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Peak to Average Power Ratio PAPR Reduction Techniques in OFDM System

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Abstract- OFDM is a digital modulation technique that is widely used in wireless communications like WiMAX and 4G due to its high data rate transmission capabilities. It offers advantages such as high data rate, spectral efficiency, and interference immunity. However, a major drawback is the high Peak to Average Power Ratio (PAPR) of the received signal, caused by nonlinear components like power amplifiers that distort the signal. Various techniques have been proposed to reduce PAPR, including clipping and filtering, Selective Level Mapping (SLM), and Partial Transmit Sequences (PTS). Simulations conducted on MATLAB analyze PAPR reduction and compare the effectiveness of these techniques.

Keywords - OFDM, PAPR, Clipping and Filtering, Selective Mapping (SLM), Partial Transmit Sequence (PTS).

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a key technology used in wireless communications such as LTE, 5G, and WiMAX. OFDM technology is a special scheme of multicarrier transmission technique that includes all sub-channels orthogonal to each, that is, it has a wide bandwidth up to about 20MHz. The basic principle of OFDM technology is to split a high-speed data stream into several streams of lower rates that are sent alternately over many subcarriers. Thus, the subcarriers are made to contract independently with each other to avoid interferences between the subcarriers. On each subcarrier, data is converted from serial to parallel channel for synchronous transmission in different channels. The most important advantages of OFDM are high data transmission, reduced exposure to selective fading like multipath, and simplified channel equalization. Also, provides a high spectral efficiency as compared to other modulation sketches and spread spectrum. The OFDM signal spectrum is characterized by several subcarriers, each subcarrier carrying a bit of total data. These subcarriers are evenly spaced in the frequency domain to avoid interference, that is, they are orthogonal with each other. Figure 1 shows the spectrum of the OFDM signal.

In the previous figure, each carrier is represented mathematically by $\frac{\sin(x)}{x}$ pulse, where the carrier spacing is $\frac{1}{T_s}$, where T_s is symbol time of each subcarrier. The main disadvantage of OFDM technology is a high PAPR, which occurs due to nonlinear distortion for the transmitted signal. OFDM has numerous individual subcarriers that are spaced apart, leading to the possibility of high peak values in the amplitude signals. The high PAPR leads to increased complexity of A/D converters and D/A converters and also decreases the efficiency of the RF power amplifier [2- 4].

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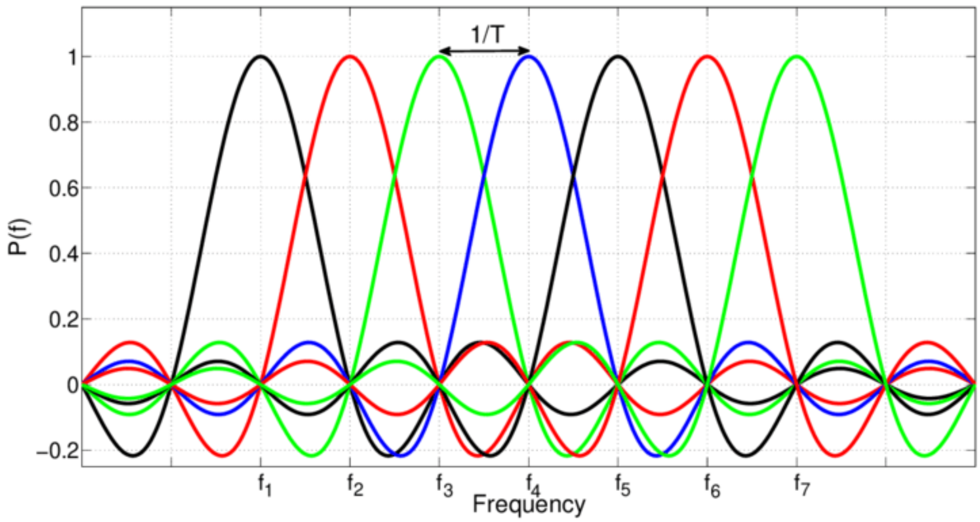

Figure 1 OFDM Spectrum [1]

