PAPR REDUCTION TECHNIQUES AND THEIR BIT ERROR RATE MEASUREMENT AT OFDM IN LTE SYSTEM

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) has become an indispensable part of waveform generation in wideband digital communication since its first appearance in digital audio broadcasting (DAB)and it is indeed in use. These descriptions are simplified version of the detailed descriptions provided by 3gpp. It is a superior technology for the high-speed data rate of wire-line and wireless communication systems. The OFDM has many advantages over other techniques such as its high capacity and immunity against multipath fading channels. However ,one of the main drawbacks of the OFDM system is the high-peak-to-average power ratio (PAPR) that leads the system to produce in-band distortion and out-of-band radiation because of the non-linearity and reduces its efficiency is the distortion of the signal caused at the High Power Amplifier (HPA) of a transmitter . Therefore, it is highly desirable to reduce the PAPR of an OFDM signal. For this, numerous techniques have been proposed to overcome the PAPR problem such as i) selective mapping(SLM) ii) partial transmit sequence (PTS), iii) clipping, iv) clipping and filtering. In this paper, the PTS technique was analytically reviewed as one of the important methods to reduce the high PAPR problem. Simulations are used to analyze the efficiency of the techniques used which signifies OFDM to be providing much better PAPR reduction and a better Bit Error Rate (BER) . From simulation results clipping method shows good PAPR reduction with significant amount of BER degradation. Clipping and filtering method shows slight increase in PAPR with small degradation in BER performance than Clipping method and both methods are computationally less complex. PTS provides good PAPR reduction with high computational complexity.

KEYWORDS

LTE, OFDM, Peak-To-Average power Ratio (PAPR), Clipping and Filtering, PTS, SLM, BER.

1. INTRODUCTION

Long Term Evolution (LTE) is the next-generation 4G technology for both Global System for Mobile communication (GSM) and Code Division Multiple Access (CDMA) cellular carriers [1].Approved in 2008 .LTE was defined by the 3G Partnership Project in the 3GPP Reles- 8 specification. Much of 3GPP Release 8 focuses on adopting 4G mobile communication technologies, including an all-Internet Protocol (IP) flat networking architecture.

LTE provides seamless service and multimode devices for the customers. It decrease the traffic communications while sending data, also allows more users to use the same frequency in a cell, which resulting in increment of Mobile Broadband users. LTE also offers faster data rate transfer which in higher download and upload rate, When the rates is increase, it will also reduce the problem of lagging in internet connection. This system uses orthogonal frequency division multiplexing (OFDM) for waveform generation [2]. OFDM meets the LTE requirement for spectrum flexibility and enables cost-efficient solutions for very wide carriers with high peak rates.

Orthogonal Frequency Division Multiplexing is a Multicarrier transmission technique based on orthogonal carriers which have become one of the most cheering developments of modern broadband wireless networks and wire line digital communication systems because of its high speed data transmission, great spectral efficiency, high quality service, robustness to the selective fading problem and narrow band interference [3]. And tolerance to multipath delay spread. Moreover, the OFDM system exhibits high spectral power efficiency, smooth equalization, and flexibility for hardware implementation with utilizing the Fast Fourier Transform (FFT) technique [4,5][6]. Furthermore, the OFDM system is better than other multicarrier techniques because it has unique features such as efficient bandwidth utilization,[7],[8],[9] less vulnerability to echoes, and less non-linear distortion.

Although OFDM has many distinctive features, the high peak-to-average power ratio(PAPR) is considered as the main drawback in OFDM that causes the OFDM system suffer from in-band distortion and out-of-band radiation [10].This can be attributed to the non-linearity nature of the high power amplifier (HPA) in the transmitter. Also, the high PAPR value increases the complexity when using some devices such as analog to digital converter (ADC) and digital to analog converter (DAC). Hence, the OFDM system requires HPA with large input back-off power (IBO), and long word length to follow the high PAPR value [11]. These constraints undoubtedly represent relevant issues that caught the attention of many researchers. The provided solution is the reduction of PAPR. In addition, a number of techniques are found in the literature belonging to different categories such as clipping, clipping and filtering techniques, SLM &PTS[12]. Probably the easiest technique to combat PAPR in OFDM signal is by using clipping, clipping and filtering [13]. Other techniques are based on multiple signal representation techniques or probabilistic techniques such as selected mapping (SLM) technique [16].These methods act on the phase of the data sub-carriers in order to mitigate the PAPR . However, as clipping is a non-linear method, it may generate in-band (IB) distortion [14] or out-of-band (OOB) radiation [15], which degrades the BER, breaks the signal down or disturbs the adjacent channel. Nevertheless, such effects can be mitigated when filtering is used after clipping.. Conversely, SLM has disadvantaged because of multiple inverse fast Fourier transform (IFFT) blocks and the computational complexity, which is directly proportional to the size of the phase vector matrix required to gain the best PAPR performance[16].

