International Journal of Research in Science & Engineering
ISSN: 2394-8299
Vol: 03, No. 02, Feb-Mar 2023
http://journal.hmjournals.com/index.php/IJRISE
DOI: https://doi.org/10.55529/ijrise.32.33.45

Performance Analysis of PAPR minimization in OFDM System Using Clipping, SLM and PTS Techniques

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Received: 23 October 2022 **Accepted:** 09 January 2023 **Published:** 11 February 2023

Abstract: In wireless communications, Orthogonal Frequency Division Multiplexing (OFDM) is a method of modulating multicarrier signals to transmit high speed data. OFDM systems use multiple subcarriers to transmit the modulated symbols. There is a high peak to average power ratio (PAPR) in OFDM. PAPR can be reduced by using various methods. Different PAPR minimization techniques, like clipping, selective mapping (SLM) and partial transmit sequence (PTS) are presented in this project. This paper also focuses on Bit Error Rate (BER) and Signal to Noise Ratio (SNR) relative performance. A significant reduction in the PAPR and computational complexity can be seen from the results. The purpose of this study is to compare the results of an analysis recommended for PAPR reduction methods.

***Keywords:** OFDM, PAPR, Clipping, HPA, SLM, PTS.*

1. INTRODUCTION

A transmission technique called orthogonal frequency division multiplexing allows for the simultaneous transmission of data and information over a number of evenly spaced subcarrier frequencies. The Fourier transform is employed for data modulation and demodulation. For a variety of radio and wireless communication systems, including local area networks and digital audio and video transmission, the multicarrier data transformation method is presented[1]. Multiple carriers are modulated individually and independently in an OFDM system while retaining an orthogonal interface. In compared to single-carrier systems, high peak to average power results from increasing the number of subcarriers to a certain amount. As a result, linear, high dynamic range digital and analogue converters with power amplifier systems are needed[2].

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To improve the performance of communication networks, multicarrier modulation uses a number of orthogonal carriers to send data in concurrently. OFDM is immune to multipath fading, is unaffected by impulsive noise, and simplifies the hardware design of equalisers in order to minimise complexity[1,3]. Wireless communication systems are implemented utilising FFT and DWT methods. Several carriers share the spectrum while having multiple low bandwidth signals modulated into them using OFDM. OFDM distributes the available spectrum effectively to avoid interference, provided the channels are orthogonal and separated fairly. On orthogonal carriers, distinct subsets of information are modulated and seem to be stored. High spectrum efficiency and resistance to symbol interference and frequency-dependent fading are two key benefits of OFDM[6]. The high-power nonlinear amplifier in OFDM, on the other hand, results in significant PAPR and signal distortion (HPA). HPA's power efficiency is severely constrained to prevent nonlinear distortion; otherwise, high PAPR has a major impact on performance[5]. To lower the high PAPR, a number of methods have been devised. Better performance and faster data rates are two of OFDM's main advantages. Multiple carriers are employed to provide high data rates, and the usage of guard interval leads to performance enhancement, reducing ISI. In addition to these fundamental advantages, it also improves spectral efficiency, reduces multipath distortion, and many other things. With these advantages in mind, it has a pretty excellent market penetration. WLAN is one of the most valuable technologies, and IEEE 802.11a/g/n designs successfully employ OFDM[4].

Orthogonal Frequency Division Multiplexing (OFDM)

One of the Multicarrier transport technique called OFDM, it is used in high-speed communication systems. A single data stream is divided into many narrowband channels at various frequencies using the OFDM method of digital signal modulation to minimise interference and crosstalk[7]. The idea for OFDM technology initially emerged in the 1960s and 1970s. OFDM comes from Frequency Division Multiplexing(FDM). A single spectrum is split up into a number of smaller subcarriers using OFDM, and data is sent in parallel streams. As a consequence, symbol length is increased and the complexity of the equalisation, which has an equaliser for each subcarrier, is reduced. Subcarrier data rate is lower than the actual desired data rate. The frequency spectrum of the subcarriers in an OFDM multicarrier system is overlapped with the smallest possible frequency spacing, and orthogonality is obtained between the various subcarriers[8].

