Analysis of PAPR Reduction techniques in OFDM System

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Abstract: In the present modern wireless communication world, OFDM technique plays an important role in the transmission of multiple signals simultaneously over a single transmission path. OFDM is the good choice for multipath propagation systems. But, this multi carrier modulation technique is suffering with a PAPR problem due to the addition of number of narrow orthogonal sub-carries at OFDM transmitter. This PAPR problem leads to power inefficiency in RF section of the transmitter. To reduce this PAPR in OFDM system, numbers of techniques are proposed and implemented. In this paper we done analysis of different PAPR reduction techniques of OFDM systems and compared their PAPR values through simulation results.

Index Terms - Orthogonal Frequency division Multiplexing, Peak to Average Power Ratio, CCDF and RF Power amplifiers.

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I. INTRODUCTION

OFDM is one of the most popular Modulation technique which is widely used in modern wireless communication applications like 3G and 4G (LTE and Wi-Max) systems. The main advantage of OFDM is its high spectral efficiency, robustness to frequency selective fading channel and easy implementation with FFT (Fast Fourier Transform) [1],[2].Due to these advantages it plays a very key role in high data rate transmission applications like DVB-T, DAB, Wireless LAN 802.11a and HIPERLAN_2 etc.But other side this OFDM modulation scheme suffering with a major problem of PAPR (Peak to average power Ratio) .This PAPR problem arises before D/A and HPA at transmitter due to summation of all the narrow-band sub-carriers which are carrying the OFDM symbols .Due to High PAPR of the transmitted signal leads to in-band distortion across sub-carriers and undesired spectral growth if the linear range of high power amplifier is not sufficient at the OFDM transmitter. To avoid this PAPR problem [1],[2] in OFDM there are so many PAPR reduction techniques which are classified as two types. They are Distortion and Non-Distortion or (scrambling or Probabilistic) techniques. Clipping and filtering [3] and Companding transforms [7]-[13] are classified under distortion techniques and PTS (partial transmit sequence) [6], SLM (selective mapping) [4], [5] and coding techniques [1],[2] are classified under Non-distortion technique. In the following subsequent sections all these techniques will be discussed theoretically and compared the Complementary Cumulative Distribution functions (CCDF's) of the PAPR through MATLAB simulations.

INTRODUCTION TO PAPR AND CCDF:

A). PAPR (Peak to Average Power Ratio)

The peak-to-average power ratio (PAPR) is a measure of the amplitude fluctuations of the signal. Any multicarrier signal with a large number of subcarriers may have a high PAPR due to coherent combining of subcarriers results in the saturation of high power amplifier (HPA). As a result, the digital-to-analog converter (DAC) and HPA with extremely large dynamic range are required to avoid the nonlinear distortion. It is defined as the ratio of the maximum to the average power.

$$PAPR_x = \frac{\max_{n \in [0, N-1]} \left\{ |x_n|^2 \right\}}{E \left\{ |x_n|^2 \right\}} = \frac{Maximum\ Power}{Average\ Power}$$

Where $E [.]$ is the expectation operator.

B) CCDF (Complementary Cumulative Distribution Function)

The Cumulative Distribution Function (CDF) is one of the important parameter used to measure the efficiency of any PAPR reduction technique. Normally, the Complementary Cumulative Distribution Function (CCDF) is used instead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold.

$$CCDF(PAPR(x(n))) = \text{Pr}ob(PAPR(x(n)) > PAPR_0)$$

III.DIFFERENT PAPR REDUCTION TECHNIQUES:

Clipping and Filtering:

One of the most simplest and signal distortion method is clipping. Using this method, the high peaks of the OFDM signal is clipped based on the predetermined clipping level prior to passing it to the power amplifier.

$$T(x(n)) = \begin{cases} x(n) & if \; |x[n]| \le A \\ Ae^{j \angle x[n]} & if \; |x[n]| > A \end{cases} ----(1)$$