On the other hand , Partial Transmit Sequence (PTS) has been the most promising one due to its good PAPR reduction capability without restriction on the number of subcarriers [17]. In PTS ,the data block which is divided into disjoint sets called subblocks and the subblocks are combined followed by multiplication of a phase vector. In PTS, design of the optimal transmit phase selection of the optimum phase vector from a set of known solutions is most challenging [18]. For that reason ,this paper highlights PTS technique is the best by using OFDM modulation .

Furthermore, in simulation the ordinary techniques are introduced and discussed in terms of PAPR and Bit error rate(BER). The simulation results express that PTS has the lowest PAPR. So,PTS method are the best methods in the frequency domain, the modulation stage, and the time domain, respectively[19] to reduce PAPR.

This paper is organized as follows. Section II describes the OFDM system and Section analyzes III.OFDM advantages & disadvantages, Section IV analyzes PEAK TO AVERAGE POWER

(PAPR). Section V. The numerical analysis for PAPR REDUCTION TECHNIQUES. RESULTS is discussed in Section VI. Lastly, the study conclusions are given in Section VII. In Section VIII the References are given.

2. OFDM SYSTEM

The downlink of LTE system is OFDM based and this is so for good reason. OFDM possesses a remarkable characteristic of being able to be adapted in a straightforward manner to operate in different channel bandwidths according to spectrum availability. Another advantage of OFDM is the low complexity in the design of the receiver.

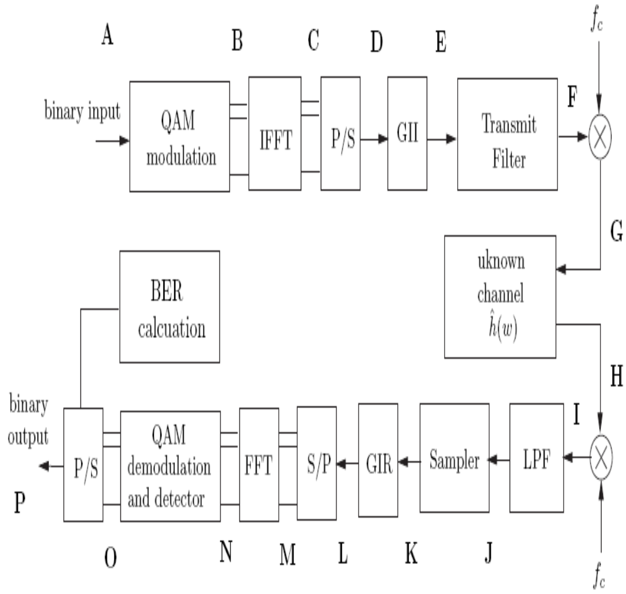

Figure 1. Block diagram of OFDM system.

The OFDM sequence is generated by summing all N modulated subcarriers when applying IFFT operation, with the consideration that; the subcarriers are allowed to be orthogonally one another. To understand the concept of OFDM, let $X = \{ Xk,\ k= 0; 1; : : : : : : ; N - 1\}$ is the complex representation of the input data block symbols after constellation mapping operation, where Xkrepresents the block data of k th subcarrier, and N is the number of subcarriers. Therefore, the complex baseband OFDM signal is defined as [20]

$x(t)=1\sqrt{N}\Sigma\ Xkej2\pi k\Delta ftN-1k=00\leq t\leq T$ ----------- (1)

where $ej2\pi\Delta ft$ is the twiddle factor of the k th subcarrier, T represents the total time of symbol, Δf is the frequency space between subcarriers, and $j= \sqrt{-1}$.The bandwidth of the symbol is $B = N.\ \Delta f$, and $\Delta f$is set as $1/T$ to ensure the orthogonally between the subcarriers of the symbol. Therefore,

the baseband OFDM signal can be written as

$x(t)=1\sqrt{N}\Sigma Xkej2\pi kt/T\ 0\leq t\leq TN-1k=0$ --------------(2)

The baseband OFDM signal is sampled by applying Nyquist rate ($t = T/N$). Therefore, the discrete OFDM signal in the time-domain can be expressed as,

$x(n)=1\sqrt{N}\Sigma Xkej2\pi kn/N$ $0\leq n\leq N-1N-1k=0$ --------------(3)

where n represents the discrete sampling index, whereas the discrete OFDM signal vector is written as