The serial to parallel (S/P) converter divides the input stream into parallel data streams. In order to be transferred via M low-rate data streams, the incoming data must be transformed from serial to parallel and then grouped into bits each to produce a complex number s. A subcarrier of the form $\Theta_m(t) = e^{j2\pi f_m t}$, where f_m is the frequency of the m^{th} subcarrier, is connected to each low-rate data stream. A baseband OFDM sign with M subcarriers is

$$x(t) = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} s_m \theta_m(t); 0 < t < L$$

where L is the length of the OFDM symbol and s_m is the m^{th} complex data symbol. The timing sequence of the streams is then created by passing that via an IFFT block[9-10]. The

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length of the OFDM symbol time sequences is increased by adding a cyclic prefix(CP). The CP is created by the cyclic expansion of the OFDM symbol over a period of time T and is used in the guard period between succeeding blocks:

$$x(t) = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} s_m \theta_m(t); -\mathrm{T} < t < LT$$

A discrete time linear convolution is transformed into a discrete time circular convolution via the CP. As a result, transmitted data may be represented as the circular convolution of the transmitted data block and the channel impulse response, which in the frequency domain corresponds to the point wise multiplication of FFT samples[10]. The received signal then becomes into

$$r(t) = x(t) * h(t) = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} H_m s_m \theta_m(t); 0 < t < LT$$

$$\text{where} \quad H_m = \int_0^T h(t) e^{j2\Pi f_m t} dt$$

Here, the m[th] subcarrier now contains a channel component called H_m, which is the Fourier transform of the signal h(t) at the frequency f_m. The resulting analogue signal is then converted to digital form and sent through the channel. After eliminating the CP at the receiver end, the signal is digitally reconstituted, and the FFT is obtained in the received streams. In the receiver, the OFDM symbol is sampled (t = nL and f_m = m/ML) and demodulated using an FFT. As a result, the data is received as,

$$r_m = H_m S_m; \ m = 0 \ to \ M - 1$$

Then, the parallel streams are combined into one stream that is identical to the one that was first delivered. With M parallel one-tap equalisers, the received real data may be recovered.

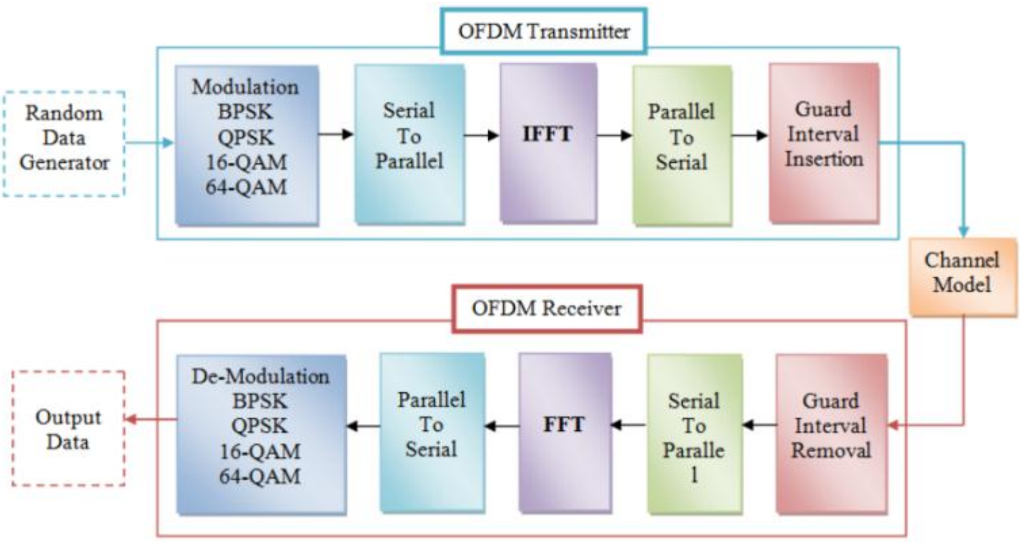

Figure 1. OFDM System

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Peak to Average Power Ratio (PAPR): Methods

The sum of independently modulated subcarriers creates an OFDM signal, which has a high instantaneous peak power and substantial envelope changes in the time domain. This signal is identified by its PAPR. The peak power of the OFDM signal climbs in proportion to the average power as the number of subcarriers rises, increasing the PAPR statistics[11]. In real-world communication circumstances, the high PAPR OFDM signals are a key challenge for the OFDM systems. Such a high PAPR imposes strict constraints on the transmitter side in terms of implementation costs and also causes the practical communication system's performance to degrade.