II. THE MATHEMATICAL FORMULA OF THE OFDM SIGNAL

It's important to discuss the mathematical model definition of the OFDM signal because it allows us to know how to generate an OFDM signal in the transmitter and how to deal with it at the receiver, also in order to understand the impact of signal distortion caused by the transmission channel at the receiver, it is important to explore the tools available. OFDM technology relies on a multitude of orthogonal subcarriers in the frequency domain. This necessitates a corresponding number of modulations and filters at the transmitter, as well as demodulations and equalizations at the receiver. To streamline this process, digital modulations and demodulations such as Fourier Fast Transform (FFT) and Inverse FFT are recommended. [5].

Mathematically, each carrier can be written as a complex waveform:

$$S_c(t) = A_c(t)e^{j[\omega_c t + \emptyset_c(t)]} \tag{1}$$

where $S_c(t)$ is the carrier signal, $A_c(t)$ is the amplitude of the carrier signal and $\emptyset_c(t)$ is the phase of the carrier signal.

Since the OFDM signal consists of many carriers as shown in Figure 1 . Then $S_c(t)$ can be written as:

$$S_c(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_n(t)e^{j[\omega_c(t) + \emptyset_n(t)]} \tag{2}$$

where N is the number of subcarriers and $\emptyset_n = \emptyset_0 + n\Delta\emptyset$

This is for a continue signal. Every component of the signal over one symbol period can take fixed values of the variables like:

n$\emptyset n(t) \rightarrow \emptyset_n$

$An(t) \rightarrow A_n$

If we applied the sample on the signal by sampling frequency of $1/T$, then the resulting signal can be written as:

$$S_s(KT) = \frac{1}{N}\sum A_n\, e^{j[(\omega_0 + \omega\Delta n)KT + \emptyset_n]} \tag{3}$$

Where T is time interval between samples, and K is overlapping factor, if ω_0 = 0, then the signal will become:

$$S_s(KT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n\, e^{j[(\omega\Delta n)KT + \emptyset_n]} \tag{4}$$

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We can compare (4) with the general form of the Inverse Fast Fourier Transform (IFFT):

$$g(KT) = \frac{1}{T}\sum_{n=0}^{N-1} G\left(\frac{n}{NT}\right) e^{j[\frac{2\pi nk}{N}]} \quad (5)$$

Where $g(KT)$ is the signal in frequency domain. By comparing (4) and (5) we note that $A_n\, e^{j\emptyset_n}$ no more definition of the signal in frequency domain, and $S_s(KT)$ is the signal in time domain. So Eq (4) and (5) are equivalent if:

$$\Delta f = \frac{\Delta\omega}{2\pi} = \frac{1}{NT} \quad (6)$$

Figure 2 shows a simple block diagram of an OFDM system:

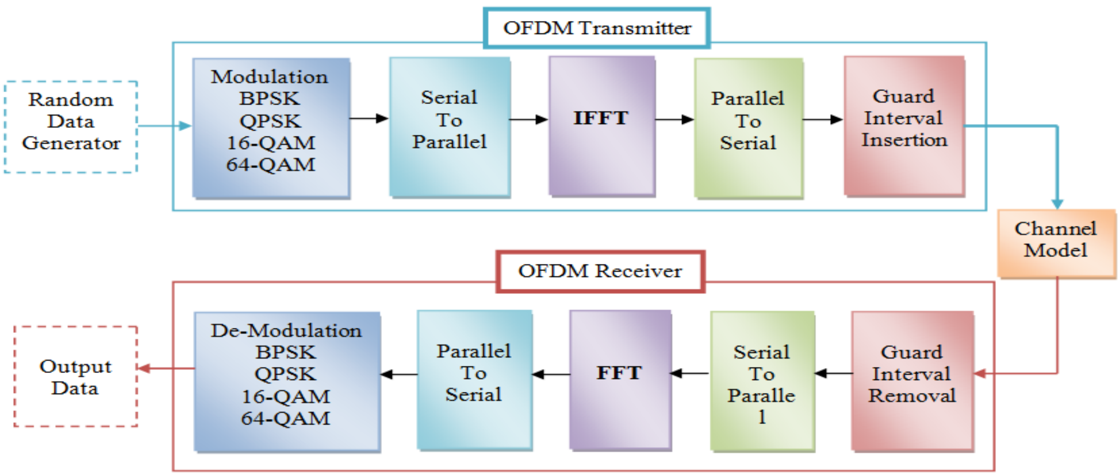

Figure 2 Block diagram of OFDM System [6]

