"Applying Statistical Algorithm to Reduce PAPR in OFDM Signal"

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Submitted by

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DECLARATION

I Rubina, student of B.Tech-M.Tech (ECE) under Department of ECE of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-II report is based on my own intensive work and is genuine.

This report does not, to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university or any other university without proper citation.

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CERTIFICATE

This is to certify that **Rubina Rajbongshi,** bearing **Registration no.11006707**, have completed Dissertation-II report titled, **"Applying Statistical Algorithm to Reduce PAPR in OFDM Signal"** under my guidance and supervision. To the best of my knowledge, the present work is the result of her original investigation, effort and study. No part of the work has ever been submitted for any other degree at any University.The report is fit for submission and the partial fulfillment of the conditions for the award of B.Tech-M.Tech (Integrated)-ECE.

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ABSTRACT

The work initiated is basically about the PAPR reductions made in an OFDM system. The signal that comes across various distortions also undergoes an increase in bit error rate and increase in peak to average power value. The main concern is about reducing the peak to average power value and maintaining an error free system compatible to use with less complexities. In this work, I have presented a hybrid technique to reduce the value of PAPR in an OFDM system. The typical algorithms used to accomplish this objective are PTS, Clipping and Companding technique, while avoiding their disadvantages. PTS, which falls in the statistical category, displays its effects in reducing the PAPR value by applying in each blocks of the signal. The signal is now compressed using μ-LAW Companding technique which avoids the occurrences of interferences. An effect of a high power amplifier in addition to clipping and the elimination of noise are highlighted. The PAPR of each of these sections are presented using waveforms and compared. According to simulation results, it is then observed that the proposed hybrid technique has much better performance in reducing the PAPR than individual performance of each technique.

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List of Abbreviations

OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
BER	Bit Error Rate
DFT	Discrete Fourier Transform
IDFT	Inverse Discrete Fourier Transform
CP	Cyclic Prefix
TDMA	Time Division Multiplexing Access
FDMA	Frequency Division Multiplexing Access
PSK	Phase Shift Keying
SLM	Selective Level Mapping
PTS	Partial Transmit Sequence

Chapter 1: Introduction

Wireless communications have been around a century and have found developments the entire round. Modulation being the fundamental to all wireless communication is the process of impressing the data with respect to the characteristics of high frequency carrier.[1] With initiation in digital modulations availability of spectrum has also been limited making the scenario critical than it has ever been. The main goal today is to transmit data as much as possible with least and efficient usage of the spectrum. [1] Multiple techniques have been developed considering proper use of resources and parameters that effects transmission. Digital band pass modulations have been broadly categorized into two halves which are: [1]

- **Single carrier modulation:**

  In single carrier modulation, the data is transmitted using a single radio frequency (RF) carrier wave.

- **Multi carrier modulation:**

  In multi carrier modulation, the data is transmitted by simultaneously modulation with multiple radio frequencies (RF) carrier wave.

Here the study is mainly concerned with a particular type of modulation Orthogonal Frequency Division Multiplexing (OFDM) which falls under the multi carrier modulation category. OFDM has gain popularity in number of applications in wireless networks. It also has a strong contribution in the fourth generation of cellular mobile communication. [2] In a particular communication system, the digital data is encoded on a multiple subcarrier where the several sub streams on the multiple subcarriers are orthogonal to each other. Symbols that are to be transmitted through this very system are obtained using number of methods like coding, interleaving and several others at the transmitted side. These symbols are then passed through the serial to parallel converter to obtain OFDM symbols. Few adjustments are also made considering time duration and frequency spacing in order to achieve the orthogonality. Therefore, OFDM transmits data in by modulating a set of orthogonal sub carriers and the set of data is in parallel. [2] OFDM is preferable because it admits relatively easy solutions to the challenges faced in single carrier modulation techniques on a wireless channel. Removal of ISI is considered to be the primary advantage over single carrier modulation technique. There has been a dramatic increase in interest in this particular modulation method in recent years. The developments have grown widely in transmission side as well as in detection whether it is coherent or direct detection and in an experimental level, the net transmission rate grew at a factor of 10 per year. [2]

A very desirable factor in most application is high data rate. However, with increase in data rate, the symbol duration reduces giving rise to inter symbol interference (ISI) caused by the dispersive fading of wireless channels and needing of more effective equalization methods. In OFDM, the entire channel is divided into many narrow band sub channels in which the data is transmitted in parallel and do not undergo ISI due to long symbol duration which is why OFDM is chosen for many standards and it has become an important technique for high data rate transmissions through wireless channels.[2]

When a signal is divided into several parts, each part is used by different user which is known as multiple accesses. With an extension of the term we can also define OFDM as a Hybrid Multiple Access which means the combination of techniques like TDMA and FDMA for GSM. Similarly OFDM is a combination of the techniques like spread spectrum techniques, multiplexing and modulation where each signal generated are used by different users. The OFDM technique can be further be extended by merging with CDMA popularly known as OFDM-CDMA.

With the vast spreading of this technique, it has also been found sensitive to frequency offset and phase noise, OFDM also undergoes a large peak to average power ratio, which is one of the major disadvantage to this technique. It tends to reduce the power efficiency to the radio frequency (RF) amplifier. Many existing techniques including OFDM, we can remark that it will provide solutions to many problems in wireless communications. Robustness against frequency-selective fading and compatibility with systems are the attractive features for high data rate transmissions. OFDM scheme has matured well through various research and developments for high data rate transmissions. [2]

This report reflects some brief introduction and theoretical background on the transmission and reception of an OFDM signal. We will review the entire process step by step. The history of OFDM and its developments are discussed in short. The major problem that is mentioned above is also explained in detail and the techniques used yet to overcome the problem of PAPR. This is followed by expanded discussion of few specific research and developments and methods to which can bring further modifications to these. Several considerations are made to achieve the required results and modified outcomes. This would also involve elimination of effects like ISI and ICI and reduction of PAPR with efficient use of spectrum available.

1.1 Historical Perspective of OFDM

OFDM has contributions in both wired and wireless communications in today's era. The history starts with telegraph which was started in 1870s where frequency division multiplexing was used to carry information through various channels. The extended version which is the OFDM was proposed by Chang to overlap multiple channels within a particular bandwidth eliminating interference considering certain characteristics. Robert W. Chang published his work on synthesis of band limited orthogonal signals for multi channel data transmission in 1960. He also secured a patent for his work in the year 1970. He presented new schemes fin his work for multiple channels by eliminating the effect of ICI and ISI.

The basic concept behind OFDM is to divide the frequency selective channel into number of parallel sub channels and produce orthogonality between the sub channels to eliminate interferences. This is achieved using Fourier transforms and it also enables to establish individual channel transmission rates equal to the channel bandwidth which is half the ideal Nyquist rate. But because they are synchronized, they also have 50 per cent probability to overlap.

In 1967, Saltzberg gave the performance of the parallel data transmission systems, where he concluded that in building these systems one should concentrate on reducing crosstalk between the channels than working on individual channels. The orthogonality between the channels is preserved using QAM technique. AN/GSC, an early application introduced was a data rate modem for high frequency radio. PSK was used in 34 parallel channels. Orthogonal frequency assignment was used with spacing of 82 Hz which provided a guard time between the adjacent channels. After such developments, many researchers worked in this particular area and adopted the standards. Even though OFDM started a long time ago but the major developments started in the late 1990s. In the late 2000s, the advantage of OFDM in an optical channel was introduced. Two broad areas were disclosed which are direct detection optical OFDM for simple realization and low cost and CO-OFDM for high spectral efficiency and receiver sensitivity. The first real time optical OFDM was demonstrated in 2009. [2]

The following table shows few major developments in radio frequency domain:

1.2 Fundamentals of OFDM

The basic and fundamental concepts about OFDM are discussed. It is well known that OFDM is a special case of multi carrier transmission and its implementation is also shown further. It also explains various block of OFDM. The generation and transmission part is stressed upon. The key distinction is the feature orthogonality which is also highlighted.

1.2.1 Orthogonality

One of the major parts of an OFDM transmission is to maintain the orthogonality without which its advantage is reduced. When the number of sub carriers are increased the modulation, synchronization and demodulation produces a complex circuit and leads to additional cost and impractical analog implementation of Fourier transforms using oscillators at desired frequencies. The orthogonality was tough to maintain due to oscillator drift and this led to occurrence of ICI. The maintenance of orthogonality is necessary as it allows high spectral efficiency. This particular feature cannot be preserved but it can be improved by using guard intervals in the form of cyclic prefixes and forward error correction techniques. The equipment in OFDM systems is also linear and therefore it can eliminate other phase alterations. [3] The reason why the transmitted signal can still be separated is so called orthogonality relation, giving the method its name. By implementing IFFT, we choose the spacing between the sub carriers in such a way that at the frequency where we evaluate the received signal, all the other signals are zero.

Few specifications must be true in order to maintain the orthogonality, which are as follows:

- Proper synchronization must be maintained between the transmitter and the receiver.
- They must assume the same modulating frequency and the time scale for transmission and reception.
- To use a fine high quality of transmitter and a receiver.
- Multipath channel must be avoided. [3]

1.2.2 IFFT and FFT

In an OFDM system, the data points are first modulated or are mapped into symbols. This entire procedure takes place in a frequency domain, but since we need to generate a signal and transmit it through the channel, we require this signal to convert it into time domain. This is why we use IFFT (Inverse Fast Fourier Transform) to convert it into time domain. IFFT is an algorithm used to compute IDFT. It is a linear transformation and allows the rapid transformations to take place in the system. The performance of the input signal using IFFT reduces the hardware complexity of the system. The result of the system remains exactly the same as the IDFT, it only makes the formulation faster than usual.

