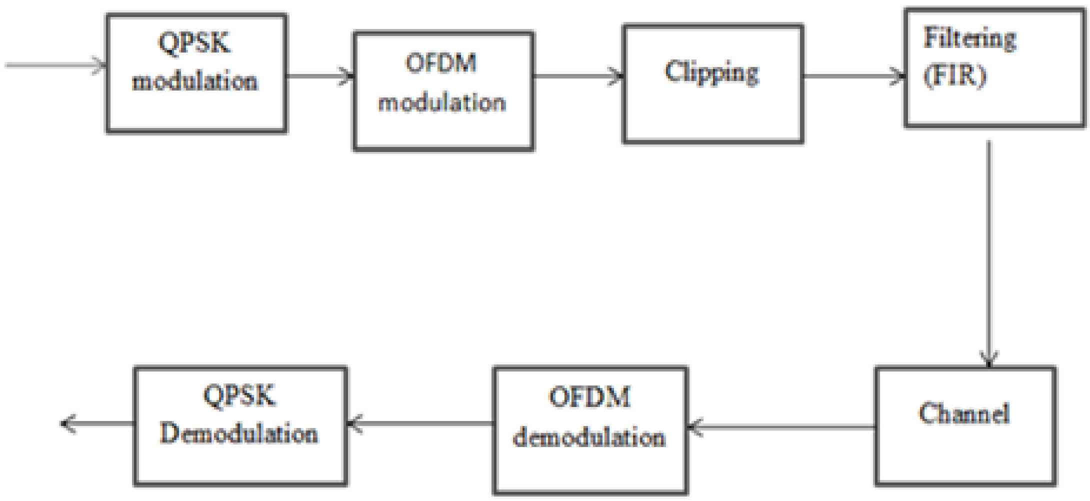

Figure 2 Block diagram of clipping method [2].

Iterative clipping and filtering (ICF) algorithm

In ICF, the approach is similar to time domain clipping and filtering method. In this method, the time domain signal having higher peak amplitude then threshold level are reduced by directly clipping magnitudes that are exceeding threshold level. Further, the clipped signals are sent to filter to reduce the out-of-band radiations.

But due to filtering, the signal faces the problem of peak regrowth. Thus, to remove the peak regrowth and to achieve the required PAPR value, the clipping and filtering process is revised up to a definite number of iterations [2,3].

Simplified clipping and filtering (SCF)

In SCF, the clipping operation is performed in frequency domain using scaled clipping noise. In this method, the noise is combined to the established ICF technique. On the basis of this additional operation, PAPR reduction is achieved [4].

2.2 Selective mapping technique

Selective mapping (SLM) is easy and simple approach to reduce PAPR value of OFDM signal. In this technique, different symbol of OFDM is generated containing same information and similar length but with different phase value. Then, the signal having least PAPR value is being transmitted through channel. Figure 3 represents the block diagram of selective mapping technique [6].

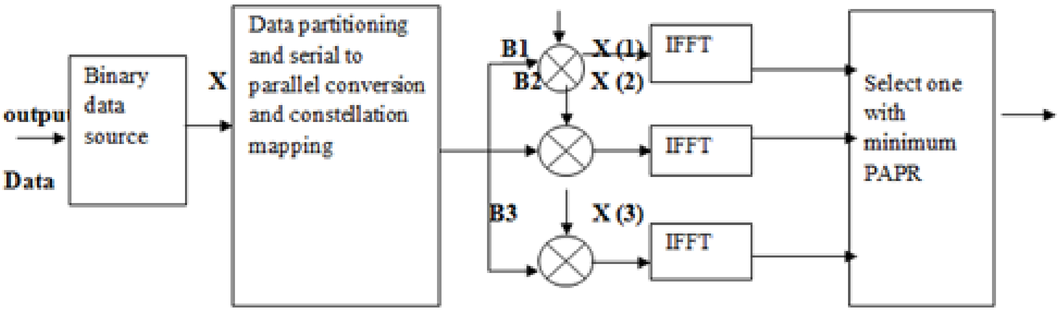

Figure 3 Block diagram to represent selected mapping technique [7].