III. PEAK TO AVERAGE POWER RATIO (PAPR)

The CS technique has been applied in various areas, such as imaging, radar, speech recognition, and data acquisition. In communications, compressive sensing is largely accepted for sparse channel estimation and its variants. With this in mind, compressive sensing promises to estimate the channel with much less pilot overhead or at higher accuracy with a limited number of pilots [16]. The channel estimation of the Massive MIMO System with an assisted System is formulated as a sparse signal recovery problem by exploiting the channel's angular-domain sparsity. In this paper, the popular compressed sensing (CS) algorithms, such as the orthogonal matching pursuit (OMP) techniques are applied to recover the channel at a much reduced number of measurements [20]. Also, the Double Structure-OMP (DS-OMP) based cascaded channel estimation scheme by integrating the double structured sparsity into the classical OMP is discussed and proposed [21].

One of the main disadvantages of OFDM technology is a high Peak Average Power rate (PAPR). This high value of PAPR is due to the large number of subcarriers in the OFDM system. For this reason, the peak value will be advanced than the average value, and this distorts the transmitted signal if the transmitter contains nonlinear factors similar as power amplifiers. These nonlinear components at transmitter will cause interferences for OFDM symbols in-band and out-of-band [7] [8].

PAPR of the OFDM signal in continuous time can be expressed as:

$$PAPR = \frac{P_{Peak}}{P_{Average}} = \frac{max|x(t)|^2}{E|x(t)|^2} \quad (7)$$

Where E is the expectation operator of the random signal, and PAPR at the discrete time signal is:

$$PAPR = \frac{max|x(n)|^2}{E|x(n)|^2} \quad (8)$$

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$X(n)$ is transmitted signal.

To analyze the PAPR in OFDM system, we use the Complementary Cumulative Distributive Function (CCDF) which describes the probability where PAPR exceeds certain threshold values.

$CCDF$= Probability (PAPR>P_0 , P_0 is the threshold value [9].

$CCDF = 1 - (1 - \exp(-P_0))^N$, where N is number of carriers.

To determine the percentage reduction in peak power, we use:

$$Effecincy = \left[\frac{(1 - PAPR_{dB})}{PAPR_{dB}}\right] \times 100 \quad (9)$$

IV. PAPR REDUCTION TECHNIQUES

Several methods have been suggested to mitigate the issues related to (PAPR).

A. Signal Scrambling Techniques

1. Block Coding
2. Selective Level Mapping (SLM)
3. Partial Transmit Sequence (PTS)

B. Signal Distortion Techniques

1. Amplitude Clapping and Filtering
2. Peak Windowing
3. Peak Power Suppression (PPS)
4. Peak Cancellation

This paper primarily focuses on three common techniques employed to reduce PAPR in (OFDM) systems, namely (SLM), Limiting and Filtering, and (PTS).

A. Selective Level Mapping (SLM)

In this approach, the input data sequence is multiplied by each phase sequence to generate an alternative input symbol sequence. The basic idea of SLM is based on the phase rotation sequence. In Figure 3, if we consider data block B(U) are multiple by U phases of length N.