It is also categorized further into two types which are DIF (Decimation in Frequency) and DIT (Decimation in Time). IFFT here is performed in the transmitter side before transmitting the signal through the channel. The reverse function of this is performed in the receiver side, which is known as FFT (Fast Fourier Transform). It is an algorithm which gives exactly the same result as DFT in a faster manner. It transforms the time domain signal into frequency domain again such that the signal can go all the reverse procedures at the receiver side. The signal at the receiver side has to be demodulated and so it is required to obtain the signal in frequency domain from time domain. This is carried out by performing FFT.

1.2.3 Cyclic Extension

An OFDM signal is a type which undergoes multi carrier modulation which rises a constraint that is to be maintained. The name itself defines the feature of orthogonality that it to be maintained throughout the procedure. So to acquire this feature, an additional band is required between the sub carriers which are known as a guard interval or a cyclic extension. This prevents the occurrence of ICI as well as maintains the orthogonality between the carriers. The carriers are spaced such that it doesn’t lead to ICI while transmitting it through the channel. There are ways of placing the guard interval which are zero power method and null guards. The cyclic extensions are again removed in the receiver side to obtain the original signal. After removal of this band we find that there is no effect of the channel in the receiver side. So, we can see that cyclic extensions play an important role in the protection of the signal and preventing unwanted distortions.

1.2.4 Coding and Interleaving

Coding is one of the methods which are performed in the generation of the OFDM signal. It can be seen in the block diagram that coding is performed in the initial stages of the system for forward error correction. The basic motive is to protect the signal by adding redundant bits of stream to the signal such that if any of the bits are disturbed, we can still obtain the original signal. Several occurrences takes place which leads to attenuation of the signal. The signal can go through multipath fading which can cause phenomena like reflection and scattering. To avoid this, we need to perform coding such that we can obtain an undisturbed signal at the receiver side. Coding techniques which can be used in the system are LDPC codes, Hamming Codes, Convolutional codes etc. Each one of these has its own benefits and limitations which is why we consider several parameters to select the coding technique to implement in the system.

Coding is again followed by another method typically known as interleaving. Interleaving is the procedure used to arrange the coded bits in the form such that we can still obtain the original signal after occurrence of any kind if error. The bits are repeated in a particular form which are further arranged and transmitted through the channel. Deinterleaving is performed in the receiver side which again arranges the coded signal in the original form and helps us to obtain a signal without loss even after attenuation.

1.2.5 Symbol Mapping

The information signal fed into the system in mapped using modulation techniques which plays an important role in the transmission of the signal. An OFDM signal consists of multiple numbers of sub carriers, each of which contains the modulated symbols. Different types of modulation can be used to map the bits into symbols like PSK (phase shift keying) and QAM (quadrature amplitude modulation). One of these is explained in the following section.

Phase shift keying (PSK):

It is a digital modulation technique which conveys data by changing the phase of the carrier. With respect to the change in the carrier, we note a variable change in the information signal which is known as the PSK. The information signal here is in the digital form and with the change in the information bit, we note a change in the phase of the modulated wave also. PSK uses a finite number of phases in which each phase is assigned a unique pattern of binary digits and they encode an equal number of bits. The demodulator used in this particular technique is specifically designed for the symbol set and it determines the phase of the symbol and maps it back to a symbol. This requires the receiver the ability to compare the received phase to a reference signal. Such a system is known as coherent demodulator. This way we obtain the original signal in the form of bits or the information bit stream after performing demodulation.

Other modulations also fall into this category based on the number of information bits. If the information is only single bit, then we use BPSK, if it contains two bits, then we use QPSK. With increase in the bits the type of modulation scheme can also be changed accordingly. Modulations like QAM are also used with variable value of M. It depends upon the system and the requirement that which type of modulation will be more suitable to map the bits into symbols. [3]

1.2.6 Transmission and Reception of OFDM

Various methods and processes are combined to form the complete system like coding, IDFT, modulation in the transmitter side and DFT, decoding, demodulation in the receiver side. Also the step of adding and eventually removing a guard interval that is the cyclic prefix is also there. The fundamental concepts of OFDM used for its transmission and reception can be well understood by the following block diagram. It is the most basic diagram needed to be understood for going to the next step of OFDM study.

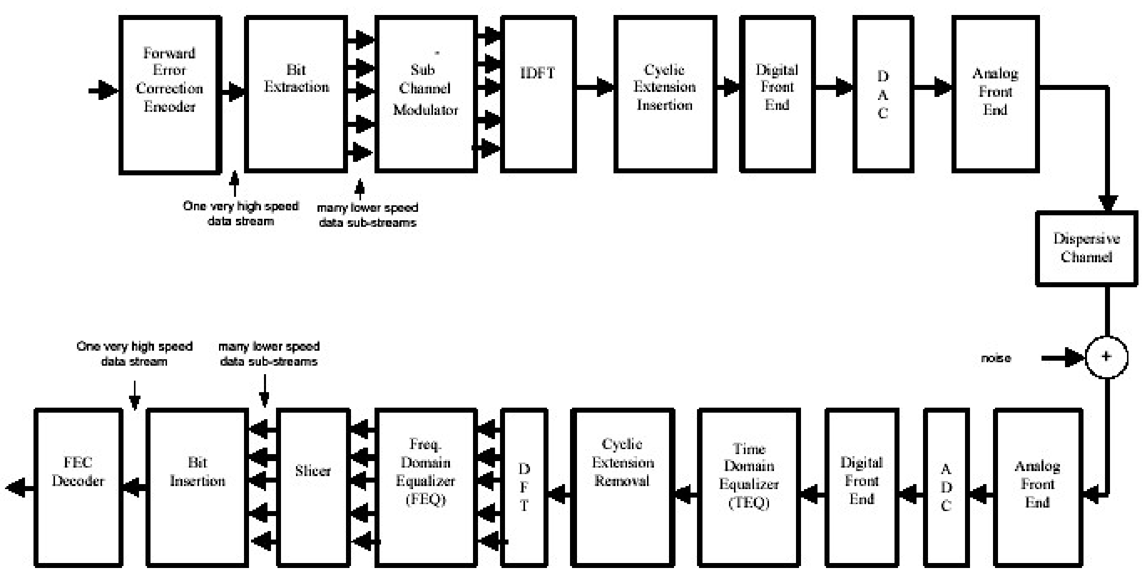

Fig no. 1.1 Transmission using OFDM [2]

1.2.7 Design of the OFDM signal

The main goal of this research is to develop one such system which can be used practically in different applications. So we need to consider few hardware related considerations which are often neglected in theoretical studies. The elements which have great impacts on the transmission process as well as on the signal are mentioned here.

1. The nature of the mobile channel is usually considered to be time dispersive. So the transmission scheme must be generated in such a way that it is able to cope with any kind of channel.
2. Bandwidth is one such parameter which needs consideration. It should be used in a limited manner as well as efficiently. Minimum usage of the bandwidth and minimum interferences should be considered.
3. The system also requires oversampling as the bandwidth used is minimized as compared to the practical one which is term of sampling property.
4. Up and down converter are used for phased jitters and frequency offset. [3]

1.2.8 PAPR

It stands for Peak-to-Average Power Ratio. It is attained by division of the peak amplitude square by square of the RMS value. It occurs due to involvement of noise which takes the peak to a higher value as compared to the average power of the signal. This is one of the major drawbacks in OFDM systems which are required to be reduced by using several techniques. Unfortunately, this requires an excess large saturation power for the power amplifier, which inevitably leads to low power efficiency. High peak-to-average power ratio (PAPR) has been cited as one of the major drawbacks of OFDM modulation scheme. In the RF systems, at the transmitter end of the power amplifiers one of the major problems resides, i.e., the amplifier gain will saturate at high input power. One of the ways 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. But 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 (predominantly an Erbium-doped amplifier) is ideally linear regardless of its input signal power due to its slow response time in the order of millisecond. Nevertheless, due to the nonlinearity in the optical fiber the PAPR still poses a challenge for optical fiber communications. The expression for calculating PAPR is given as:

$$\text{PAPR}=10log_{10}\frac{\max|\mathrm{X_k}|^2}{E[|X_k|^2]} \qquad (1)$$

Where

E[ ] is the expected value operation. [4]

X_k is the OFDM signal

k is the number of symbols

Chapter 2: Terminology

1. **OFDM-**

   OFDM stands for Orthogonal Frequency Division Multiplexing. It is a way of digital modulation in which a high data rate modulating stream is divided and placed onto many slowly modulated narrowband close-spaced subcarriers. It is less susceptible to frequency selective fading.

2. **IFFT and FFT-**

   FFT stands for Fast Fourier Transform. It is a method to calculate the Discrete Fourier Transform (DFT) using fast algorithm. It transforms the signal from time domain to frequency domain.

   IFFT stands for Inverse Fast Fourier Transform. It is a method similar to FFT but is used to calculate Inverse Discrete Fourier Transform (IDFT). It transforms the signal from frequency domain to time domain.

3. **Orthogonality-**

   Orthogonality in general means perpendicular to each other. In context to OFDM, the subcarrier frequencies are chosen in such a way that they are always orthogonal. Since OFDM is a multi carrier system and spacing between the sub carriers is required to avoid interferences, so these sub carriers are orthogonally spaced such that there is no chance of overlapping or any kind of interferences between them.