Mathematical representation of SLM method

Y_m, $0 \leq m \leq M\text{-}1$ represents the different OFDM symbol having same information and each symbol length is N. The symbol Ŷ to be transmitted is represented as,

$$\hat{Y} = \mathrm{argmin}_{0\leq m\leq M-1}[\mathrm{PAPR}\ (Y_m)] \qquad (3)$$

In "equation (3)" [7], argmin indicates that the argument of its value is minimized.

The set of OFDM symbol having same information can be derived by multiplying the original data set Y, with M different phase sequences p_m by element by element method, and each sequence has length of N. The multiplication is done before taking IDFT of symbol. The modified symbol Y_m , $0 \leq m \leq M\text{-}1$, will become IDFT of the multiplied symbol Y and p_m.

$$Y_m = \mathrm{IDFT}\ [Y_1\, e^{j\varphi_{m,1}}\ Y_2\, e^{j\varphi_{m,2}}\ \ldots\ldots\ldots\ldots\ldots\ Y_N\, e^{j\varphi_{m,N}}]$$

Since, the symbol is transmitted, the phase sequence that has been selected, is also sent as side information so that at the receiver side the recovery of symbol can be done easily. But the side information increases some problems in system like the additional information sent decreases the data rate. And if the side

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information is detected by intruder, it can destroy the whole system. Therefore, it is very important to protect side information [7].

2.3 Partial transmit sequence

Partial transmit sequence method is proposed in 1997 by Muller and Hubber. Partial transmit sequence method is probabilistic approach to reduce PAPR value of OFDM signal. Generally, it is considered as modification in SLM method. The base concept of PTS method is to divide the data stream into sub-blocks that are non-overlapping in nature and each sub-block has different phase shift value [8, 9].