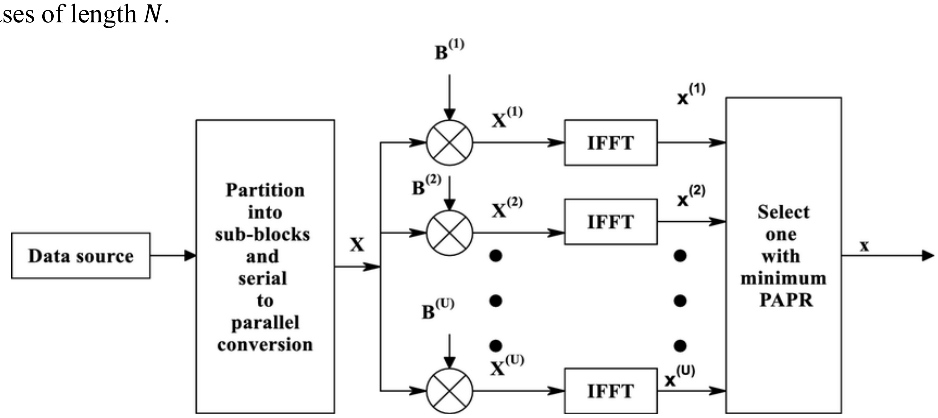

Figure 3 Block diagram of SLM Technique [10]

$$B(U) = [bu_0, bu_1, bu_2, bu_3, \dots \dots \dots . . bu_{N-1}]^T \quad (10)$$

then the result of multiplication will be U[th] phase sequences after multiplication is

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$$X(U) = \left[X_0, b_{u,0}, X_1, b_{u,1} \ldots \ldots \ldots \ldots \ldots \ldots \ldots X_{N-1} b_{u-1}\right]^T \quad (11)$$

where $u\ is\ 1,2,3 \ldots .U$. Among the modified data block $X(U), u = 1,2,3 \ldots ..U$, Only one with the lower PAPR is selected for sending. The information side must be sent at the specified phase sequence where the receiver will determine the source of the information. In this method, each symbol sequence $B(U)\ \ 1 \leq 1 \leq U$, is generated by multiplying the input data sequence by inverse phase matrix P^u

Where $1 \leq u \leq U$, U is the modified OFDM signal [11].

In this scheme the reduction of PAPR will be better if we increased number of phase sequence. Therefor the probability of PAPR can be written as:

$$(PAPR > P_0) = 1 - (1 - e^{-P_0})^N \quad (12)$$

N is the number of subcarriers and U is the phase sequence.

B.Amplitude Clipping and Filtering

Clipping is one of the simplest techniques used to reduce PAPR, which decreases the peak level of the transmit signal. The basic idea of this technique is to clip amplitude parts of signals that have a high peak outside the permissible area. However, an excessive clipping of the signal may lead to distortion of the original signal [12].

$$z(t) = x(t) + n(t) \quad (13)$$

Where $n(t)$ is noise level, $z(t)$ is the received signal and $x(t)\ = \ |x(t)|$ the magnitude

$$r_z(t) = \ |z(t)| \quad (14)$$

$$r_z(r_x) = \begin{cases} r_x & r_x \leq A \\ A & r_x > A \end{cases} \quad (15)$$

Where A: is the clipping level and r_x is the clipped magnitude.

Clipping and Filtering are effective techniques used to reduce (PAPR) and decreases the peak level of the transmit signal. Clipping is a simple method that involves reducing the amplitude of the signal, while filtering helps remove unwanted components from the wide spectrum. Although filtering can help reduce spectrum broadening and out-of-band radiation, it may also cause the clipped signal to experience peak re-growth. To effectively reduce PAPR, an iterative approach of clipping and filtering is necessary. Figure 3 shows the process of clipping and filtering [13].

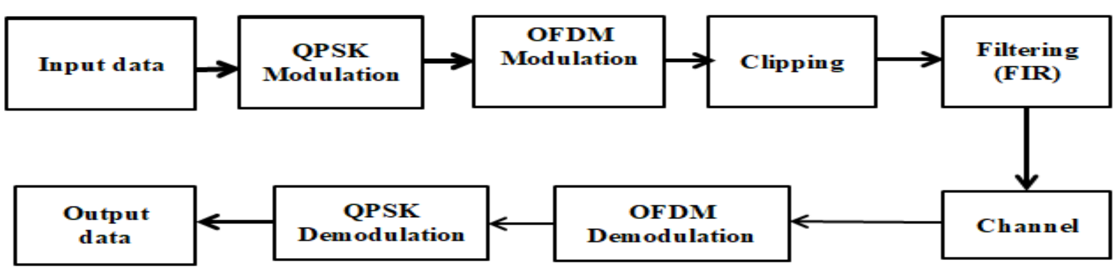

Figure 3 Process of Clipping and Filtering [14]

C. Partial Transmit Sequence (PTS)

This is the most effective technique for reducing PAPR. PTS algorithm refers to technology that brings improvements The signal is multi-carrier static. Basic idea the algorithm of PTS is to segment the OFDM sequence Divide the original sequence into multiple subsequences, and for each subsequence Each time, the subsequence is multiplied by a different weight whenever a best value is selected [15].