$x(n)=[x0,x1,x2,\ldots\ldots\ldots\ldots..\ xN-1]T$ ---------------- (4)

The original OFDM signal is, where the transmitted data is 35^2, IFFT_bin_length = 1024
carrier count = 20
bits per symbol = 3
symbols per carrier =3
SNR = 2

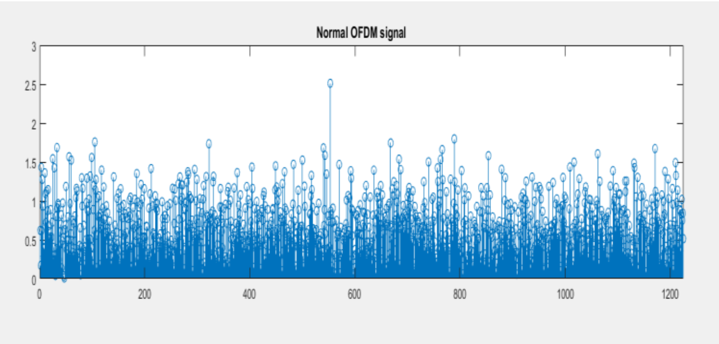

Figure 2. Original OFDM signal.

2.1. OFDM advantages & disadvantages

OFDM advantages

OFDM has been used in many high data rate wireless systems because of the many advantages it provides.[21]

• *Immunity to selective fading:* One of the main advantages of OFDM is that is more resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels.
• *Resilience to interference:* Interference appearing on a channel may be bandwidth limited and in this way will not affect all the sub-channels. This means that not all the data is lost.
• *Spectrum efficiency:* Using close-spaced overlapping sub-carriers, a significant OFDM advantage is that it makes efficient use of the available spectrum.
Resilient to ISI: Another advantage of OFDM is that it is very resilient to inter-symbol and inter-frame interference. This results from the low data rate on each of the sub-channels.
• *Resilient to narrow-band effects:* Using adequate channel coding and interleaving it is possible to recover symbols lost due to the frequency selectivity of the channel and narrow band interference. Not all the data is lost.
• *Simpler channel equalisation:* One of the issues with CDMA systems was the complexity of the channel equalisation which had to be applied across the whole channel. An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler.

OFDM disadvantages

Whilst OFDM has been widely used, there are still a few disadvantages to its use which need to be addressed when considering its use.

• *High peak to average power ratio:* An OFDM signal has a noise like amplitude variation and has a relatively high large dynamic range, or peak to average power ratio. This impacts the RF amplifier efficiency as the amplifiers need to be linear and accommodate the large amplitude variations and these factors mean the amplifier cannot operate with a high efficiency level.
• *Sensitive to carrier offset and drift:* Another disadvantage of OFDM is that is sensitive to carrier frequency offset and drift. Single carrier systems are less sensitive.

OFDM, orthogonal frequency division multiplexing has gained a significant presence in the wireless market place. The combination of high data capacity, high spectral efficiency, and its resilience to interference as a result of multi-path effects means that it is ideal for the high data applications that have become a major factor in today's communications scene.

3. PEAK TO AVERAGE POWER (PAPR)

High PAPR has been cited as one of the drawbacks of the OFDM modulation format. In RF systems, the major problem resides in the power amplifiers at the transmitter end, where the amplifier gain will saturate at high input power. One way to avoid the relatively “peaky” OFDM signal is to operate the power amplifier at the so-called heavy “back-off” regime where the signal power is much lower than the amplifier saturation power. Unfortunately, this requires an excess large saturation power for the power amplifier, which inevitably leads to low power efficiency. In the optical systems, the optical power amplifier (predominately erbium-doped amplifiers are currently in use) is ideally linear regardless of its input signal power due to its slow response time on the order of milliseconds. Nevertheless, PAPR still presents a challenge for optical fiber communication due to the optical fiber nonlinearity.[22]

Presence of large number of independently modulated sub-carriers in an OFDM system the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio. Coherent addition of N signals of same phase produces a peak which is N times the average signal. [23]

The high PAPR of OFDM means that if the signal is not to be distorted, many of the components in the transmitter and receiver must have a wide dynamic range. The output amplifier of the transmitter must be very linear over a wide range of signal levels. In wireless system, the expense and power consumption of these amplifiers are often the important design constraints . Moreover, the presence of a large number of subcarriers with varying amplitude results in high peak-to-average power ratio of the system (OFDM) and has implication in the efficiency of the radio frequency amplifier. This degrades the bit error rate and increases the cost of the system.[24]

To respond to the above mentioned problems, different methods and techniques were proposed by researchers such as coding techniques, tone injection, filtering, oversampling and multiple signal representation. The main purpose of this study is to propose techniques for the reduction of peak-to-average power ratio in OFDM system with emphasis on 4G network.[25] PAPR is defined as:

PAPR= $PMAXPAV$ ………………….(5)
Where, $Pmax$=Maximam power of the signal.