4. **Cyclic Prefixes-**

   It is used in OFDM to act as a buffer region so as to protect the signal from ISI (Inter Symbol Interference) which enables in a reliable operation. The CP is introduced in a manner so that each OFDM symbol is headed by a copy of the ending part of the very same symbol. Cyclic prefixes are used as guard intervals between the carriers to avoid interferences between them.

5. **Modulation-**

It is the process of superimposing a low frequency information signal on a high frequency carrier signal so that the information signal with low energy can travel much longer distance and the data loss is minimized. In an OFDM system, modulation is carried out to map the bits in the form of symbols. Modulation types used in such systems can be BPSK, M-PSK and M-QAM as per the system's requirement.

6. **PAPR-**

It stands for Peak-to-Average Power Ratio. It is attained by division of the peak amplitude square by square of the RMS value. It occurs due to involvement of noise which takes the peak to a higher value as compared to the average power of the signal. This is one of the major drawbacks in OFDM systems which are required to be reduced by using several techniques.

7. **CCDF-**

CCDF stands for Complementary Cumulative Distribution Function. This functional curve are used for studying signal performance on the basis of power level and also tells us that how frequently a random variable is above the average or a particular level.

8. **Clipping-**

It is one of the techniques used to reduce the PAPR of an OFDM signal. The clipping method is used to clip of high power signals for which we need to mention a particular threshold. The peaks beyond this threshold are clipped off and rests are transmitted further.

9. **PTS-**

PTS stands for Partial Transmit Sequence. It is a methodology used for reducing PAPR value in OFDM systems. In this method, the sequences are divided into sub blocks and these individual sequences are phase rotated by multiplying an optimum phase factor. PAPR of each blocks are calculated and the sequence with minimum PAPR is transmitted for further procedure.

10. Companding-

It is the process of compressing a signal before transmission and then expanding (decompression) the signal at the receiving end by using the same non-linear scale so as to restore the signal to its original form but with less noise. This method eliminates the effect of out of band distortion which is created by the clipping method.

11. SLM-

SLM stands for selective mapping which is a technique used to reduce the PAPR value of an OFDM system. This technique is compatible with any kind of modulation performed in the system. In this technique, the signal with lowest PAPR is selected from several numbers of signals representing the same information.

12. Coding-

Coding is the process of converting the signal in form of codes such that there is no effect of attenuation left once the signal is received and minimum amount of loss in the signal. There are various types of coding which includes LDPC codes, Hamming codes, Golay codes etc which also ensures security of the encoded bits.

13. ISI-

ISI stands for Inter Symbol Interference. In this, one symbol undergoes spreading resulting in that symbol interfering with another symbol. The occurrence of ISI is high in case of high data rate applications. Symbol rate in such applications is high compared to delay in the channel which means the ability of transmitter is more than the channel.

14. ICI-

ICI stands for Inter Channel Interference. It is caused due to one or more signal(s) from one channel interfering with one or more signal(s) in another channel. It is prominent in multi carrier systems where one channel is divided into many sub channels. Spacing of these sub channels is very less than the Doppler spread and since there is less difference in frequencies, so chances of occurrence of ICI is more.

15. MATLAB-

MATLAB is a high-level language which is very user friendly and provides a platform which enables to perform computational tasks faster as compared to other programming languages like C, C++. It has several features like developing algorithms, numerical computations, data visualization, analyzing the data and results and applications.

16. PSK-

It is a digital modulation technique which conveys data by changing the phase of the carrier. With respect to the change in the carrier, we note a variable change in the information signal which is known as the PSK. The information signal here is in the digital form and with the change in the information bit, we note a change in the phase of the modulated wave also.

17. BER-

It is the number of error bits with respect to the total number of bits after transmission.

Chapter 3: Review of Literature

AN OVERVIEW OF TECHNIQUES FOR REDUCING PEAK TO AVERAGE POWER RATIO AND ITS SELECTION CRITERIA FOR ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING RADIO SYSTEMS

V. Vijayarangan, DR. Sukanesh [4]:

In this various techniques proposed for reducing PAPR has been discussed. Based on the requirement and considerations the selection criterion is different to choose a technique. The historical background is explained and how all the techniques have been useful to minimize the noise. The techniques has been compared their results have been shown. The goal is mainly concentrated upon the fundamental ideas and understanding of the concept introduced. This is done primarily to give an overview of all the techniques which have been known since past few decades and the modification area has widen to a large extent today. High PAPR causes saturation in power amplifiers which has an effect in the inter modulation products. Therefore it is great need to reduce this effect. The techniques that have been discussed in this paper are clipping, coding, companding etc. But along with reducing the PAPR we also need to focus the complexity of the system. The system should be less complex to reduce mathematical complications as well as cost. The factors which are to be considered are also mentioned in this paper such that for a particular purpose of developing an OFDM system, we choose the most effective technique and related tradeoffs properly.

A NEW SLM AND PTS SCHEMES FOR PAPR REDUCTION IN OFDM SYSTEMS

Dr.S.P.Vimal, M. Kasiselvanathan and U. Saravanakumar [5]:

The proposed work in this paper is about the reduction of PAPR with modified statistical techniques in an OFDM system. The extended work reduces the complexity along of the system along with the reduction of PAPR which is shown by the simulation results. The methods, SLM and PTS are simplified and used for the system. PTS is simplified by using partitions and optimizing phase values for alternate partitions which helps in reducing the complexity of the system. The weight vectors of the odd sequences are changed and even sequences are assumed for little iteration. For SLM, new phase sequences are selected. The phase vector is changed only for off components and the even components are assumed for little iteration. Although the proposed method reduces the complexity, however there are tradeoffs to be made between performance and complexity in both the techniques. Simulation results shows the comparison between the ordinary techniques and the modified techniques by taking an input sequence of length 32 which is divided into 4 sub blocks whose length is 8. The modulation type used is OPSK and the experiment has been performed for about 1000 times. Further it is shown that for ordinary methods the PAPR value is lesser but the proposed methods have less complexity as the PAPR increases. The work can also be extended for other techniques to reduce the PAPR of an OFDM system.

PAPR REDUCTION TECHNIQUES WITH HYBRID SLM-PTS SCHEMES FOR OFDM SYSTEMS.

Hong-Jie Chou, Ping-You Lin and Jung-Shan Lin [6]:

This paper further modifies the hybrid scheme used to reduce the PAPR in an OFDM system. Both the methods are implemented together which also reduces the complexity of the system. The methods are employed into different sequences and then linearly added to obtain different more sequences on which the algorithm is again applied. The proposed work reduces the PAPR with lower computational complexity. The paper describes both the conventional as well as additional hybrid schemes whose results are then compared. In the conventional hybrid schemes both PTS and SLM are applied into the divided sub blocks of the sequences. The signal with lowest PAPR is selected by each optimization block. The method can be continued for several iterations and the value of PAPR can be further reduced.

In additional hybrid scheme, the number of IFFT points is less but the performance for PAPR is not compromised. The less number of IFFT points reduces the computational complexity. Both the methods are modified in the additional hybrid scheme and then combined to obtain a further better system. The sequences are linearly added to obtain a complete sequence of OFDM system. According to the simulation results, it is seen that the PAPR value is further reduced with increase in the number of phase rotation. After comparison, it is found that the modified scheme gives a better result than the conventional scheme. The PAPR value for conventional scheme is obtained as 6.4 dB whereas it is 5.6 dB for the modified scheme. The results are obtained for various number of phase rotations considering all the schemes mentioned.

REDUCTION OF THE PAPR IN OFDM SYSTEMS BY INTELLIGENTLY APPLYING BOTH PTS AND SLM ALGORITHMS

Chunjiang Duanmu Hongtao Chen [7]:

Several developments gave rise to the use of OFDM and now it has emerged its application in 4G communications also. In spite of its advantages the problem of PAPR still happens to dwell in OFDM systems today. The existence of various algorithms has been repeatedly used and a lot of researchers are still working on this field to minimize the value further to obtain a better performing system. The algorithms involved in this area are clipping, statistical methods, companding, pre coding techniques etc. This paper also describes various techniques and compares them with each other. The general factors are considered in comparing the performance of each technique. It also has less BER than the clipping algorithm and less distortion than the companding methods.

Thus, this paper proposes a new algorithm where both the techniques SLM and PTS are combined to reduce the PAPR value. Coding technique has the disadvantage that if the numbers of carriers are more, the throughput of the system degrades gradually and spectrum efficiency also reduces. PTS and SLM are the signal randomization algorithms whose main objective is to reduce the probability of high occurrence of PAPR. This technique is found to be more effective.

The algorithms are such that two blocks are formed from the original OFDM data. SLM is applied in one block and PTS is applied in the other block. After this both the blocks are combined to carry on the transmission process. This algorithm takes the advantage of both the techniques and at the same time the computational complexities and the BER performance of the algorithm also remains same as the original PTS and SLM algorithms. The sections are also divided according to even and odd. One section consist the even part and the other section consists the odd part. PTS is applied in the even section and PTS is applied in the odd section of the signal. After this the signal is combined and transmitted.

PAPR REDUCTION IN OFDM SYSTEMS USING PTS: WITH NEW PHASE SEQUENCES

Vrushali P. Phale1, Dr. S. K. Shah [8]:

The paper focuses on one of the important methods to reduce the PAPR value of a system. It is shown that the mentioned techniques, PTS have several IFFT operations which increase the complexity of the system. But, in the proposed scheme, the number of IFFT points is reduced to half at the cost of slight PAPR degradation. The simulations are performed in MATLAB with the QPSK modulation technique. The ordinary method is known as conventional PTS or C-PTS where a phase rotation factor is multiplied with each IFFT block and then added to obtain the complete sequence. The sequence with lowest PAPR is chosen to further transmit the signal.