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In figure 4 shows the block diagram of conventional PTS. The principle of PTS can be explained as follows, first of all we define the symbol using vector data X, after thar we divide the vector into groups of M, denoted as $\{X_m$ where $m = 1, 2 \ldots M\}$. Then Then Group M summarizes as follows:

$$X'(b) = \sum_{m=1}^{M} b_m X_m \tag{16}$$

b_m is s the weighted coefficient, therefore $b_m = e^{j\emptyset m}$,where $\emptyset_m \epsilon [0,2\pi]$ can usually considered as useful information, later adopted by Inverse Discreet Fourier Transform (IDFT) on $X(b)$, so we can get $X'(b) = IDFT\{X(b)\}$. We can use instruction of IDFT for M separate as:

$$X'(b) = \sum_{m=1}^{M} b_m . IDFT\{X_m\} = X'(b) = \sum_{m=1}^{M} b_m X_m \tag{17}$$

The weighted coefficient is selected so that the PAPR can be reduced, which is written as:

$$[b_1, b_2, \ldots . b_m] = arg_{min}\{b_1, b_2, \ldots b_m\} \left(Max_{1 \le n \le N} \left| \sum_{m=1}^{M} b_m . X_m \right) \right.^2 \tag{18}$$

Argument (.)represents the sentence condition that defines the function that archives its smallest value [16].

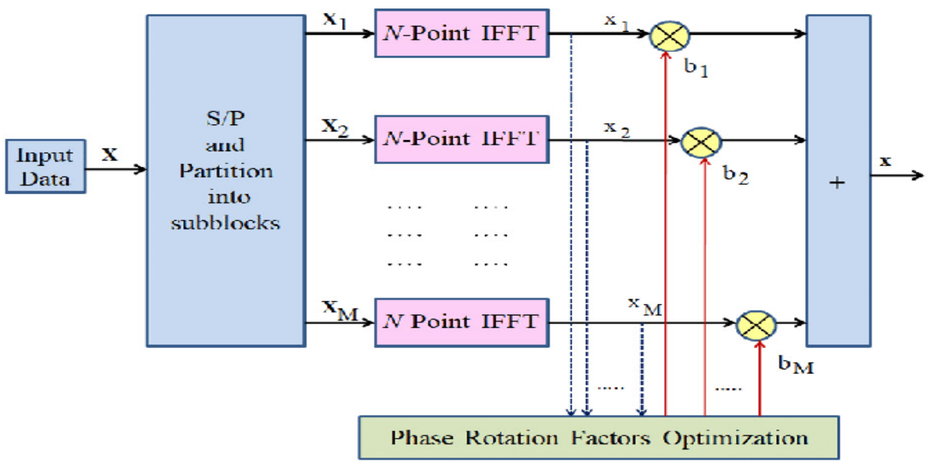

Figure 4 Block Diagram of PTS Technique [17]

V. Simulation and Results

In this part, we have chosen MATLAB's communication toolbox for conducting the paper simulation. The simulation is carried out using MATLAB version 7.14.0. The performance evaluation of three PAPR reduction techniques (SLM, Clipping and filtering, and PTS) is done and simulated. These three techniques are compared with each other. In table 1 Lists the parameters used for this simulation. In this simulation, we chose QPSK modulation for clipping and filtering to decrease PAPR, and also, we used the CCDF of the PAPR.