Pav=Average power of the signal.
The major disadvantages of a high PAPR are-
1. Increased complexity in the analog to digital and digital to analog converter.
2. Reduction is efficiency of RF amplifiers.

3.1. PAPR Reduction Techniques

The PAPR reduction includes many techniques, and it's dependent on various factors such as Spectral efficiency, Reduction Capacity, increasing of Transmit signal power, loss in data rate, Computation Complexity, increase in BER, Peak Reduction Carrier. The PAPR reduction techniques have been proposed in order to reduce the PAPR [26] as much as possible. Some of them are: „amplitude clipping‟, „clipping and filtering‟, „coding‟, „partial transmit sequence (PTS)‟, „selected mapping (SLM)‟ and „interleaving‟. These techniques achieve PAPR reduction at the expense of transmit signal power increase, bit error rate (BER) increase, data rate loss, computational complexity increase, and so on.

3.1.1. Clipping

Amplitude clipping is considered as the simplest technique which may be under taken for PAPR reduction in an OFDM system. A threshold value of the amplitude is set in this case to limit the peak envelope of the input signal.[27]Signal having values higher than this pre-determined value are clipped and the rest are allowed to pass through un-disturbed.

B(x)= $Xx\leq AAej\emptyset(x)$, $X>A$
where,
B(x) = the amplitude value after clipping.
x = the initial signal value.
A = the threshold set by the user for clipping the signal.
The clipping signal which is transmitted is:
Figure :Clipped OFDM signal.
where the transmitted data is 35^2, IFFT_bin_length = 1024
carrier count = 20
bits per symbol = 3
symbols per carrier =3
SNR = 2

Advantages:

A. This is a Simple approach.
B. Have high PAPR reduction capability.
C. No side information is required.
D. No change at receiver side.

Drawbacks:

A. Introduce more distortion.
B. Degrade BER performance.
C. Clipping causes in-band distortion which could effect the Bit Error Rate.
D. Out-of-band radiation caused by clipping leads to adjacent channels interference.

3.1.2. Clipping and Filtering

To reduce the out-of-band distortion, filtering operation is introduced. Clipping and filtering technique for PAPR reduction is used. The problem in this case is that due to amplitude clipping distortion is observed in the system which can be viewed as another source of noise. This distortion falls in both in – band and out – of – band. Filtering cannot be implemented to reduce the in – band distortion and an error performance degradation is observed here. On the other hand spectral efficiency is hampered by out – of – band radiation. Out – of – band radiation can be reduced by filtering after clipping but this may result in some peak re – growth. A repeated filtering and clipping operation can be implemented to solve this problem. The desired amplitude level is only achieved after several iteration of this process.[28]

The clipping & filtering signal which is transmitted is: where the transmitted data is 35^2,
IFFT_bin_length = 1024
carrier count = 20
bits per symbol = 3
symbols per carrier =3 ,
SNR = 2

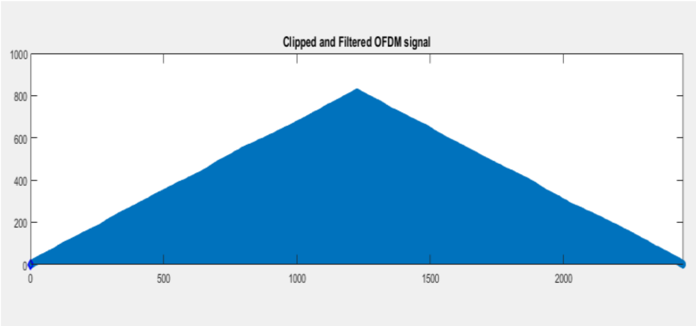

Figure 3. Clipped & Filtered OFDM signal.

3.1.3. Coding

In the coding technique, some code words are used to minimize or reduce the PAPR of the signal. It does not cause any distortion and no out-of-band radiation production, but it has a drawback of reduced bandwidth efficiency as the data rate is reduced. It also suffers from complexity issues, because it requires large memory for finding the best codes and to store large lookup tables, especially for a large number of subcarriers [29].

3.1.4. Selected Mapping

Selected Mapping (SLM) is an efficient method for peak to-average power ratio reduction in OFDM systems. In SLM technique the data sequence is multiplied with each phase sequences generated. And thus sequences which carry same information are formed. From these signals the signal with minimum P APR is selected for transmission .In SLM technique the original data block is multiplied with L phase sequences. Thus L sequences which carry the same information are generated. And from the generated L sequences the sequence with minimum P APR is selected for transmission. Along with the data the side information is also transmitted .[30] Side information indicates the phase sequence which minimized the PAPR.