The proposed method is mainly to reduce the complexity of the system taking care of the PAPR value. The complexity of the conventional method is more than the SLM method as it has more number of iterations used to find the optimum phase sequence. The proposed scheme is based upon the creation of random values from the given phase factors. The number of phase factors considered here is two. A number of random values are generated periodically many number of times. The differences in both the schemes are that the way of selecting the optimum value is different. Besides the performance and the complexity, the out of band distortion can also be examined by using non linear power amplifier. Using this, the PSD of the signal can further be suppressed. The PAPR value for different number of phase sequences are given and shown by the CCDF plot. Practically it can be useful as the power consumption is less and hence the battery life is more. The method can also be helpful to systems like WiMAX and long term evolution (LTE).

PTS-CLIPPING METHOD TO REDUCE THE PAPR IN ROF-OFDM SYSTEM

Jianping Wang, Ying Guo, Xianwei Zhou [9]:

This paper introduces a combined method, one of which is linear and the other one is non linear method. The method is implemented for Radio over Fiber and OFDM system. The PTS technique reduces the probability of the peak value which is why the clipping technique is applied later to clip the processed signal. This further reduces the value of PAPR. Although it brings a slight difference in the performance of BER by using the clipping technique but it is necessary to reduce the PAPR for proper usage of the system. The BER can also be reduced by using a filter after clipping the signal. The main motive of this hybrid method is to use the advantage of PTS and then clip off the high power value of the signal. Also the out of band power leakage is considered and usage of filter enhances the system by reducing the bit error rate value.

The simulation results shows that the proposed technique reduces the value of PAPR but it also brings a slight change in the performance of BER. The feasibility of the work in the ROF-OFDM system is shown. The PAPR value of the combined technique ranges from 6-7 dB which is also shown in the CCDF plot. The plot also compares the PAPR value of the original OFDM signal and the value obtained using only PTS. Hence it is seen that the hybrid techniques gives us better result than the individual techniques applied on the system.

BER AND PAPR REDUCTION USING COMPANDING ALGORITHMS IN OFDM

A. N. Jadhav, M. V. Kutwal [10]:

This paper presents another technique which provides the solution to the out of band problem introduced by the clipping technique. The companding technique includes different laws whose performance is compared in this paper. The companding algorithm applied after IFFT compresses the signal before transmission which doesn't allow out of band interferences to occur. The different laws used in this particular paper include mu-law, exponential companding and companding using airy function. $\mu -$ Law is the simplest and common technique used to reduce the PAPR of an OFDM system. The idea of using this method has arrived from the use of compression in speech signals. As speech signals are very familiar to OFDM signals in a way that large signals occur very infrequently, so the same technique can be used to compress the signals in an OFDM system to improve the system performance. The other technique used is exponential technique which is meant for both large and small signals by keeping the average power at the same level. In this method, first the OFDM signal is divided into uniformly distributed signals and exponential companding schemes are applied to each one of them to reduce the PAPR of the signal. The third method which falls under companding technique is companding using airy function. Out of band is the leakage into channels which is needed to be taken care of. The usage of companding techniques also needs the knowledge of PSD of the companding signal and because of non linear companding technique, it is clear that these schemes are very effective to reduce the PAPR of the signal for different modulation sub carriers.

The performance of the algorithms are shown and compared. The results include both PAPR and BER which shows that Airy companding technique gives the lowest value of BER. The signal without companding has the highest PAPR value and the $\mu -$ Law algorithm reduces the PAPR value of the original signal. The best performance is shown by the exponential companding algorithm as it is meant for both small and large signal peaks. Also, by using airy companding algorithm both BER and PAPR is effectively reduced to obtain a better system.

A LOW COMPLEXITY PTS SCHEME FOR PAPR REDUCTION IN SFBC MIMO-OFDM SYSTEMS

Sheng-Ju Ku [11]:

In this paper, PTS has been used in MIMO OFDM system to reduce the PAPR as well as complexity with space frequency block coding. MIMO OFDM has been one of the attractive techniques for high data rate. In the proposed technique, a set of cost functions are generated by using the sample powers of sub blocks derived from the input data stream. These cost functions and similarity between the sub blocks are used to develop a method which selects the samples. The samples then select the PAPR of the signals for different antennas. The main motive is to reduce the complexity without compromising the PAPR. The number of antennas used in the system is two. First, the input data is divided into sub blocks and the even and odd sub blocks are separated. IFFT is performed into these blocks which are further used to generate a cost function. The cost function then selects the samples which further estimates the PAPR of the signals as mentioned. Along with this, the similarity among the sub blocks is also chosen as criteria to develop a method for selection of samples. The simulation result shows that the PAPR value is more likely the same as the conventional PTS but the proposed method has lower computational complexity. Different thresholds are taken for which the PAPR value is evaluated and compared as shown in the CCDF plot. The PAPR value of the proposed scheme ranges from 8-9 dB.

CLIPPING AND FILTERING TECHNIQUE FOR REDUCING PAPR IN OFDM

Saleh Albdran, Ahmed Alshammari, Mohammad Matin [12]:

This paper describes the reason why OFDM is chosen over single carrier transmission and how an OFDM system develops a particular drawback known as PAPR. The method used to reduce this particular parameter is clipping and filtering. The clipping technique is one of the easiest techniques used to reduce the PAPR value. A threshold for power is set, above which the signals are clipped and the rest of the signals are transmitted. Although it us useful, it still holds few disadvantages which is the degradation in BER performance due to in band distortion and out of band radiation. This can lead to disturbances in the adjacent channels. However filters are used to eliminate the effect of out band radiation but this may also require the maximum level of clipping operation. Filtering reduces the distortions created by the clipping operation.

The filtering operation also gives a less degraded BER performance and the filter used in this paper is a low pass filter. The simulation result shows the drop in the PAPR value with the change in the clipping ratio. It is also seen that highest PAPR reduction takes place with lowest clipping ration. The PAPR value obtained with CR=1 is 5.2 dB which is shown in the CCDF plot. At the same time the performance of BER is also evaluated and observed that with higher clipping ration, the performance gets better which is why filtering operation is performed. The BER performance of unclipped signals is compared with the clipped and the filtered signals. The value obtained for BER of the clipped and filtered signal is 0.0039 at 10 dB SNR and the clipping ratio for this is 1.2. The BER of the clipped and unfiltered signal is also obtained for the same clipping ratio and SNR value which is 0.0019.

PARTIAL TRANSMIT SEQUENCES FOR PEAK-TO-AVERAGE POWER RATIO REDUCTION OF OFDM SIGNALS WITH THE CROSS ENTROPY METHOD

Jung-Chieh Chen [13]:

This paper proposes another method which is used to reduce the PAPR value in an OFDM system. It shows how the conventional method reduces the PAPR value effectively but at the same time when a vector for phase rotations is considered, it requires a high computation which increases the complexity of the system. It requires a wide search of the optimum value which is to be multiplied with the IFFT sequences. In order to eliminate this disadvantage while still improving the system performance by reducing the PAPR value, a new method is introduced which is the CE-PTS. In this method, a score function is introduced which is translated into an approximation problem. The main objective in PTS scheme is to find the phase factor which will reduce the PAPR of the signal. Now, there is also a need to have control in computational complexity which is acquired by employing the proposed method. The score function here is the inverse of the PAPR value such that it decreases as the value of PAPR increases. Therefore, we need to maximize this function. The CE method is an adaptive method and it transforms the optimization problem into sampling problems. So, first the problem is randomized including a set of distribution. The phase factor search is then formulated as a stochastic approximation such that the phase factor is the optimal value at the end of the search. Simulations are shown which shows that the PAPR is reduced up to a greater extend also taking care of the computational load.

Chapter 4: Rationale and Scope of the Study

The nature of wireless communication as we know is very unpredictable. OFDM today is considered as a new emerging scheme which is helpful in both wired and wireless communications. In current scenario, OFDM is being used in various fields of audio-video data broadcasting systems, data modems, cellular radio, etc. With various developments, a number of complications are also faced making the system quite complex for practical use.[18] But it has still found a way in today's era to reduce any kind of error with numerous methods that are discussed briefly in this report. Its uses have been extended widely in the field of digital transmissions like local area networks, audio/video broadcasting and it has also proved to be a promising technique in the fourth generation of mobile communication systems. One of the important advantages of OFDM system is its simplicity.

OFDM helps in better utilization of the available spectrum. Its robustness makes it a suitable candidate for wireless communication as it is more immune to multipath propagation. Also, due to its ability of bit loading and adaptive power, it has emerged as a band width efficient system. One of the main things to keep in mind is to keep the frequencies at both transmission and receiving end synchronized or else the orthogonality between the frequencies will not be there and the whole concept of OFDM will be defeated. Different problems that OFDM systems have been facing in years are considered and solutions are also provided. For e.g. to keep the signal from spreading the concept of interleaving is used. It is well known that the research process is never ending and the new developments are yet to come out, so there are various field of work in OFDM that provides space for new developments. [18]

A very common area for work is the channel estimation which plays a very important role as poor channel estimation leads to degradation of the system. Different methods have been developed to do this job and assuming that the estimation is done perfectly, the system's performance is evaluated in variable environments. Efficient algorithms are also introduced for channel estimation and for timing offset in OFDM systems. Its use can extended up to MIMO-OFDM systems also. Along with these techniques, several methods to reduce the PAPR value have also emerged and are compared with systems developed before. Each technique has its own advantages and disadvantages. While using PTS for reducing PAPR we face the problem of algorithm becoming too complex. Similarly, while using clipping we have the risk of out of band radiation and due to this the existing channels suffer interference. So while proposing an efficient algorithm these things are also kept in mind. In most OFDM systems, to limit the spreading of power density spectrum either linear amplifiers are used which are very expensive or quasi-orthogonality is maintained by large power back-off. So, considering the requirements and security in the transmission process and also the compatibility with the system, one of the techniques is used to minimize the PAPR value of any OFDM system. With proposed techniques of reducing PAPR, BER is also taken care of so that it doesn't affect the original signal and to obtain an efficient transmission procedure.