The deployment of OFDM systems for high-speed wireless communication networks has a significant difficulty in the form of high PAPR. This paper therefore intends to focus on investigating effective PAPR reduction strategies for the OFDM system as its main issue domain. This papers seeks to investigate and develop some unique PAPR reduction strategies for OFDM-based systems for the real world[14]. The ability of PAPR reduction, BER performance at the receiver, computational complexity, data rate loss, and increase in average power should all be taken into account while constructing a PAPR reduction technique. In this study, the system performance of the developed methods is assessed in terms of their capacity to reduce PAPR, degrade BER, and increase computing complexity. The peak instantaneous power to average power ratio of a continuous domain OFDM signal is stated mathematically as

$$PAPR_{[x(t)]} = \frac{|x(t)|^2}{P_p}$$

Here, Peak average power is $P_p = \frac{1}{T}\int_0^T |x(t)|^2 dt$

The probability that the PAPR of the OFDM signal with N subcarriers will occur with regard to a certain threshold value ρ is how the CCDF of the PAPR is stated,

$$CDF(\rho) = \Pr ob[PAPR \le \rho] = [1 - e^{-\rho}]^M$$
$$CCDF(\rho) = \Pr ob[PAPR > \rho]$$
$$= 1 - prob[PAPR \le \rho]$$
$$= 1 - [1 - e^{-\rho}]^M$$

Techniques for PAPR reduction are categorised into many methodologies. This research focused on the probabilistic (scrambling) and clipping techniques.

To lower the PAPR, the clipping approach uses clipping or nonlinear saturation around the peaks. Although it is easy to build, it could ruin the orthogonality of the subcarriers while also causing in-band and OoB interferences. This method makes use of clipping and filtering techniques.

In order to lower the possibility of a high PAPR, the probabilistic(scrambling) approach scrambles an input data block of OFDM symbols and transmits one of them with the lowest PAPR possible[16-17]. Although it is not affected by OoB power, the complexity and spectral efficiency both decline as the number of subcarriers rises. Additionally, it is unable to guarantee a PAPR below a particular threshold. This strategy makes use of PTS and SLM.

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Clipping and Filtering:

The clipping strategy, which restricts the maximum broadcast signal to a predetermined level, is the simplest PAPR reduction scheme. But it has the following shortcomings. Clipping results in in-band signal distortion, which lowers BER performance. As a result of clipping, neighbouring channels are subjected to OoB interference signals. When clipping is done with the Nyquist sampling rate in the discrete-time domain, it may impact high-frequency components of in-band signals (aliasing), even though the out-of-band signals created by clipping may be decreased by filtering[13]. However, the BER performance will be less compromised if clipping is carried out for the appropriately oversampled OFDM signals in the discrete-time domain before an LPF and the signal passes via a BPF. At the expense of peak regrowth, filtering the clipped signal can lower OoB radiation. The signal may be stronger than the clipping level allowed for the clipping operation following the filtering procedure.

Figure 2, depicts a block schematic of a clipping and filtering-based PAPR reduction technique. The shortened form of s[m], which is written as

$$s_c[m] = \begin{cases} -A; & s[m] \le -A \\ s[m]; & |s[m]| < A \\ A; & s[m] \ge A \end{cases}$$

$$s_c[m] = \begin{cases} s[m]; & if\ |s[m]| < A \\ \dfrac{s[m].A}{|s[m]|}; & otherwise \end{cases}$$

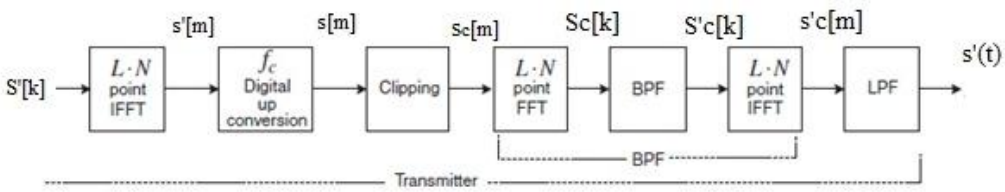

Figure 2. Clipping and Filtering

Selective Mapping:

Utilizing SLM, the PAPR in OFDM systems is decreased. Each phase sequence in the SLM technique is multiplied by its corresponding data sequence. Thus, identical data is transmitted in a particular order. Transferred signals have the least PAPR. A M phase sequence multiplies the first data block in the SLM method. M sequences with the same information are produced as a result. The sequence with the lowest PAPR has been chosen to be sent out of the M sequences that were constructed [13]. Additionally to the statistics, side information is given. A phase sequence with a low PAPR is indicated as side information. Selective mapping is a potential PAPR reduction technique for the OFDM system. Figure 3, illustrates the basic concept of selective mapping. The core principle of SLM is to generate U distinct forward sequences from a single data source while selecting the transmit signal with the lowest PAPR. The idea is based on the fact that multiplying the transmit data vectors X^m by a

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random phase would change the PAPR's properties after the IFFT since the transmit data vectors' sequence determines the PAPR [18].