Where 'A' is the clipping level. Clipping [3] is a non linear process that leads to both in-band and out-of-band distortions. Due to these distortions spectral spreading problem will occurs in the transmitted OFDM signal. This problem is eliminated by filtering the signal after clipping; the former can degrade the BER performance and cannot be reduced by filtering. However, oversampling by taking longer IFFT can reduce the in-band distortion effect as portion of the noise is reshaped outside of the signal band that can be removed later by filtering. Filtering the clipped OFDM signal can preserve the spectral efficiency by eliminating the out-of band distortion and, hence, improving the BER performance but it can lead to peak power regrowth. The block diagram of clipping and filtering is shown in fig1.below.
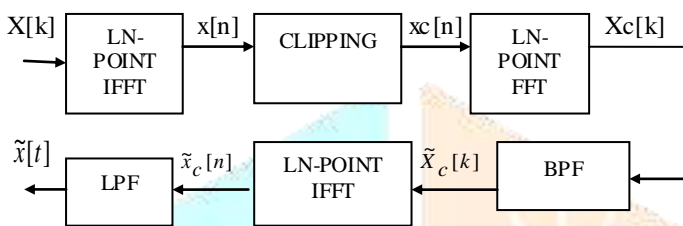

Fig: 1.Block diagram of clipping and filtering.

B Companding Transform:

However the clipping and filtering is simplest technique but it produces an additional clipping noise that degrades the system performance. Later, Wang proposed the well-known scheme named μ-law Companding technique (or named conventional Companding, Wang scheme) [7]-[11] based on speech processing, and it shows better performance than that of clipping method. However, its average signal power increases after the compression, and the compressed signals still exhibit non-uniform distributions. A new nonlinear Companding technique, called "exponential Companding" [7], is proposed to reduce the high Peak-to-Average Power Ratio (PAPR) of Orthogonal Frequency Division Multiplexing (OFDM) signals. Unlike the μ-law Companding scheme, which enlarges only small signals so that increases the average power, the schemes based on exponential Companding technique adjust both large and small signals and can keep the average power at the same level. By transforming the original OFDM signals into uniformly distributed signals, the exponential Companding schemes can effectively reduce PAPR for different modulation formats and sub-carrier sizes. Moreover, many PAPR reduction schemes, such as μ-law Companding scheme, cause spectrum side-lobes generation, but the exponential Companding schemes cause less spectrum side-lobes, and also it offers better PAPR reduction, Bit Error Rate (BER), and phase error performance than the μ-law Companding scheme. For better understanding of μ-law based, exponential based Companding and some other developed Linear and Non-Linear Companding transforms are presented in this section in mathematical and graphical form. The main advantage of Companding techniques compared to other traditional techniques like clipping & Filtering, SLM and PTS is flexibility in design and lowest computational complexity. Generally, Companding transforms are applied to speech signals, to optimize the required no of bits per sample. Since OFDM and speech signals behave similarly in the sense that high peaks occurs infrequently. So, same Companding transforms can also be used to reduce the OFDM signal PAPR because it has relatively low computational complexity compared to other PAPR reduction techniques .Companding complexity is not affected by the no of sub-carries, and one more important thing we need to mention is, Companding does not require side information and hence does not reduce bit rate. Their simplicity of implementation and the advantages they offer make Companding transforms an attractive PAPR reduction technique.

IV.DIFFERENT COMPANDING TRANSFORMS

In general Companding Transforms are classified into four types [1], [2].
1) Linear Symmetrical transform(LST)
2) Linear Asymmetrical transform(LAST)
3) Non-Linear Symmetrical transform(NLST) and
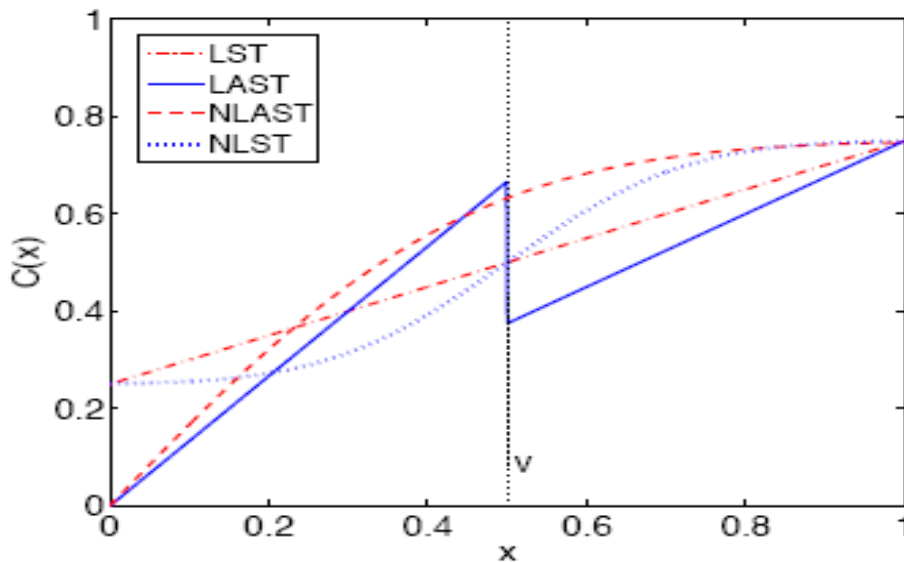4) Non-Linear Asymmetrical transform(NLSST)