Since it is a multi carrier process, ICI is one the drawback that comes into the picture. Therefore, windowing method of reducing ICI is also clubbed with ICI self cancellation scheme. Amongst these wide areas, one such area is chosen and worked upon in this particular report which is the reduction of the PAPR value in an OFDM system. The methods used to reduce the PAPR value can be categorized as statistical, linear, non linear and coding techniques. Clipping and filtering falls into the non linear method. PTS and SLM are statistical methods. Coding schemes are the ones for error correction and companding methods are of the other kinds which are used for reduction of PAPR in OFDM systems.

If we talk about the future of OFDM then one can say that it is the most suitable and prime technology for implementation of 4G in the wake of LTE (Long Term Evolution). [3] Future OFDM should be able to provide efficiently large no of users with high data rate. As the OFDM system continues to evolve the core problems of low complexity, PAPR and power efficiency will have to be solved by the use of more efficient algorithms.

4.1 Objectives of Study

The field of study for OFDM is quite wide and so every field has its own area for research. With a greater number of benefits in using OFDM system, various drawbacks also exists which holds back the performance of the system. In this particular study, the main objective is to reduce the PAPR of the signal before transmitting the signal. Various techniques are also employed in the transmitter part, receiver and channel, but this work will mainly concern the reduction in the PAPR before transmitting the signal. PAPR is one of the major drawbacks upon which researchers have been working till now. It is elaborated in further sections as how this error occurs and the techniques that are developed to reduce this particular limitation. It stands for Peak-to-Average Power Ratio. It is attained by division of the peak amplitude square by square of the RMS value. It occurs due to involvement of noise which takes the peak to a higher value as compared to the average power of the signal. This is one of the major drawbacks in OFDM systems which are required to be reduced by using several techniques.

The techniques have been studied in detail and few of these are chosen which are applied to develop a hybrid technique to reduce the PAPR. The techniques used in this work are PTS, clipping and $\mu -$ Law companding technique. These techniques are applied taking several considerations and limitations. However the main objective is to reduce the PAPR and creating a system which can be feasible with the channel. Each of these techniques have its own benefits and disadvantages which is why we need to look into the parameters which wouldn't be disturbed by upbringing such methods. The techniques are applied to different sections of the system taking care that the performance of the individual methods wouldn't be a hindrance to the other one. The results of each of these techniques are discussed and shown which reflects the variation in PAPR after applying each technique to the system. The ultimate motive is to transmit a signal with least PAPR value which is achieved by applying a hybrid technique to the system.

Chapter 5: Materials and Research Methodology

The proposed work is about the reduction of PAPR in OFDM network. PAPR is a major limitation to an OFDM system and the proposed work gives an effective way to reduce the PAPR of the system. In the proposed approach an improvement will be done over the technique which helps to reduce the particular parameter. It entire procedure involves three different techniques which are combined to obtain a better performing system with reduced value of PAPR. The basic step of a research work which is to define the research problem appropriately and represent it in the form of some general questions around which the complete work will be performed. In this proposed work, the points that will arise are given as:

- Reduction of PAPR.
- The analytically and technically improved version of the existing systems.

5.1 Sources of Data

The proposed system is about the reduction of PAPR and further enhancement in OFDM systems. Because of this, the complete data respective to the system formation and representing the different parameters of the system and the technology will be required.

The basic representation respective to work is given as follows:

- The study of basic OFDM signal generation.
- The transmission of the signal through a channel and receiving the signal.
- The evaluation of PAPR of the signal.
- Study of different existing techniques used to reduce the PAPR value of the system.

5.2 Methodology

The proposed system is developed by going through the following steps:

1. A data stream with number of data points N=100 whose values ranges from 0 to 7 are taken which is generated using a proper function.

2. The generated data points are then modulated using 8-PSK. The data generated in the form of bits are now in the form of symbols. This is also called as mapping as the bits are now mapped into symbols.
3. The symbols are now taken in a vector and sub divided into blocks. The number of blocks obtained after division are 10.
4. The next step is to perform IFFT to each of these blocks column wise. The number of IFFT points taken here are 10.
5. This is followed by the application of a statistical technique PTS. PTS is applied to each of these columns by multiplying with a phase factor. The IFFT signals are now phase rotated to give out a different signal.
6. The outputs of each blocks after applying PTS is then added to form the complete signal in a serial form.
7. The obtained signal is now compressed using μ-LAW companding. This is done to compress the signal which avoids out of band interferences and loss of signal.
8. The compressed signal is now clipped. In the clipping operation, a threshold is set based on which the peak of the signal is eliminated that crosses the threshold value. In the proposed system, the threshold value is given by t=0.7.
9. The clipping method and the use of a high power amplifier become more crucial once the signal is sent through the channel. So to represent the application of this particular technique, the procedure is also followed by an effect of high power amplifier, where a random noise is generated.
10. The obtained signal now represents the regenerated OFDM signal which is transmitted further through a channel.
11. After applying each of these techniques, the PAPR value is calculated and compared to the previous one.
12. Comparing the PAPR value after applying the mentioned techniques, we observe that the combination of the three techniques gives us the signal with least PAPR value. The comparison is shown by the CCDF plots obtained.

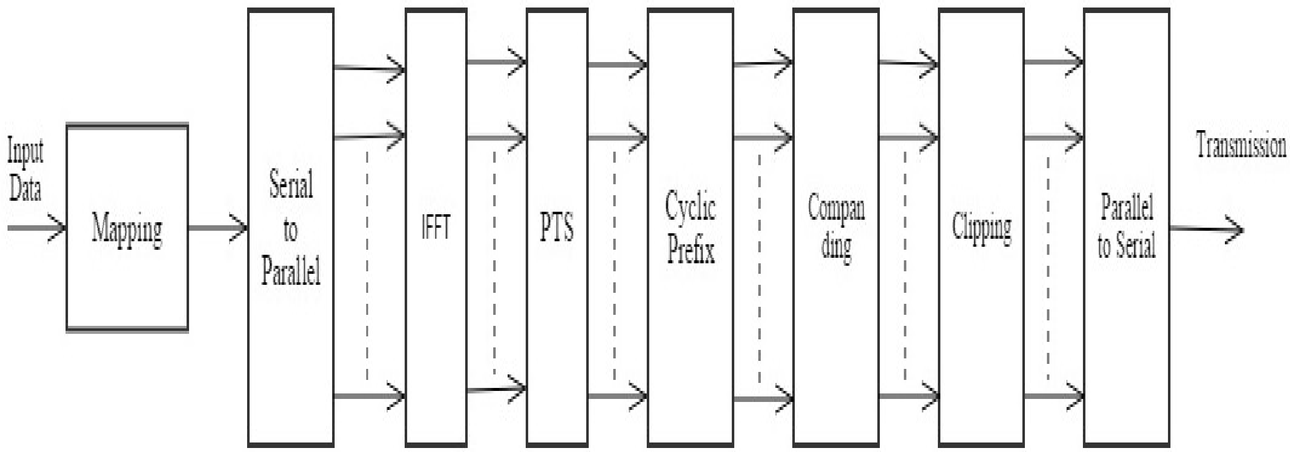

Fig 5.1: Block Diagram of Proposed Model

The basic terms related to the system include:

OFDM Signal:

The OFDM technique is defined as the transmission of a signal by modulating it with N sub carriers which are orthogonally spaced. The discrete-time OFDM signal is given as:

$$X_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n \, e^{j2\pi nk/N} \qquad (2)$$

where
k =1, 2……N-1 , j=$\sqrt{-1}$,

x_n are the symbols mapped using 8-PSK modulation technique

and n=1, 2…..N-1. [4]

This is the signal obtained from the standard defined OFDM system which is later manipulated to obtain a better performing system.

PAPR:

It stands for Peak-to-Average Power Ratio. It is attained by division of the peak amplitude square by square of the RMS value. It occurs due to involvement of noise which takes the peak to a higher value as compared to the average power of the signal. This is one of the major drawbacks in OFDM systems which are required to be reduced by using several techniques. Unfortunately, this requires an excess large saturation power for the power amplifier, which inevitably leads to low power efficiency. High peak-to-average power ratio (PAPR) has been cited as one of the major drawbacks of OFDM modulation scheme. In the RF systems, at the transmitter end of the power amplifiers one of the major problems resides, i.e., the amplifier gain will saturate at high input power. One of the ways 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. But 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 (predominantly an Erbium-doped amplifier) is ideally linear regardless of its input signal power due to its slow response time in the order of millisecond. Nevertheless, due to the nonlinearity in the optical fiber the PAPR still poses a challenge for optical fiber communications. The expression for calculating PAPR is given as:

$$\text{PAPR}=10log_{10}\frac{\max|X_k|^2}{E[|X_k|^2]} \quad (3)$$

where

E[ ] is the expected value operation [4]

X_k is the OFDM signal

k is the number of symbols

Partial Transmit Sequences (PTS):

It is one of the techniques used to reduce the PAPR of an OFDM system. Many techniques have come into existences which are used to overcome this problem amongst which one of the classical and popular is the partial transmit sequences. In this technique, the entire sequence is divided into sub blocks and is rotated independently. These sub blocks are then added to form a serial sequence which consists of rotated sequences. These signals correspond to different rotations whose PAPR value differs from each other. Now from these rotated signals, the signal with minimum PAPR value is chosen. [5] So basically the phase rotation of the signal helps to reduce the peak to average power reduction. This technique is very well known in achieving high performance and redundancy utilization. But it also has some limitations which are

- High complexity in the system.
- Elimination of transmitting the side information.