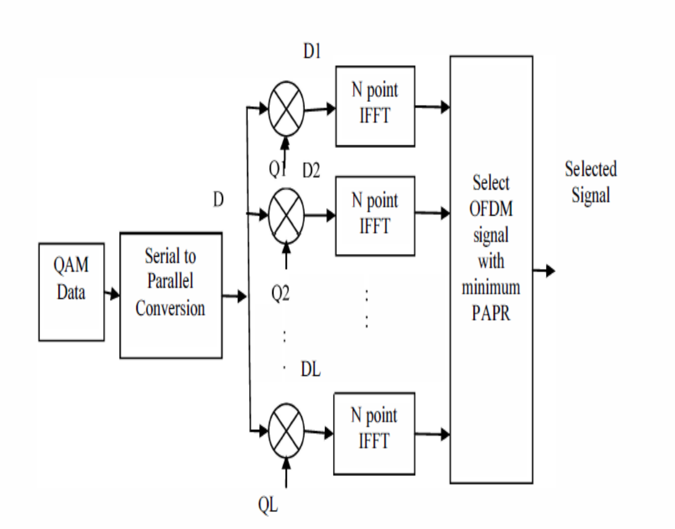

Figure 4. SLM Technique

The SLM signal which is transmitted is:

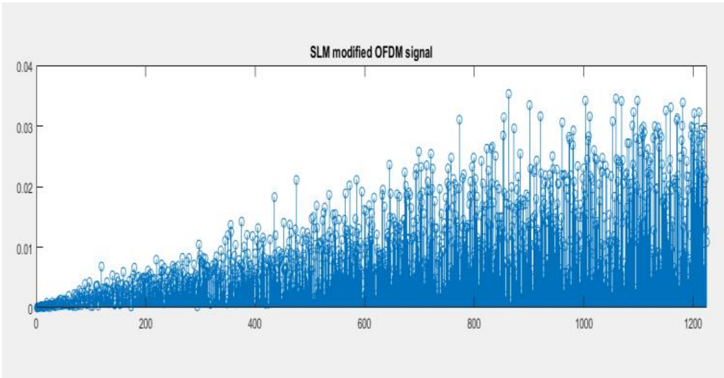

Figure 5. SLM modified signal.

3.1.5. Partial Transmit Sequence (PTS) Technique

It is the most efficient technique to reduce PAPR. In this technique, blocks of data is partitioned into no overlapping sub-blocks.This technique is the modified technique of selective mapping scheme. There are three partitioning methods for PTS scheme: adjacent, interleaved and pseudorandom. Pseudorandom partitioning provide better PAPR performance among all these schemes.[31]

Partial Transmit Sequences (PTS) generates a signal with a low PAPR through the addition of appropriately phase rotated signal parts. Below figure, shows the block diagram of the partial transmit sequence (PTS) technique. The signal to be transmitted is partitioned into disjoint sub-blocks *Xv*, of length which is represented by the vector as[32, 33] ……………………..(7)

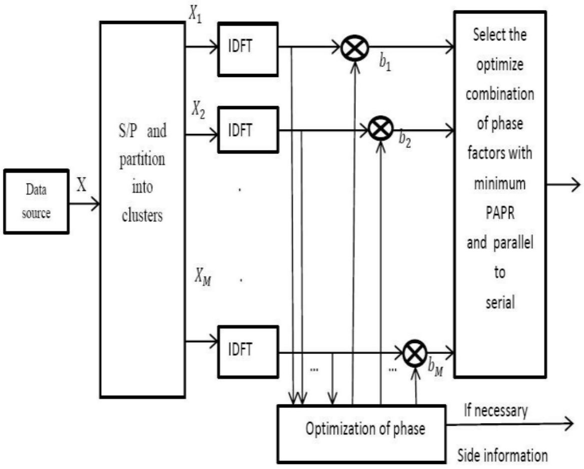

Figure 6. Block diagram of PTS scheme.