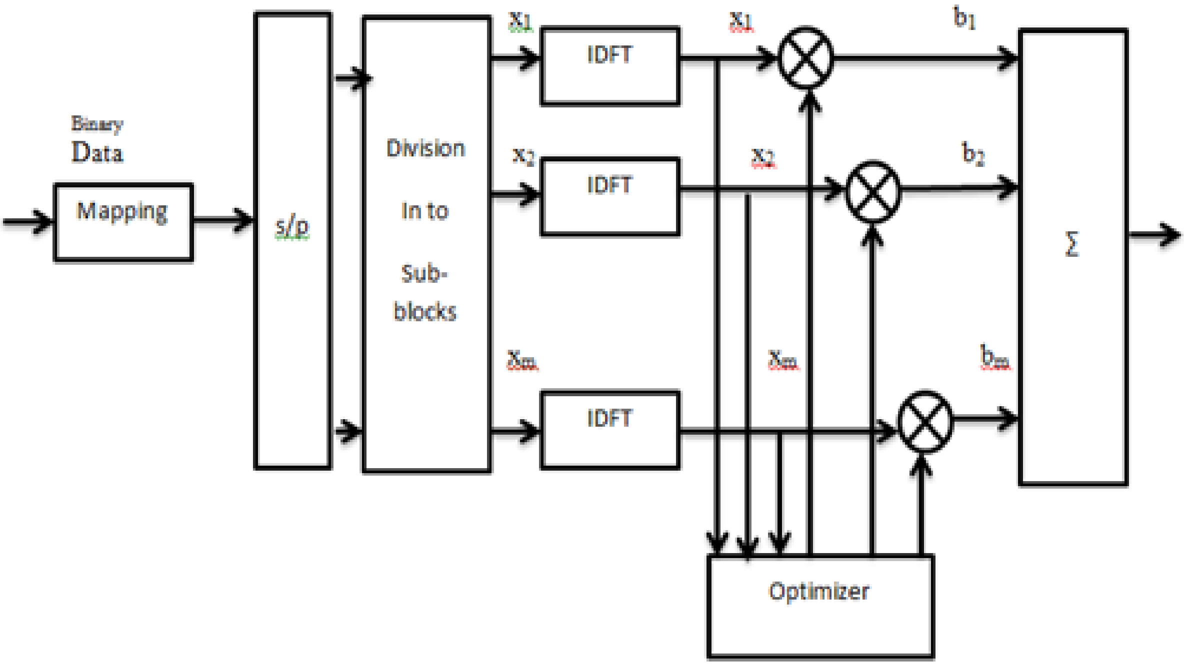

Figure 4 Block diagram of OFDM transmitter with PTS [9].

In PTS method, the data block is divided in to sub-blocks that are disjoint in nature and each having length N. These sub-blocks are then given a phase value in such a manner that when these sub-blocks are again combined they will result in low PAPR value. Figure 4 shows the PTS method approach. To divide the blocks in to sub-blocks, pseudo random processing method is used.

Mathematical representation of PTS method

Let an input data block Y be divided into segregated blocks M,

$Y_m = [Y_{m,1}\ \ Y_{m,2}\ ....Y_{m,N}]\quad 1 \le m \le M,$

Y is the combined block of all M sub-blocks. These sub-blocks are partitioned in such manner that any two sub-blocks are orthogonal to each other. It is shown by "equation (4)" [8].

$$Y = \sum_{m=1}^{M} Y_m \qquad (4)$$

After this, the inverse discrete Fourier transform for each data sub-block, Y_m, $1 \le m \le M$, is performed and p_m is the phase value by which the sub-blocks are weighted.

$$p_m = e^{j\varphi_m},$$

Here, $\varphi_{m,k} \in [0, 2\pi)$, $1 \le m \le M$.

Now, the focus is to select the p_m value in such a manner that the combining the time domain signal y will result in minimized PAPR where y is defined in "equation (5)" [8],

$$Y=\sum_{m=1}^{M} p_m\, Y_m \qquad (5)$$

This method is effective and efficient approach to reduce PAPR value. To avoid any information loss, the first phase value p_1 is considered as 1. Thus, it requires searching M-1 phase values. To improve the performance of PTS method, it will be better to have large number of M but the increasing M results in increased complexity of method.

3 Simulation

In this paper, the three reduction techniques of PAPR has been simulated that is, clipping and filtering method, selective mapping technique and partial transmit sequence. Each technique contains and results into own merits and demerits so the selection of technique is done based on requirement.

These three techniques are being selected to full fill basic requirement of transmission system i.e. complexity, performance of the system and better PAPR result.

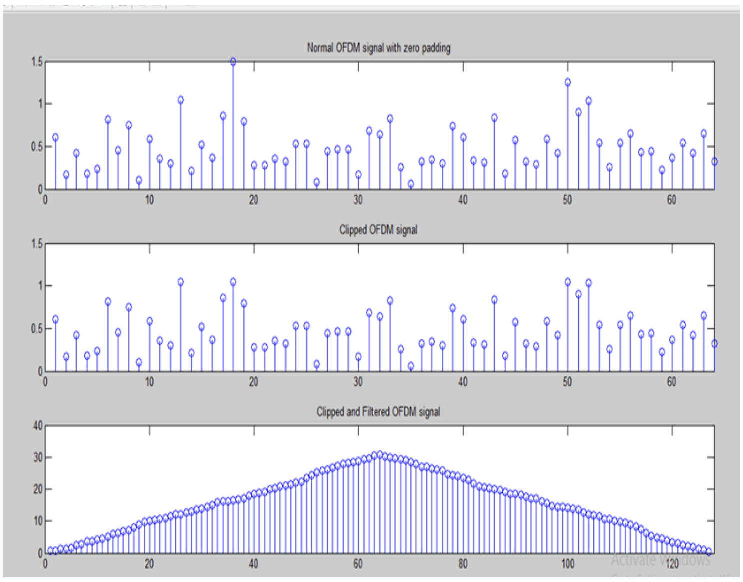

Figure 5 Original OFDM signal, clipped OFDM signal, and C&F OFDM signal.