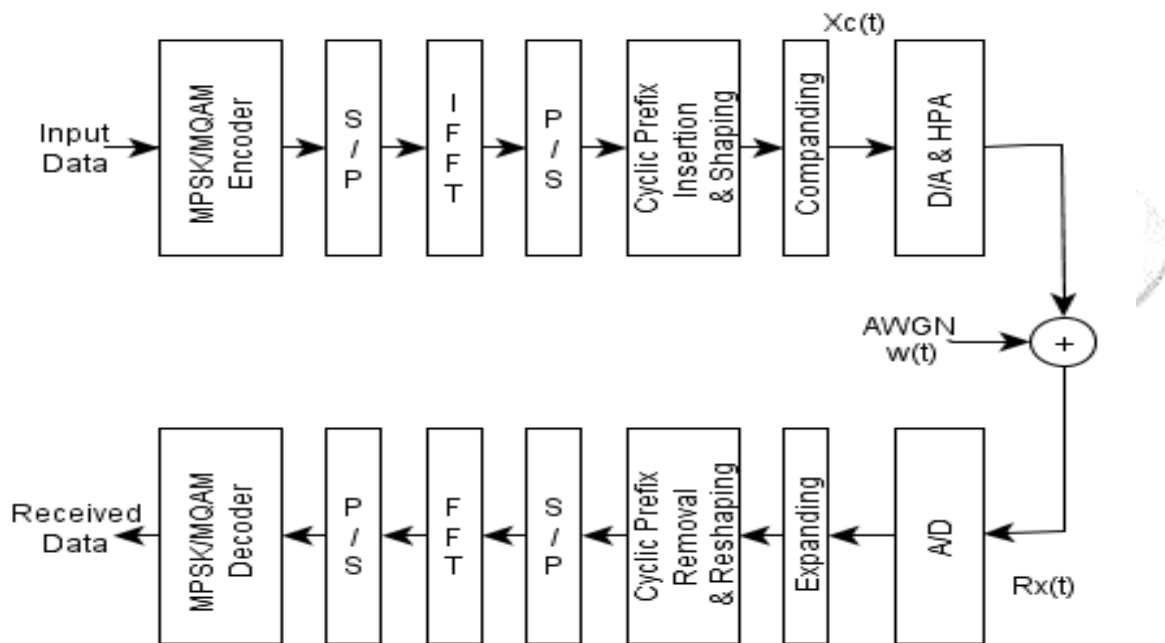Fig2: Characteristics of four transform types.

Fig 3. Basic Block diagram of OFDM Transmitter and Receiver with Companding scheme.

Some of the basic Non-Linear Companding transforms [7]-[13] used in OFDM systems are mentioned here.
a) μ-Law Companding transform defined by:

$$y = h(x) = \frac{A.sign(x).\ln(1+\mu|\frac{x}{A}|)}{\ln(1+\mu)} \quad \dots\dots\dots\dots\dots\dots(2)$$