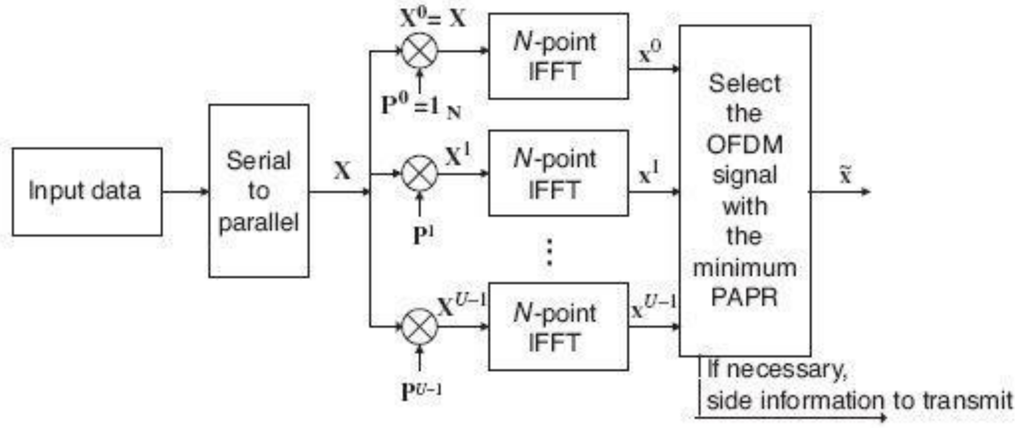

Figure 3. Selective Mapping [12]

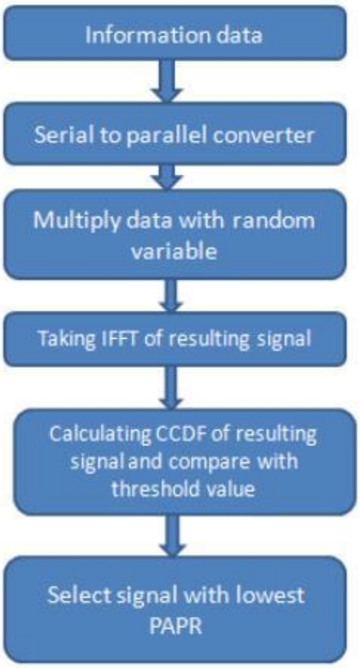

Figure 4. Flow Chart of SLM method [12]

Partial Transmit Sequence:
PTS is a possible PAPR reduction method that avoids introducing distortion into the existing methods. In PTS, the phase factors are utilized to rotate the OFDM signal's sub-blocks in order to provide a variety of candidate signals. The fundamental problem with PTS is the constrained PAPR minimization performance when the candidate signal counts are constant; also, the candidate signal portions of PTS may be considerably coupled. Another problem is the high degree of computational complexity. This paper recommends an improved PTS

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technique to reduce the correlation between the PTS candidate signals in order to improve PAPR minimization performance. Additionally, a threshold is included to control the computational complexity [13].

The PTS algorithm is one method for decreasing PAPR that requires less distortion. Every subsequence of the original OFDM sequence is multiplied by a different weight (various phase sequences) until the optimal value is found. This is the basic idea behind the PTS approach. It is common to employ the phase sequences +1, -1, +j, and -j. In the initial stages of PTS, the data input block is split up into smaller blocks, each of which represents a different portion of the actual information [19-20]. In order to create an output signal with a reduced PAPR, the sub-blocks are then transmitted to an IFFT, where they are multiplied by a matching phase value and merged.