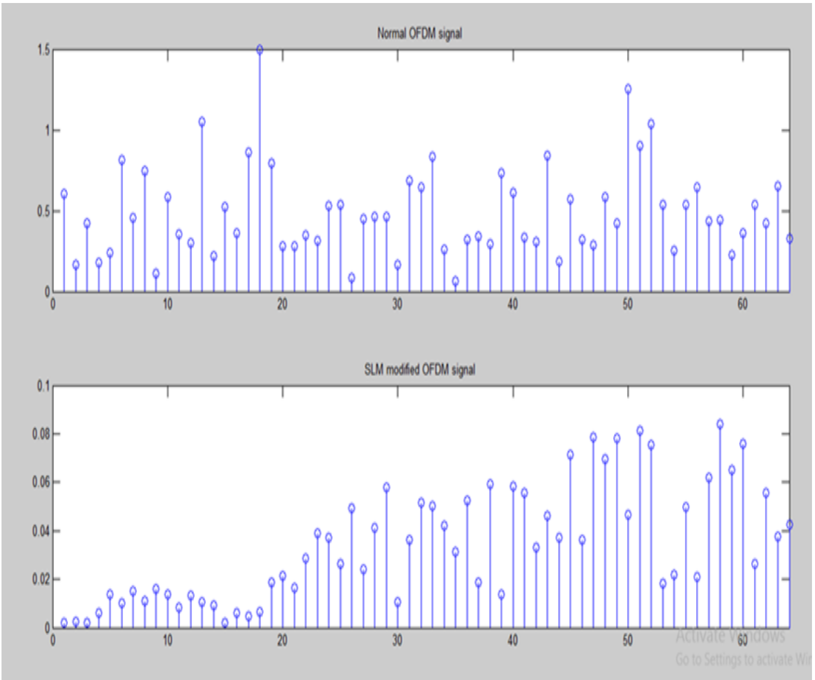

Figure 6 Orignal OFDM signal and SLM modified OFDM signal.

Figure 5 and figure 6 represent the amplitude plot for clipping and filtering method and SLM method. The amplitude plot is compared to the orignal OFDM signal plot to show the changes in the signal. As it is shown that the orignal OFDM signal having high peaks will result in high PAPR and after applying reduction techniques, the peaks are reduced that will improve the performance of our system.

System parameters that are considered during simulation is;

Channel bandwith:- 5MHz

Sub-carriers in OFDMA:-1024

Input block sie:-256

Modulation technique:-QPSK

SLM;

No. of phase sequences:-2,4,8,16,32 and 64

Complementary cumulative distribution function (CCDF)

"The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold." This function is used as the performance measure of different methods.

The cumulative distribution function (CDF) of a sample signal's amplitude is denoted by,

$$F(y) = 1 - \exp(Y)$$

For PAPR data block, here consider Nyquist rate is as Sampling rate, the CCDF is depicted as;

$$P\,(Papr > Y) = 1 - P(Papr \leq Y) = 1 - F(Y)\,N$$

$$P\,(Papr > Y) = 1 - (1 - \exp(-Y))N \qquad (6)$$

"Equation (6)" [1] is the mathematical representation of CCDF.

So we will measure the performance in CCDF manner.