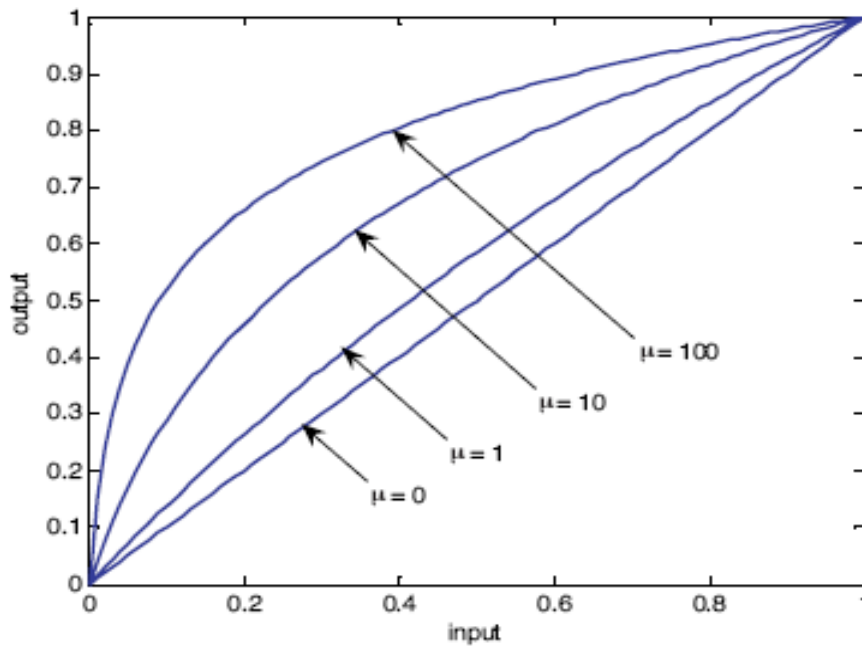Where A is a normalization constant such that $0 \le |x[n]/A| \le 1$, and μ is the Companding parameter.

Fig4.u-law Compander characteristics

b) *A-Law Companding transform defined by*,

$$y = h(x) = \begin{cases} \dfrac{1+\ln A |x|}{1+\ln A}.\mathrm{sgn}(x) \ if \ \dfrac{1}{A} \le |x| \le 1 \\ \dfrac{A|x|}{1+\ln A}.\mathrm{sgn}(x) if \ 0 \le |x| \le \dfrac{1}{A} \end{cases} ------(3)$$ Where 'A' is a value of compression parameter.
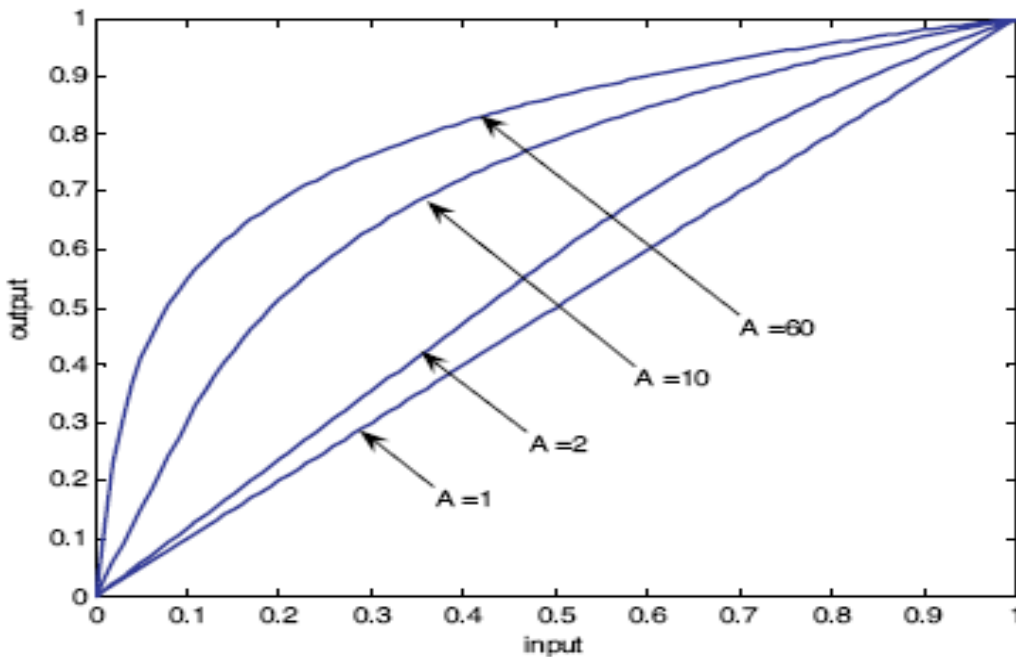
Fig5.A-Law Compander characteristics.