The complexity arises due to the search to find the optimum sequence of rotation factors. It also has different techniques which are carried on to search the optimum value. [16][17] Few of them are:

- Cross Entropy method
- Interleaving method
- Zero padding method
- Combinatorial Optimization

Another complexity arises when the receiver has to undo the rotation method in the receiver side. A proposal for modified PTS is also developed which uses an objective function based on some approximations. This method reduces the required number of multiplications. The transmission of side information is another problem that is looked after which is eliminated by implementing differential encoding into the system. These differential encoders mark the sub carriers and choosing the sequence from the code words. This particular method is inspired by trellis-shaping technique. This reduces the redundancy and complexity as well. [8][13]

Companding:

It is the process of compressing a signal before transmission and then expanding (decompression) the signal at the receiving end by using the same non-linear scale so as to restore the signal to its original form but with less noise. This method eliminates the effect of out of band distortion which is created by the clipping method. [21] There are different techniques which are used for companding the signal. In the context of OFDM, we can use companding techniques which are used to compress the speech signals. So one of the techniques which is explored in this work is the companding technique which helps to reduce the PAPR value in an OFDM system.[22]

Various techniques used for companding are as follows:

1. μ-LAW Companding

The $\mu -$ Law companding is one of the simple methods to compress a signal yet it is very effective for systems like OFDM. OFDM signals are more or less like the speech signals in the way that the appearance of large signals is very infrequent. This allows us to use a similar technique to compress the signal such that it will give a reduced PAPR value of the OFDM system. The $\mu -$ Law expression for a signal x when compressing can be given as:

$$F(x) = \operatorname{sgn}(x)\frac{\ln(1+\mu|x|)}{\ln(1+\mu)} \quad \text{when } -1 \leq x \leq 1 \ \ [10] \tag{4}$$

The inverse of this function can also be obtained which is known as expansion. The compressed signal is expanded again at the receiver side whose equation is given as:

$$F(y) = \operatorname{sgn}(y)\frac{((1+\mu)^{|y|}-1)}{\mu} \quad \text{when } -1 \leq y \leq 1 \ \ [10] \tag{5}$$

Where

x is the input signal

and the value of $\mu = 255$

After performing IFFT, the data is compressed and at the receiver the expanded data in an OFDM system can be sent to FFT block for conversion into frequency domain.

2. A-LAW Companding

This is another type of companding which can be used to compress signals. For an input data x, the compressed signal can be defined by an expression which is given as:

$$F(x) = \operatorname{sgn}(x)\frac{A|x|}{1+\ln(A)} \quad \text{when } |x|<1/A \ \ [10] \tag{6}$$

$$F(x) = \operatorname{sgn}(x)\frac{1+\ln(A|x|)}{1+\ln(A)} \quad \text{when } 1/A \leq |x| \leq 1 \ \ [10] \tag{7}$$

This signal is again expanded at the receiver end which is given by the following expressions:

$$F(y) = \operatorname{sgn}(y)\frac{|y|(1+\ln(A))}{A} \quad \text{when } |y|<1/1+\ln(A) \ \ [10] \tag{8}$$

$$F(y) = \operatorname{sgn}(y)\frac{\exp(|y|(1+\ln(A))-1)}{A} \quad \text{when } 1/1+\ln(A) \leq |y| < 1 \ \ [10] \tag{9}$$

Where x is the input signal

And the value of A is 57.56

3. Exponential Companding

This is one of the types which are used to compress both types of signals which are large as well as small. Besides it also keeps the PAPR level up to a same level. In an OFDM system the original signal is transformed into uniformly distributed signals and this method can effectively reduce the PAPR of the system. The expressions for this are given as:

$$\text{F(x)= sgn(x)}\sqrt[d]{\propto [1 - \exp(\frac{-x^2}{\sigma^2})]} \quad [10] \qquad (10)$$

The inverse of this function which is used to expand the signal at the receiver side is given as:

$$\text{F'(x)= sgn(x)}\sqrt{-\sigma^2 \log(1 - \frac{x^d}{\alpha})} \quad [10] \qquad (11)$$

Where α is the average power of the output signals.

4. Companding using airy function

Another method used for companding is the use of airy function. The expression for this is given as:

$$\text{F(x)= } \beta \cdot sign(x) \cdot [airy(0) - airy(\alpha \cdot |x|)] \quad [10] \qquad (12)$$

Where

α is the parameter that controls the degree of companding and

β is the factor that adjusts the input power.

The expansion function which is the inverse function of F(x) used in the receiver side is given as:

$$\text{F'(x)= } \frac{1}{\alpha} \cdot sign(x) \cdot airy^{-1}[airy(0) - \frac{|x|}{\beta}] \quad [10] \qquad (13)$$

Clipping:

The clipping technique is one of the easiest techniques used to reduce the PAPR value. It is one of the techniques used to reduce the PAPR of an OFDM signal. The clipping method is used to clip of high power signals for which we need to mention a particular threshold. The peaks beyond this threshold are clipped off and rests are transmitted further. A threshold for power is set, above which the signals are clipped and the rest of the signals are transmitted. Although it us useful, it still holds few disadvantages which is the degradation in BER performance due to in band distortion and out of band radiation. [19] This can lead to disturbances in the adjacent channels. However filters are used to eliminate the effect of out band radiation but this may also require the maximum level of clipping operation. Filtering reduces the distortions created by the clipping operation. The filtering operation also gives a less degraded BER performance and the filter used in this paper is a low pass filter. [25]

The expression for clipping the signal is given as:

$$x(i) = \begin{cases} -A \; when \; x(i) \leq -A \\ A \; when \; x(i) \geq A \end{cases} \tag{14}$$

Where

x(i) is the input signal

A is the threshold mentioned based on which the peaks are clipped off. [12]

Clipping ratio is another parameter that is represented by:

$$Cr = \frac{A}{\sigma} \tag{15}$$

Where

σ is the RMS value of the OFDM signal.

The effect of noise can also be included in the signal which is again clipped. The effect is shown by using a high power amplifier and the operation depicts the clipping of high peak powers or excess power patterns. [12]

5.3 Objectives

The field of study for OFDM is quite wide and so every field has its own area for research. With a greater number of benefits in using OFDM system, various drawbacks also exists which holds back the performance of the system. It is well known that the research process is never ending and the new developments are yet to come out, so there are various field of work in OFDM that provides space for new developments. In this particular study, the main objective is to reduce the PAPR of the signal. Various techniques are employed in the transmitter part, channel and the receiver. The proposed research work will cover the following research objectives.

1. The existing schemes to reduce PAPR will be studied and analyzed accordingly.
2. OFDM system will be implemented on the given software.
3. An improved hybrid technique combining different techniques will be implemented.
4. The proposed approach will be implemented in MATLAB Environment.
5. PAPR will be calculated.
6. Results will be analyzed using waveforms.

5.4 Tools

1) The code is written on the editor window on MATLAB.
2) The obtained results can be seen in the command window of the software.
3) The waveforms will be produced in the figure window as final results.

5.4.1 An Overview of MATLAB Environment

MATLAB is a high-level language which is very user friendly and provides a platform which enables to perform computational tasks faster as compared to other programming languages like C, C++. It has the following features:

1. Development of Algorithms
2. Analyzing the Data
3. Data Visualizations
4. Numerical Computations
5. Results and Applications

The MATLAB system functions can be described five sections:

1) Language (MATLAB) :
   It is a type of language which can be described as having functions like data structures, functions, flow chart expressions and OOPs concepts. In order to make either very large or very small functions and projects possible, this tool is being used.

2) Environment of its working :
   An arsenal of tools and advantages available in MATLAB helps us to work with it in a comparatively easier manner.
   It holds in itself the facilities for managing available library variables in the workspace and sending and receiving of data. Developing, managing, debugging, and profiling M-files are also included as MATLAB applications.

3) Graphics Handle
   It is also act as a graphic system as MATLAB is complained with it. 2-dimensional and 3-dimensional high level commands are used for various applications like animation and graphics representation and data visualization or image processing. We can fully customize the interface as we desire. It also has the aspects for running the low level commands too.

4) Function Library (Mathematical)
   The collection and libraries present in abundance in the MATLAB serves a great purpose of solving equations and large mathematical formulations using simple computational algorithm. Some examples include FFT, Bessel functions, matrix inverse etc.

5) Application Program Interface :
   It is an aspect of the software through which we can write down different programming language. The language compatibility is not a major problem in MATLAB. It facilitates the dynamic linking between M files.

Chapter 6: Results and Discussions

The system worked upon is the developed system whose PAPR value is much lesser than the existing ones. Apart from the reduction of PAPR, it is also taken care that the techniques involved will not affect other parameters like increased complexity and bit error rate. The proposed work develops a system which is better than the existing ones.