Where, is the number of subcarriers and V is the number of sub-blocks. Complex phase factors,

$$b^v = e^{j\varphi_v},\ \varphi_v \in [0, 2\pi) \text{ and } v = 1, 2, \dots, V \quad \dots\dots\dots\dots\dots 8$$

are introduced to combine the PTS's in the block diagram. All subcarriers positions which are occupied in another sub-block are set to zero. An IFFT is performed on each sub-block, which are then all summed together to create a possible transmit symbol as:[34]

$$\mathbf{x} = IFFT\{\textstyle\sum_{v=1}^{V} b^v\ X^v\} = \sum_{v=1}^{V} b^v\ IFFT[X^v] = \sum_{v=1}^{V} b^v\ \mathbf{x}^v \quad \dots\dots\dots\dots\dots\dots\dots\dots 9$$

The phase vector is chosen so that the PAPR can be minimized, which is shown as[34]: (

$$[\tilde{b}^1, \dots, \tilde{b}^V] = \underset{\{b^1, \dots, b^V\}}{arg\,min} \left[\underset{n = 0, 1, \dots, N_c - 1}{max} \left| \textstyle\sum_{v=1}^{V} b^v\, x^v(n) \right| \right] \quad \dots\dots\dots\dots\dots\dots 10$$

Then, the corresponding time-domain signal with the lowest PAPR vector can be expressed as:

$$\tilde{\mathbf{x}} = \textstyle\sum_{v=1}^{V} \tilde{b}^v\, \mathbf{x}_v \quad \dots\dots\dots\dots\dots\dots\dots 11$$

The receiver must have knowledge about the generation process of the transmitted OFDM to recover the received data for PTS approach. The phase factors must then be transmitted as side-information so the data can be decoded.[35] noted that the number of angles should be kept low to keep the side information to a minimum. If each phase rotation is chosen from a set of admissible angles, then the required number of bits for side information is bits per OFDM symbol. The computational complexity of PTS method depends on the number of phase rotation factors allowed. The selection of the phase factors is limited to set of elements number to reduce the search complexity[36]. The sets of phase factors should be searched to find the optimum set of phase vectors. Furthermore, the search complexity increases exponentially with the number of sub-blocks and also depends on the sub-block partitioning.

The concept of the PTS technique is to partition the input data symbols into the disjoint subsets and these subsets are rotated with different rotation factors. After that, the modified partitioned subsets are combined again to generate set of the candidate signals named partial transmit sequences (pts). Finally, one of candidate sequence which has the minimum PAPR value is chosen for transmission [37]. In the PTS technique, the number of the inverse fast Fourier transform (IFFT) blocks is the same as the number of subsets. The PTS technique can achieve better PAPR reduction performance than the other probabilistic techniques such as selective mapping (SLM) and interleaving techniques [38]. However, the PTS technique holds a high computational complexity when finding the optimum rotation factor and needs to send side information (SI) as index information in order to recover the original data at the receiver side [39]. On the other hand, PTS is regarded as a distortionless method [40] because it relies on the scrambling signal technique to reduce the PAPR value. Hence, PTS considers a probabilistic method to reduce the PAPR of the OFDM signal. Therefore, the PTS method does not suffer from the bit error rate (BER) degradation or the power signal distortion.[41]

4. RESULTS

SIMULATION 1

AIM: To find the Bit Error Rate (BER) of an OFDM System and plot it against Signal – to – Noise Ratio (SNR).

Where the transmitted data is 35^2, IFFT_bin_length = 1024

carrier count = 30
bits per symbol = 5
symbols per carrier =3
SNR = 2
Length Of OFDM Data = 20.

RESULT:

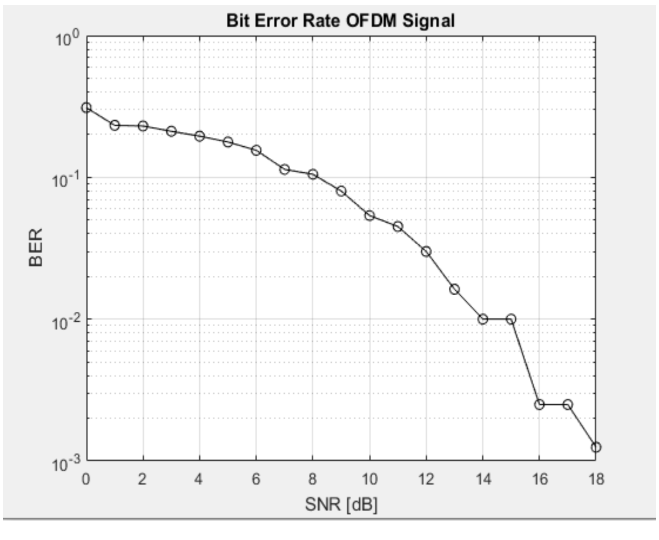

Figure 7. Bit error rate of OFDM signal.

SIMULATION 2

AIM: To calculate the BER of an OFDM Signal after *Amplitude Clipping* .
Where the transmitted data is 35^2, IFFT_bin_length = 1024, carrier count = 30
bits per symbol = 5 ,symbols per carrier =3 ,SNR = 2 Length Of OFDM Data = 20.