The N-symbol input data are divided into V disjoint sub-blocks using the PTS method as follows:

$$X = [X_0, X_1, ..., X_{v-1}]^T$$

Here, X_i refers for the sub-blocks that are evenly spaced apart and organized in a sequential manner. The PTS technique, shown in figure 5, applies scrambling to each sub-block as opposed to the SLM approach's scrambling of all subcarriers. Each split sub-block is then multiplied by the appropriate complex phase factor $b^v = e^{j\phi v}; v = 1 \text{ to } V$, and the resulting product is then calculated using the IFFT.

$$x = IFFT\left[\sum_{v=1}^{V} b^v X^v\right]$$

$$x = \sum_{v=1}^{V} b^v . IFFT\left[X^v\right]$$

$$x = \sum_{v=1}^{V} b^v x^v$$

A PTS is shown here as x^v. It is considered on the phase vector to reduce the PAPR.

$$\left[\tilde{b}^1, ..., \tilde{b}^V\right] = \underset{\left[b^1, ..., b^V\right]}{\arg\min}\left[\max_{n=0,...,N-1}\left|\sum_{v=1}^{V} b^v x^v[n]\right|\right]$$

In view of this, the time-domain signal and its corresponding minimal PAPR vector may be expressed as,

$$\tilde{X} = \sum_{v=1}^{V} \tilde{b}^v X^v$$

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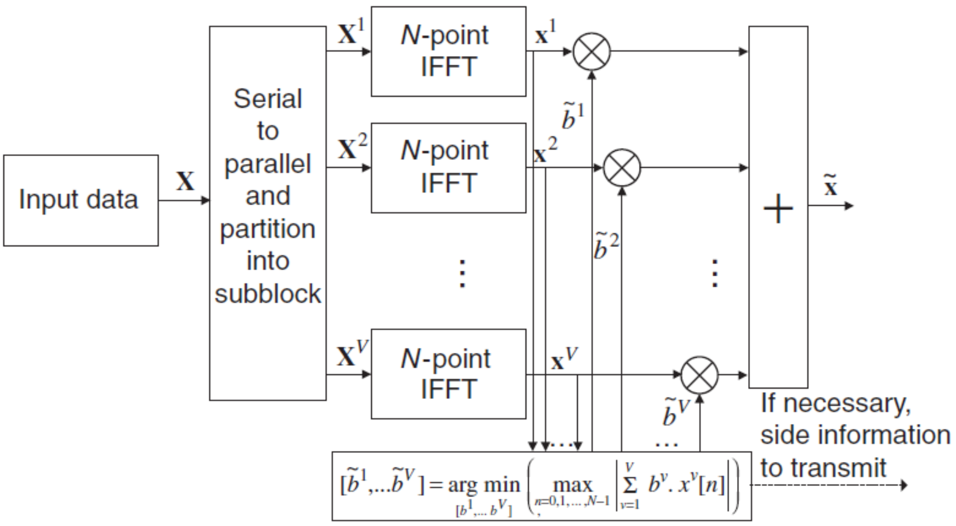

Figure 5. PAPR minimization for PTS [15]

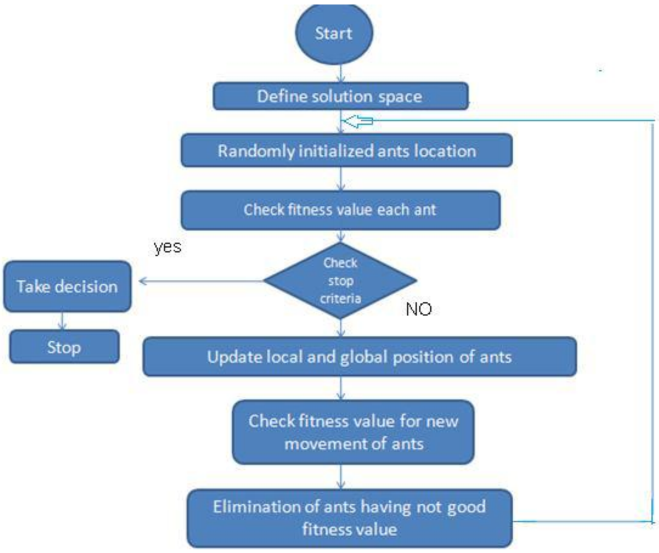

Figure 6. Flowchart of PTS using ACO [15]

Table 1. Comparison of Clipping, SLM & PTS

Parameter	**Clipping**	**SLM**	**PTS**
PAPR Minimization	Less	Better than Clipping	Better than Clipping, SLM
Computational Complexity	Low	High	High
Bandwidth Expansion	No	Yes	Yes
Power Increase	No	No	No
Loss of data rate	No	Yes	Yes
Distortion less	No	Yes	Yes

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2. RESULTS

Utilizing MATLAB, the implementation procedures have been carried out. Table 2 provides a summary of the parameters that were utilised for the study. The three PAPR reduction strategies have been simulated in this work. The choice of method is made based on requirements because each approach has strengths and drawbacks of its own. These three strategies were chosen to meet the fundamental requirements of the transmission system, namely complexity, system performance, and improved PAPR results.