c) *Exponential Companding transform:*

$$y = h(x) = A.sign(x).[1 - \exp(-b\dfrac{|x|}{A}]................(4)$$

$$h^{-1}(y) = \dfrac{A.sign(y)}{-b}.\log[1 - \dfrac{|y|}{A}]...................(5)$$

d) *Companding transform using inverse hyperbolic sine   function [17]*:

$$h(x) = \begin{cases} \mathrm{sgn}(x).\gamma.ar\sinh(K|x|), |x| \le cA_x \\ \mathrm{sgn}(x).\gamma.ar\sinh(KcA_x), |x| > cA_x \end{cases} ....(6) \quad Where, \ A_x = \max_{n\in[0,LN-1]}\{|x_n|\}$$

and $ar \sinh(x) = \ln\left(x + \sqrt{x^2 + 1}\right).$

Where, $\sinh(x) = \dfrac{e^x - e^{-x}}{2}$ is the hyperbolic sine function.

C. Partial Transmit Sequence (PTS) Technique:

In PTS method [6], an input data block of N symbols is partitioned into v disjoint sub blocks. Then, rotation of phase independently (scrambling) is performed on each sub block, i.e. each partitioned sub block is scrambled by multiplying a corresponding complex phase factor and follows the IFFT operation to yield,

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

Where X is digitally modulated signal, $\{x^v\}$ is referred to as a partial transmit sequence (PTS), and b^v denotes the phase factors.
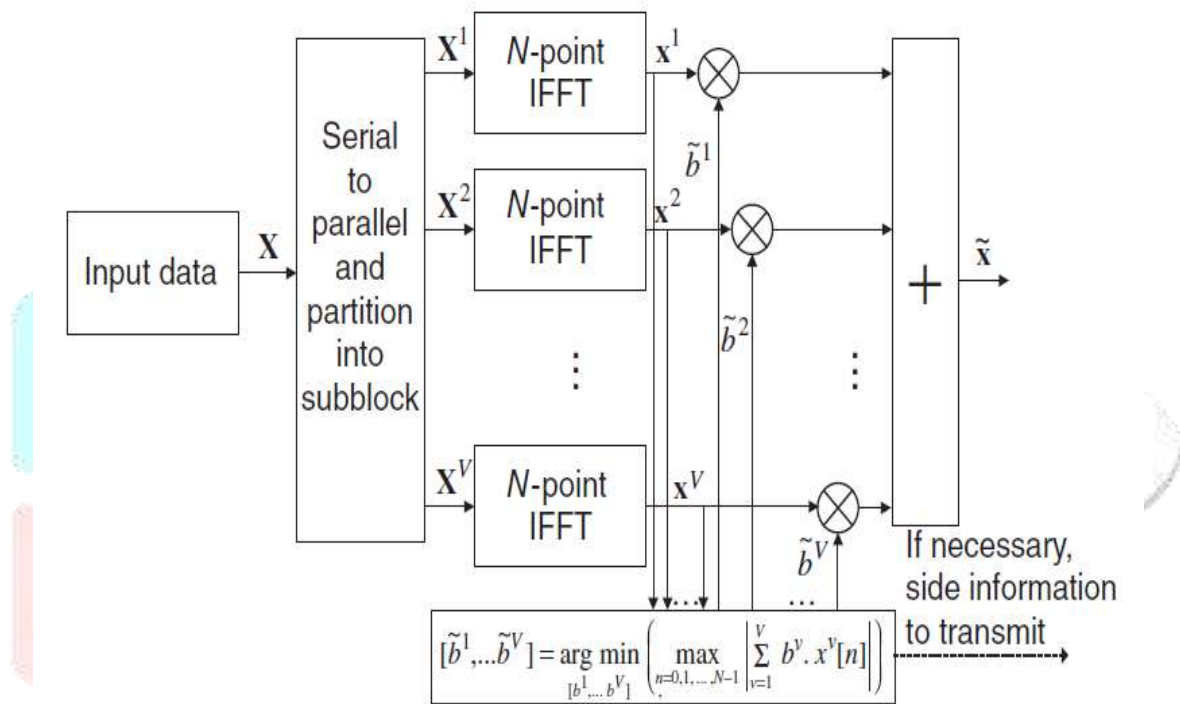

Fig: 6 Block diagram of Partial transmit sequence (PTS).