Parameters	Specifications
Number of transmitted Symbol	256
Modulation Type	QPSK
Number of Bits	16
SNR	20

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Table I: Parametres *Simulations*

Channel	AWGN
Clipping Factor (L)	1.2

Before applying the clipping and filtering for OFDM signal, we generate waveform of QPSK signal by adding odd and even sequences modulated waveforms as shown in Figure 5.

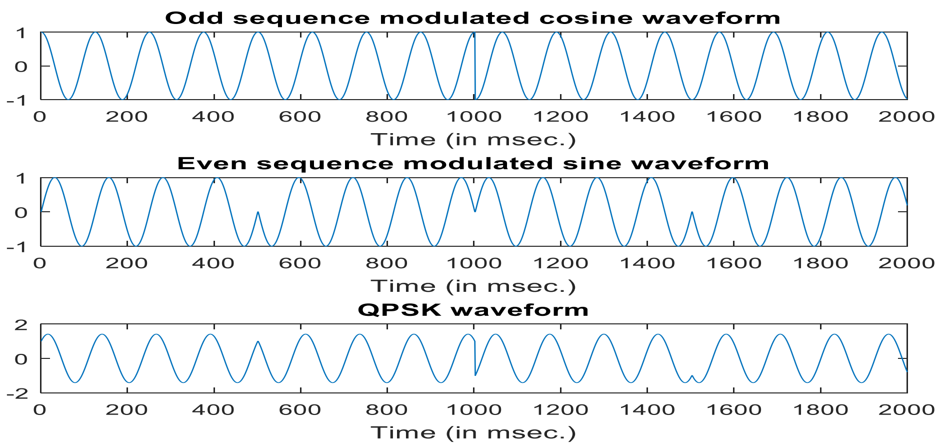

Figure 5 QPSK signal

In Figure 6, we applied clipping and filtering for the OFDM signal, before we applied clipping and filtering, we note the peak power of the original signal is 2, and after applying clipping the peak amplitude of the signal decreases to 1.5. After filtering the signal, the peak power level decreases to 1.2 along with an increase in the sampling number without any distortion.

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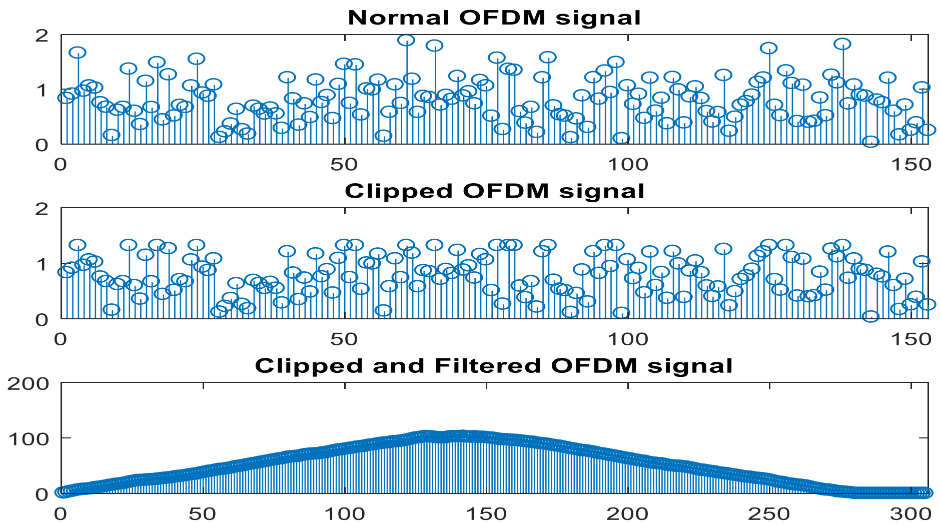

Figure 6 Clipping and Filtering Signal

In Figure 7, we apply the SLM technique for the OFDM signal, before applying the selective mapping we note the normal OFDM signal it has a very high amplitude peak value of approximately 1.5 but after applying the SLM the peak power decreases to 0.05 and hence low PAPR is experienced.