Table 2. Simulation parameters

Parameter	**Values**
FFT Length	1024
No. of Carriers	16, 32, 64, 128
No. of bits/symbol	8
No. of symbols/carrier	8
SNR(dB)	100
Phase factors	1, -1, j, -j
oversampling factor	4
Channel	AWGN

As shown in Fig 7, a clipping and filtering approach are used to improve BER performance by minimising the impact of in-band and out-of-band aberrations. The PAPR of conventional OFDM is 20.0547, the PAPR of clipped OFDM is 10.132, and the Efficiency of Clipping and Filtering method is 47.213 when 64 symbols are broadcast, the alphabet size is 16, and the L factor is 1.3. The BER performance is decreased by the clipping and filtering procedure.

If SLM is not used, the peak signal amplitude in Figure 8 is close to 1. The PAPR of standard OFDM is 18.97dB when 64 symbols are transmitted and the size of the alphabet is 16. The peak level of the amplitude is substantially lower in the case of SLM (0.08), and a modified SLM OFDM signal has a PAPR of 17.08dB. The PAPR can be stated to be lower in the case of SLM.

Figure 9, depicts how well each of the three PAPR minimization strategies performed. The PTS approach produces the greatest results since it performs better on the CCDF than the clipping and SLM methods, however this will make the system more complicated. Using creating more subblocks, we can also get the same outcome as the PTS by the SLM technique, but this is a probabilistic method, and it will make the system more complex. But because of its straightforward methodology, the clipping and filtering approach is the one that is most suited for PAPR reduction.

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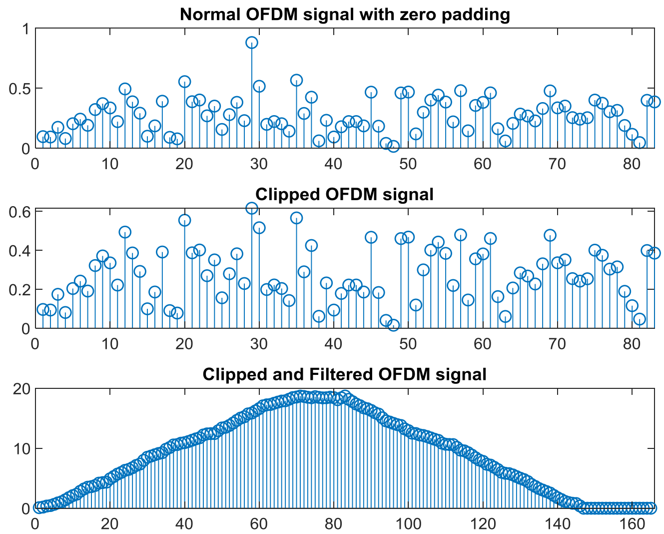

Figure 7. Clipping and filtering

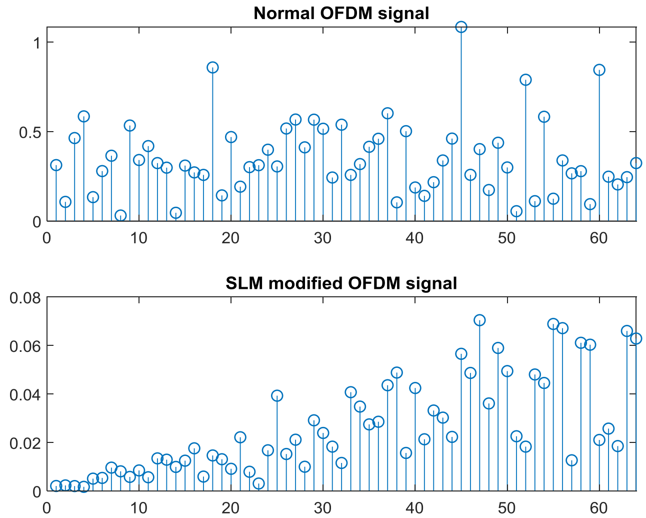

Figure 8. PAPR reduction using SLM Technique

Table 3. PAPR comparison of OFDM, Clipping, SLM and PTS methods

No. of Carriers	PAPR(dB)			
	OFDM	Clipping	SLM	PTS
16	15.1	15.31	10.12	5.31
32	18.21	16.6	13.1	5.40
64	21.32	17.68	16	5.48
128	24.09	17.92	18.2	5.57
256	27.18	18.7	21.7	5.6