RESULT:

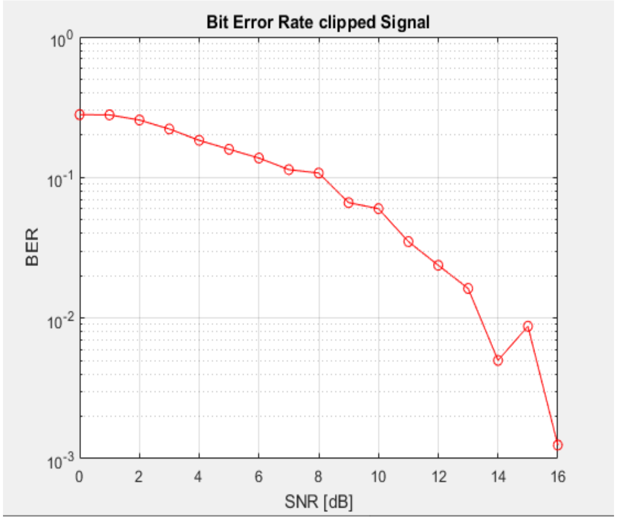

Figure 8. Bit error rate of clipped OFDM signal.

SIMULATION 3

AIM: To calculate the BER of an OFDM Signal after *Clipping &filtering.*

Where the transmitted data is 35^2, IFFT_bin_length = 1024
carrier count = 30 ,bits per symbol = 5 ,symbols per carrier =3 ,SNR = 2 ,Length Of OFDM Data = 20.

RESULT:

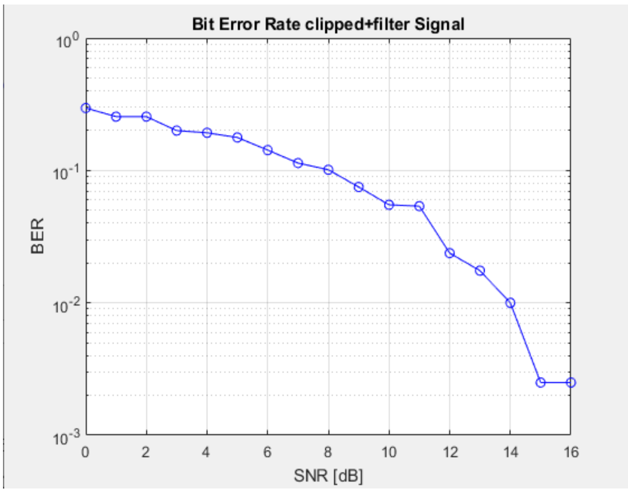

Figure 9. Bit error rate of clipped & filtered OFDM signal.

SIMULATION 4

AIM: To calculate the BER of SLM modified Signal.
Where the transmitted data is 35^2, IFFT_bin_length = 1024

carrier count = 30
bits per symbol = 5
symbols per carrier =3
SNR = 2
Length Of OFDM Data = 20.

RESULT:

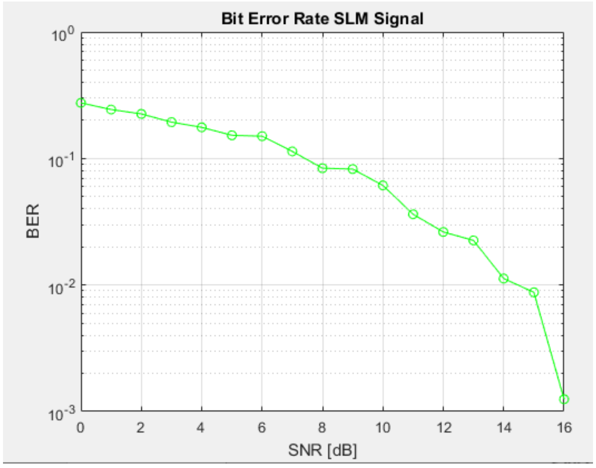

Figure 10. Bit error rate of SLM modified signal.

SIMULATION 5

AIM: To calculate the BER of Partial Transmission Siquences(PTS) Signal.
Where the transmitted data is 35^2, IFFT_bin_length = 1024
carrier count = 30
bits per symbol = 5

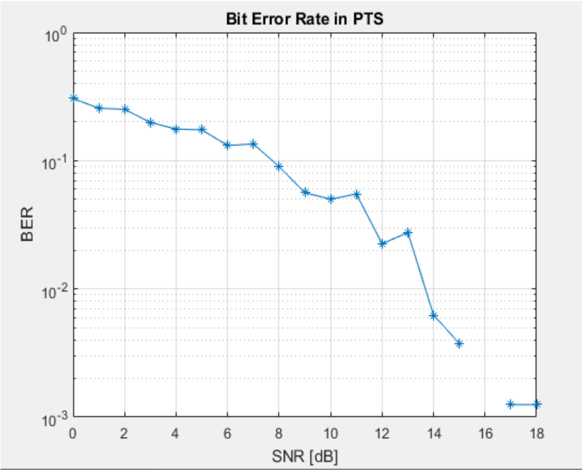

Figure11. Bit error rate of PTS signal.