6.1 Experimental Work

OFDM Model and PAPR

The OFDM technique is defined as the transmission of a signal by modulating it with N sub carriers which are orthogonally spaced. The discrete-time OFDM signal is given as:

$$X_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n \, e^{j2\pi nk/N} \tag{16}$$

where

k =1, 2……N-1 , j=$\sqrt{-1}$,

x_n are the symbols mapped using QPSK modulation technique and

n=1, 2…..N-1. [4]

This is the signal obtained from the standard defined OFDM system which is later manipulated to obtain a better performing system. The signal when transmitted gives out a PAPR value which is defined as the ratio of maximum to average power and is expressed by:

$$\text{PAPR}=10log_{10} \frac{\max |X_k|^2}{E[|X_k|^2]} \tag{17}$$

Where E[ ] is the expected value operation. [4]

Application of PTS in OFDM system

The PTS scheme is applied in joint with the IFFT block of an OFDM system. The data symbols are first converted into parallel form typically known as sub blocks. Let the input data be *X* which is divided into *M* sub blocks which are represented as:

$$X = \sum_{m=1}^{M} X_m \tag{18}$$

Where

m =1,2……M [14]

These sub blocks contains equal number of sub carriers over which the partitioned signals will be modulated. The next step is performing IFFT into these blocks to convert them into time domain which is given as:

$$x_{ifft} = IFFT\{\sum_{m=1}^{M} X_m\} \quad (19)$$

Where

$x_{ifft} = [x_{1,}x_2, \ldots\ldots x_M]$ [14] are the signals obtained after performing N point IFFT of a particular length and known as partial transmit sequences.

The obtained sequences are then multiplied by the complex phase factors to minimize the value of PAPR which are given as:

$$b_m = e^{j\emptyset_m} \quad (20)$$

Where

m=1,2…..M

The sequencex_{ifft} is combined with $b_m$and the combined sequences are appended together by passing it through a parallel to serial converter. The signal now is expressed as:

$$x(b) = \sum_{m=1}^{M} x_{ifft} \,.\, b_m \quad (21)$$

Where

$x(b)$ =[$x_1(b), x_2(b), \ldots \ldots x_M(b)$]. [14]

Now, we obtain a set of sequences whose PAPR value can be calculated and the sequence with least PAPR value can be transmitted further. However, in this paper the combined signal is again operated through a different technique which is mentioned in the following section.

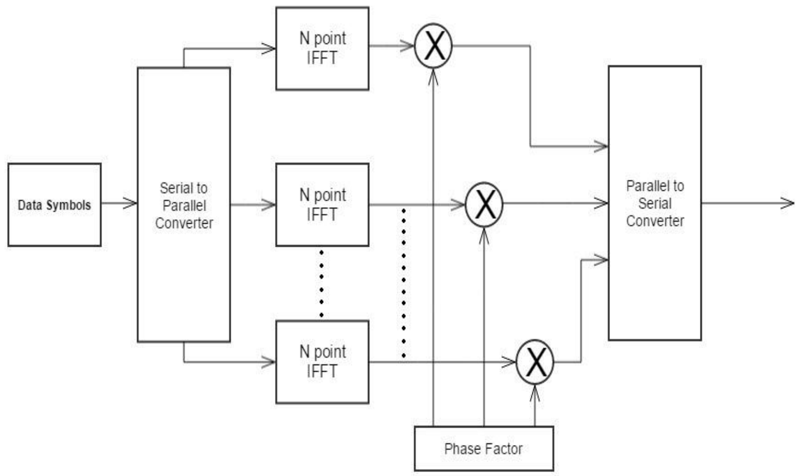

Fig.6.1 Block diagram of PTS technique [9]

Application of μ-LAW companding

The MU-LAW companding is one of the simple methods to compress a signal yet it is very effective for systems like OFDM. OFDM signals are more or less like the speech signals in the way that the appearance of large signals is very infrequent. This allows us to use a similar technique to compress the signal such that it will give a reduced PAPR value of the OFDM system. The MU-LAW expression for a signal x when compressing can be given as:

$$F(x)= \mathrm{sgn}(x)\frac{\ln(1+\mu|x|)}{\ln(1+\mu)} \quad (22)$$

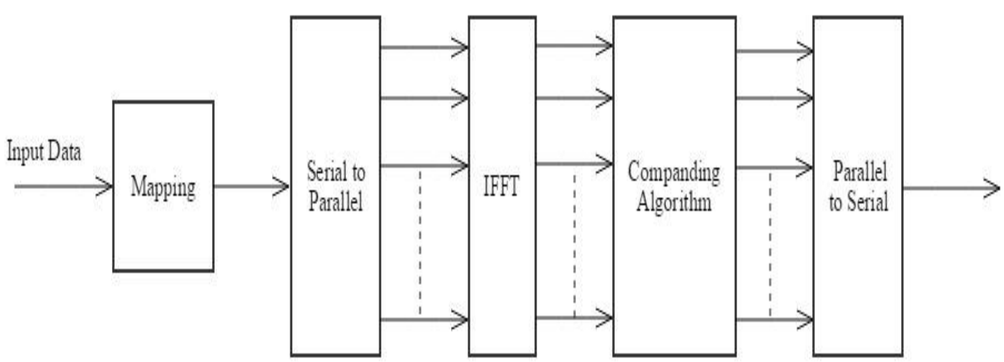

Fig 6.2 Block Diagram of Companding Technique [21]

The signal which is obtained after applying PTS is then compressed using this law and is forwarded to the next technique.

The Clipping Method

The clipping method is one of the simplest techniques to reduce the PAPR value. In this technique, a threshold is set based on which the peak of the signal is eliminated that crosses the threshold value. [9] In the proposed system, the threshold value is given by t=0.7 and the signal $x(b)$ is compared to the taken value. The clipping method and the use of a high power amplifier become more crucial once the signal is sent through the channel. So to represent the application of this particular technique, the procedure is also followed by an effect of high power amplifier, where a random noise is generated given by $n(b)$.

The noise is then added to the obtained sequence given by:

$$x'(b) = x(b) + n(b) \tag{23}$$

Where

$x(b)$ is the companded signal

This is again compared to the threshold t to clip the effect of noise.

6.2 Performance evaluation

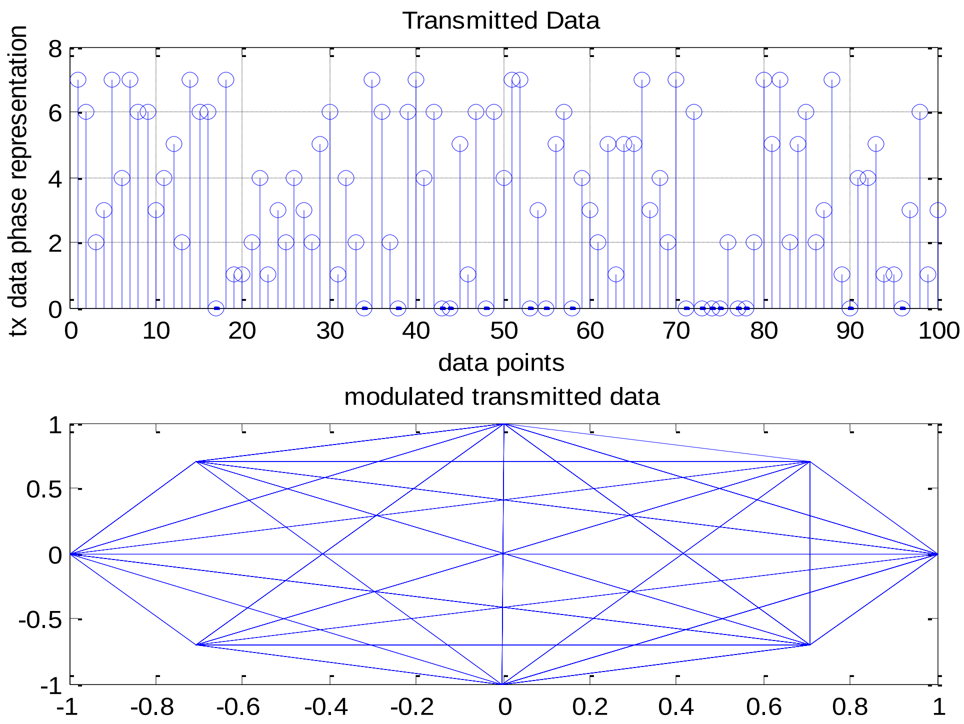

Fig 6.3 Data points and Modulated Data

The first waveform represents the data points that are to be transmitted. It consists of variable points that are obtained using an in built function 'randsrc'. This particular function generates a matrix of the given size and the range of variable values that can also be given by the user.

The second waveform is the modulated data. The data points that are obtained in the first waveform are modulated using 8-PSK modulation technique. In an OFDM system, we need to map the bits into symbols and therefore we need to use a particular modulation technique which is compatible with the system. The modulated data points are then further processed in the system. The modulated data is stored in an empty matrix which is then divided into different blocks. IFFT is performed into each block and cyclic prefixes are added to maintain the orthogonality of the signal.