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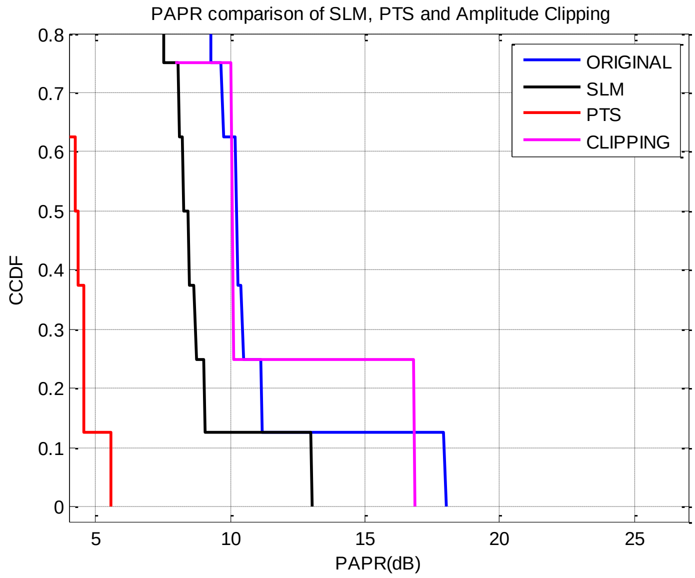
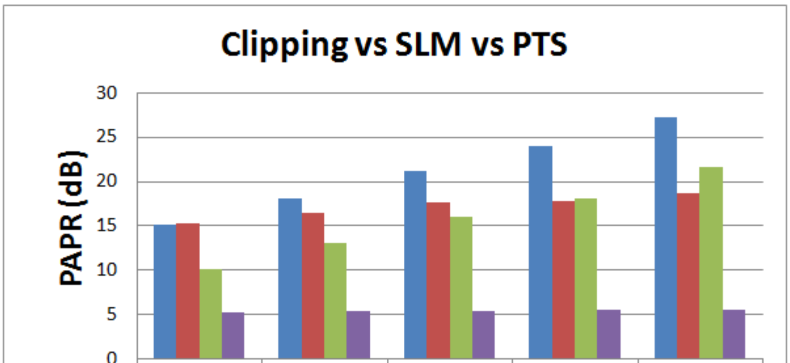


Figure 9. PAPR of SLM, PTS & Clipping



	16	32	64	128	256
OFDM	15.1	18.21	21.32	24.09	27.18
Clipping	15.31	16.6	17.68	17.92	18.7
SLM	10.12	13.1	16	18.2	21.7
PTS	5.31	5.4	5.48	5.57	5.6

Figure 10. PAPR comparison of OFDM, Clipping, SLM and PTS for various subcarriers

3. CONCLUSION

This work compares the clipping and filtering method, chosen mapping, and partial transmit sequence based on a thorough reading and analysis of related papers and literature in this field of study. The PAPR system performance and OoB power performance are optimised using the clipping and filtering method. The difficulty with OFDM is the high PAPR. This study examines many techniques for lowering PAPR in an OFDM system and compares their effectiveness in terms of PAPR and BER. For comparing and showing PAPR performance with a fixed CCDF, several phase settings and clipping ratios were utilised. The PTS approach works the best for PAPR. With a good range in performance, we can use this

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strategy to alleviate the PAPR problem. The complexity was higher than previous approaches. Any particular PAPR reduction method does not combine well with OFDM. Prior to selecting the best PAPR approach, it is important to take into account factors such data rate loss, higher transmission power, increased computational complexity, and increased BER. When comparing PAR reduction capabilities to redundancy, PTS and SLM are close to being at their best. They appear to be the most effective techniques currently available for lowering OFDM peak power without non-linear distortion.

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