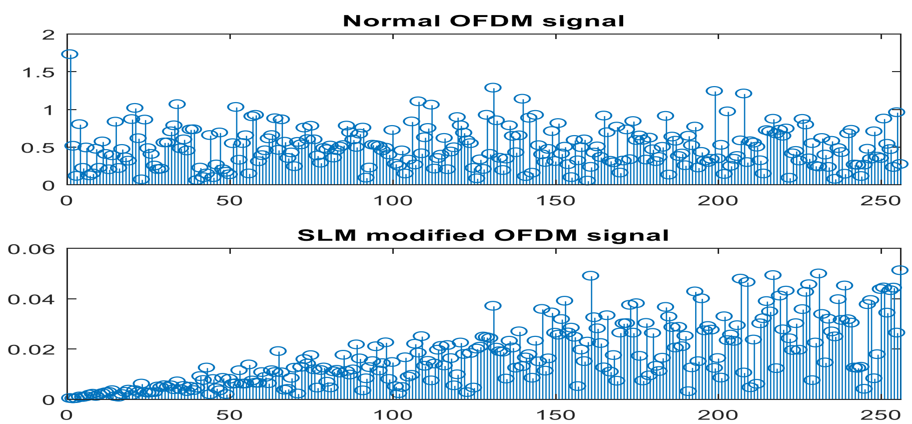

Figure 7 SLM Modified Signal

Table 2 shows the percentage of the reduction for these two techniques and compare them with each other.

Table 2: Comparisons between clipping &filtering and SLM.

Type	PAPR in dB	Efficiency in Percentages
Normal OFDM	22.4521	--------------------------
Clipping and Filtering	10.4420	54.4898
SLM	17.5066	20.2397

A. CCDF Comparing Clipping &Filtering, SLM and PTS

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Figure 8 shows the performance of all techniques to reduce PAPR. The best suitable result is provided by the PTS technique as the performance of the CCDF for the PTS technique is better compared to other techniques, but the complexity of the system increases. In the SLM method, if we increase the number of subcarriers, we will get the same result of the PTS method, but this will lead to more complexity of the system. Clipping and Filtering is the most appropriate technique to decrease PAPR.

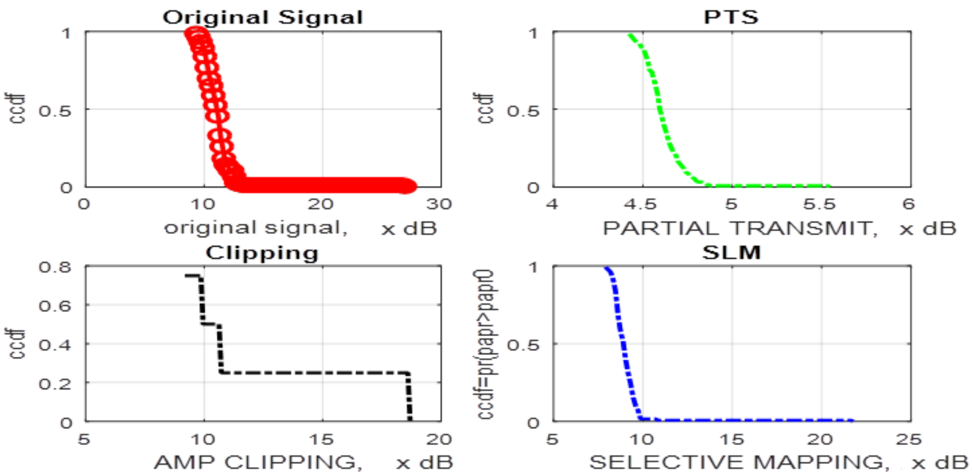

Figure 8 CCDF for Clipping, SLM and PTS methods

VI. Conclusion

In this study, we conducted simulations of methods employed to reduce PAPR in OFDM systems including Clipping & Filtering, Selected Mapping (SLM), and Partial Transmit Sequence (PTS). Upon evaluating the PAPR values across different scenarios, we observed that while the clipping and filtering technique effectively minimizes PAPR, it also introduces signal distortion due to amplitude reduction. SLM and PTS techniques are also studied to reduce PAPR. All these techniques have the potential to significantly reduce PAPR. PTS technique as the performance of the CCDF for the PTS technique is better compared to other techniques, but the complexity of the system will increase.

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