SIMULATION 6

AIM: To compare the performances of original OFDM signal ,Clipped signal ,Clipped & filtered signal, Selected Mapping and Partial Transmit Sequence Techniques.
Where the transmitted data is 35^2, IFFT_bin_length = 1024
carrier count = 30
bits per symbol = 5
symbols per carrier =3
SNR = 2
Length Of OFDM Data = 20.

RESULT:

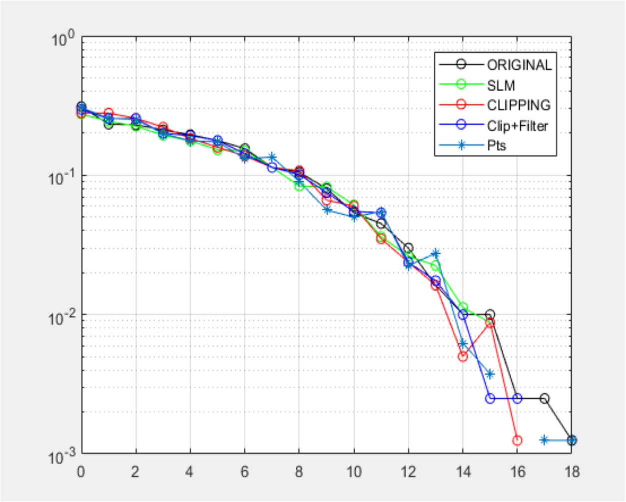

Figure 12. Comparing Bit error rate of all techniques.

SIMULATION 7

AIM: To calculate the PAPR of all techniques & give the figure which can determine the best technique to reduce PAPR.
Where,
PAPR of normal OFDM = 26.3723.
PAPR of clipped OFDM =21.8031
PAPR of clipped+filter OFDM = 19.2972
PAPR of SLM modified OFDM = 11.0091
PAPR of PTS OFDM = 9.135.
RESULT:

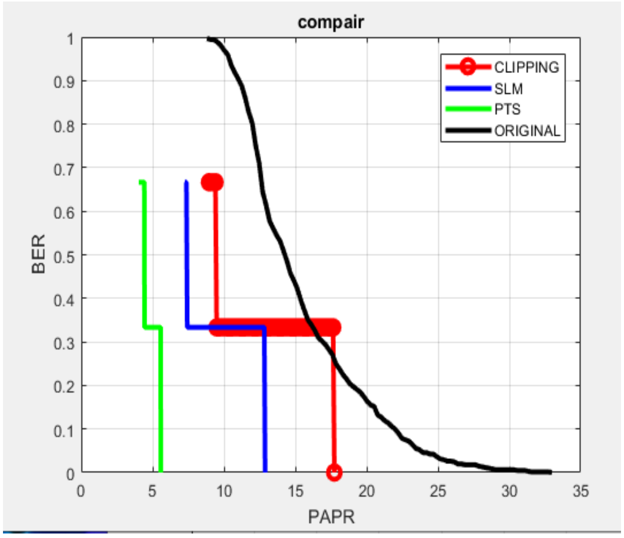

Figure 13. Comparison of PAPR

5. Conclusion

OFDM is a very attractive technique for multicarrier transmission and has become one of the standard choices for high – speed data transmission over a communication channel. It has various advantages; but also has one major drawback: it has a very high PAPR. In this project, the different properties of an OFDM System are analyzed and the advantages and disadvantages of this system are understood. The bit – error – rate is also plotted against the signal – to – noise ratio to understand the performance of the OFDM system.

We have also aimed at investigating some of the techniques which are in common use to reduce the high PAPR of the system. Among the three techniques that we took up for study, we found out that Amplitude Clipping and Filtering results in Data Loss, whereas, Selected Mapping (SLM) and Partial Transmit Sequence (PTS) do not affect the data. From the comparison curve of the SLM and PTS techniques, we could infer that PTS is more effective in PAPR reduction.

However, no specific PAPR reduction technique is the best solution for the OFDM system. Various parameters like loss in data rate, transmit signal power increase, BER increase, computational complexity increase should be taken into consideration before choosing the appropriate PAPR technique.

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