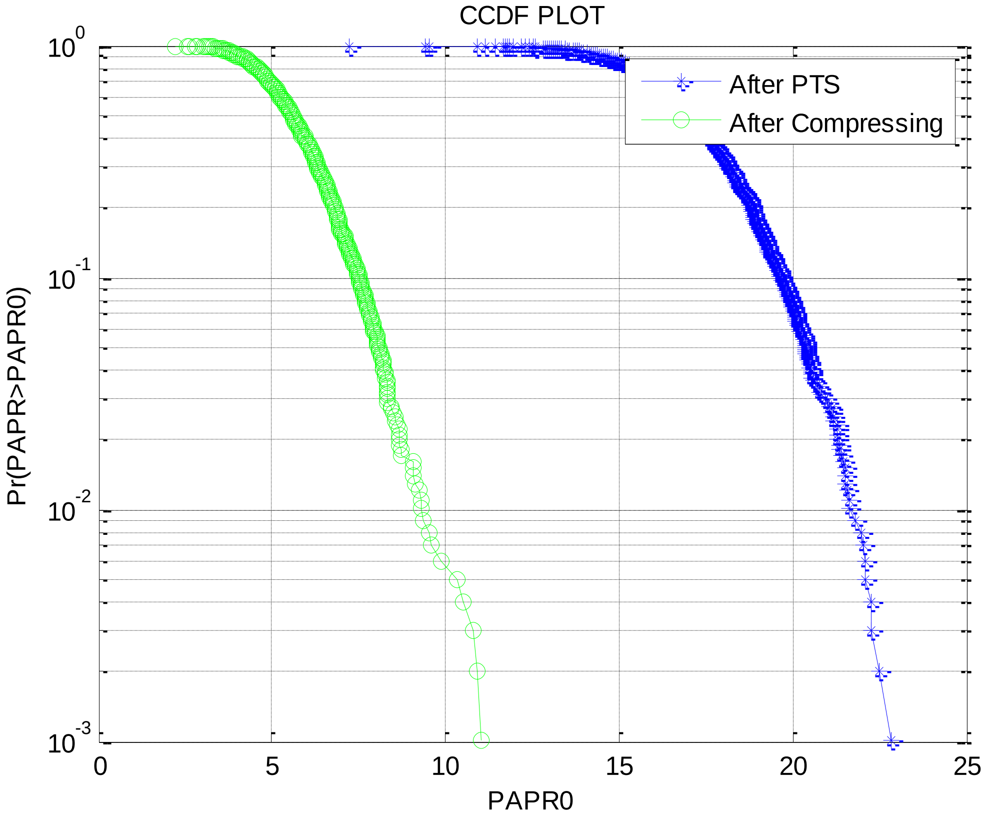

Fig 6.4

CCDF plot of OFDM signal after applying PTS and Companding

The plot shows the gradual degradation in the PAPR value after applying the mentioned techniques. From the figure, we can see that after applying PTS, the PAPR value is 23.5 and when this signal is companded, the PAPR value reduces to 11.8.

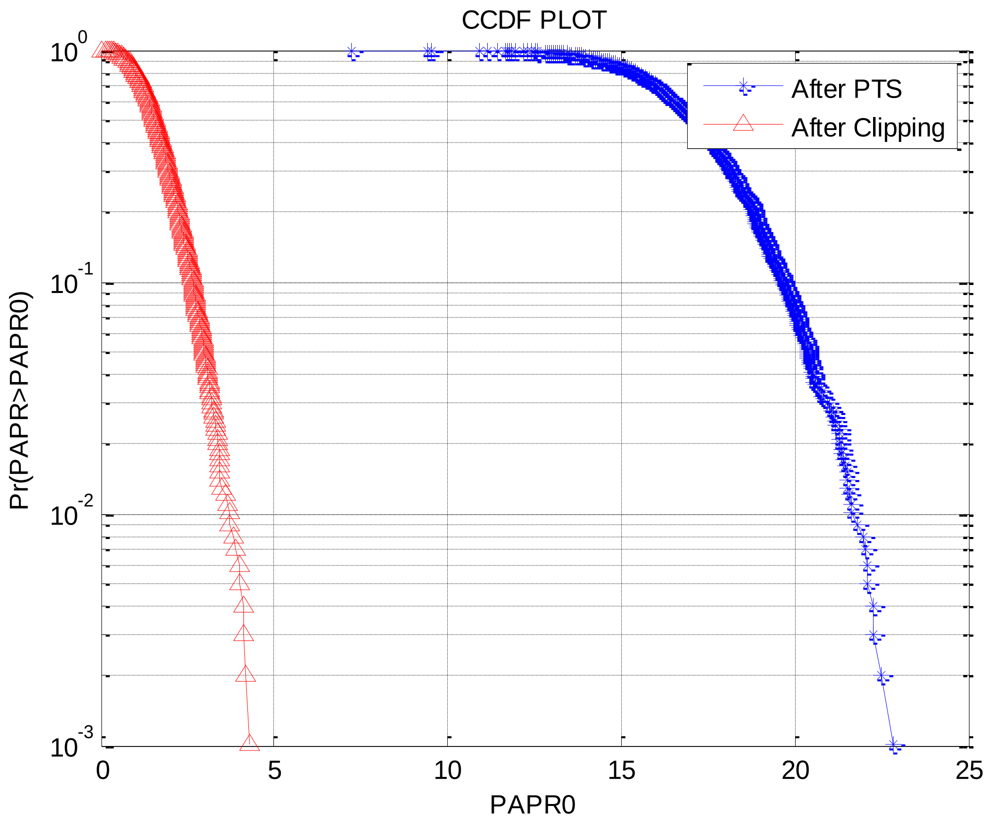

Fig 6.5

CCDF plot of OFDM signal after applying PTS and Clipping

The waveform reflects the further decrease in the PAPR value after applying the third technique. The signal obtained after applying PTS has the PAPR value of 23.5 which gets reduced after the clipping operation. The final PAPR value obtained is 4.62.

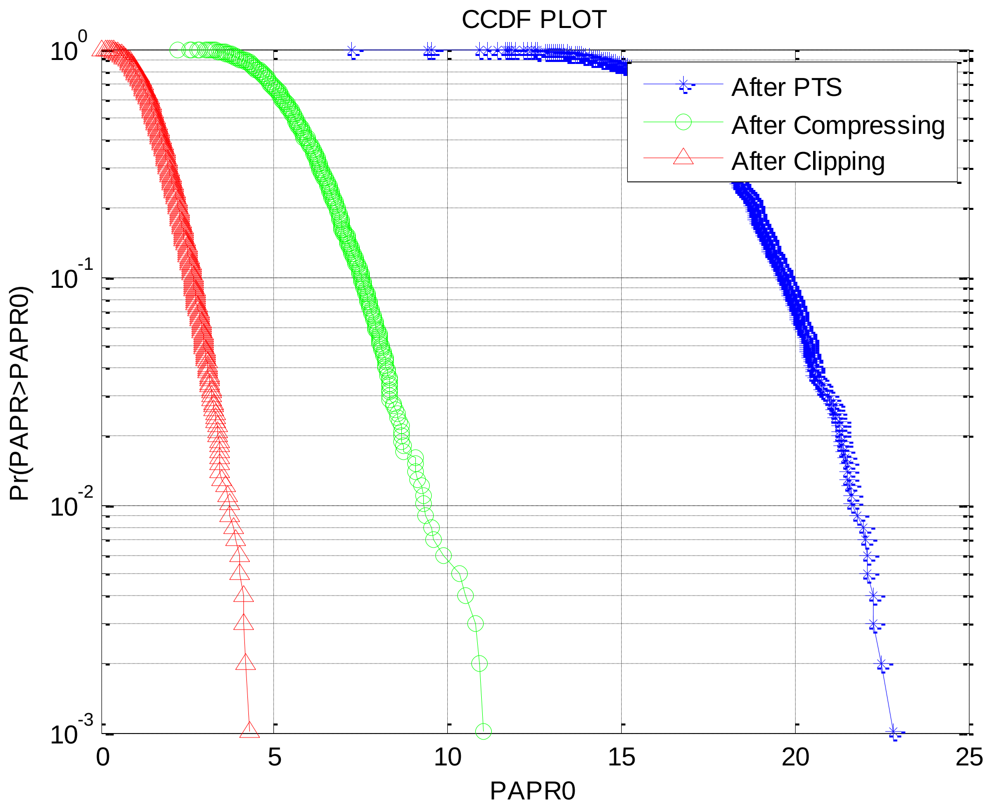

Fig 6.6

CCDF plots comparing PAPR values of applied techniques.

The waveform displays the ranges of PAPR value based on which the corresponding signal can be used for further transmission and use. The most probable occurrence of the signal approaches the PAPR value at 4.62 dB. However, we also obtain signals those posses the value of PAPR as 4.5 dB, 4.3 dB so on. The results of the rest of the techniques are also shown which gives the value of PAPR as 23.5 and 11.8 after performing PTS and companding at CCDF=10^{-3}. The waveform reflects the gradual reduction of PAPR value after applying the three different techniques in the OFDM system.

Techniques Applied	PAPR Value
Partial Transmit Sequence	23.54
μ-LAW Companding	11.86
Clipping	4.62

Table 6.1 PAPR values obtained after applying different techniques

Conclusion and Future Scope

The importance and purpose of using an OFDM system has been established in this era. The developments made yet and the reason behind why research is still on its way to obtain a better system has been totally justified by now. The advantages of such a system are wide spread and the applications have reached every corner of the world today. The developments are never ending and new research works are still upcoming with a better performing system.

This work is mainly concerned about one of the limitation (PAPR) that occurs while designing an OFDM system. A system is introduced which involves an integration of three different techniques into a single system. PTS is applied to each of the sub blocks which give out partial sequences with a lower PAPR value. This is followed by the companding algorithm which compresses the signal. This is followed by the clipping operation which clips out the sub carriers whose amplitude is above the defined threshold. The effect of noise has also been shown by passing the sequences through a high power amplifier and the noise effects are again eliminated by the same method. The combination of these techniques which is a hybrid technique has proved to obtain a reduced value of PAPR and a better performing OFDM system.

Future Scope

To enhance the developed technology and to obtain a better performing system. Its uses can be extended widely in the field of digital transmissions like local area networks, audio/video broadcasting and it has also proved to be a promising technique in the fourth generation of mobile communication systems.

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