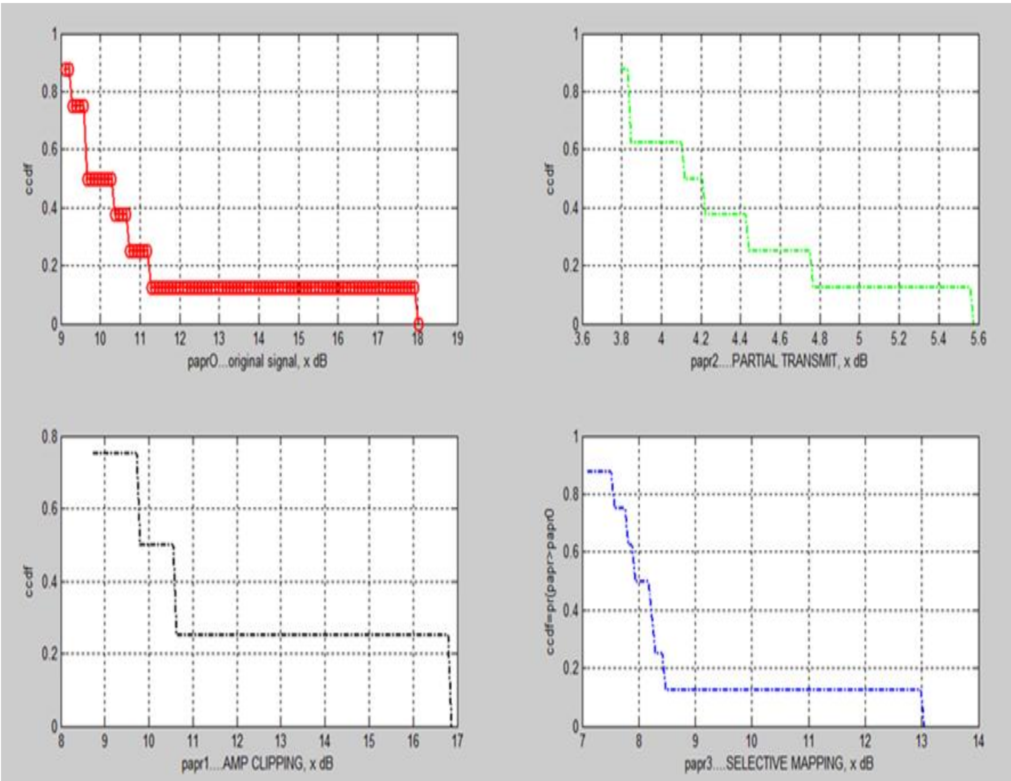

Figure 7 CCDF performance analyses for original signal, PTS, clipped signal and SLM signal.

Figure 7 shows the performance of all the three techniques. The best suited result is given by PTS method as the CCDF performance of PTS method is better in comparison to clipping and SLM method, but the complexity of the system will increase. We can also get the same result of PTS by SLM method by generating more number of sub blocks but that is a probabilistic approach and it will increase the complexity of the system. But the clipping and filtering method is best suited method for PAPR reduction and it is widely adapted because of its simple mechanism.

To understand the changes in different parameter by different approach we can consider a table;

TABLE 1 COMAPRISION OF DIFFERENT METHODS

Name of scheme	**Name of parameter**		
	Distortion less transmit ion	***Power increase of signal***	***Loss in bit error rate***
Clipping and filtering method	Not Acchived	Not increased	No BER loss
Selective mapping (SLM)	Acchived	Not increased	Yes BER loss
Partial transmit sequence	Acchived	Not increased	Yes BER loss
Coding method	Acchived	Not increased	Yes BER loss
Interleaving method	Acchived	Not increased	Yes BER loss
Tone reservation (TR)	Acchuved	Yes increased	Yes BER loss
Tone injection(TI)	Acchived	Yes increased	No BER loss

Table 1 provides the information about different techniques and the parameters affected by these methods.

4 Conclusion

OFDM is very advantageous approach for multicarrier communication. It has become widely adapted communication technology, because of its numerous advantages but it needs to focus on its disadvantage of high PAPR value. As mentioned in paper, there are numerous approach to reduce PAPR of system. Some of these techniques are analyzed in this paper. All the three techniques analyzed in present work, results to reduce PAPR. On the basis of CCDF performance, the best result is given by PTS approach but PTS method will improve the complexity of the system. There is no way to identify single reduction approach that will suit for every communication system. The choice of method depends on multiple parameters like data loss, BER performance, transmit power increment, computational complexity. These parameters need to be considered before choosing a method.

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