Finally, with suitable phase sequences, the signal vector with lowest PAPR is identified for transmission. If the block size increases then PAPR is reduced for different sizes of disjoint blocks. Though the significant PAPR reduction is achieved. PTS suffers from the high complexity of searching of the optimal set of phase vectors, when the number of sub blocks increases. This scheme requires v IFFT operations for each data block and a $log_2 W^v$ (W indicates the number of allowed phase factors) bits as side information is required to transmit to the receiver.

D. Selective Mapping (SLM):

It is one of the scrambling techniques [4], [5], in which the input data block is multiplied by U different phase sequences results in a modified data block. Then, among different modified data blocks, one of the data blocks is identified with lowest PAPR value for transmission as shown below.
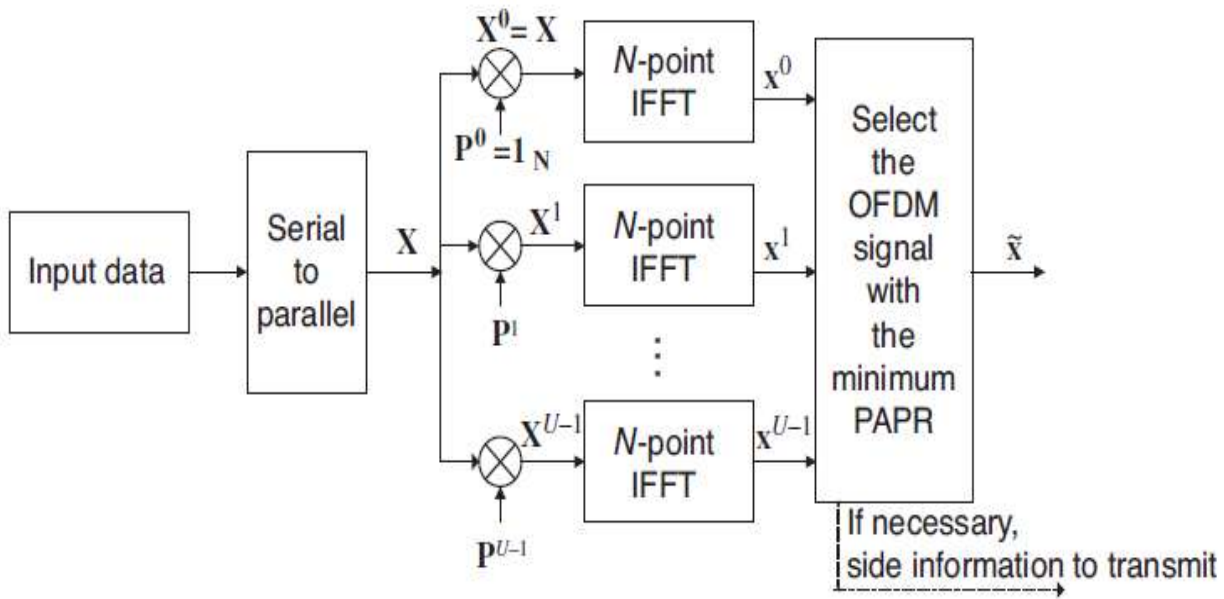
Fig: 7 Block diagram of Selective mapping (SLM)

The modified data block denoted as,

$$\tilde{u} = \arg\min_{n=1,2,\ldots U}\left(\max_{n=0,1,\ldots N_s -1}\left|x^u[n]\right|\right)$$

In order to recover the original data block at the receiver, the information about the selected phase sequence is to be transmitted as a Side Information (SI) to the receiver. PAPR plot of SLM is shown in Fig: 9. SLM suffers from the high complexity of searching the optimal set of phase sequences. To implement SLM technique, U number of IFFT operations, $\log_2 U$ bits of side information for each data block are required.

E. *Coding Techniques*:
        PAPR reduction with coding is bandwidth and power inefficient and requires high complex transmitters and receivers.

V. SIMULATION RESULTS
        In order to evaluate the performance of the different PAPR Reduction Techniques (Distortion and Non-Distortion) a MATLAB simulation was performed by considering 1024 sub-carriers in the base band OFDM system.
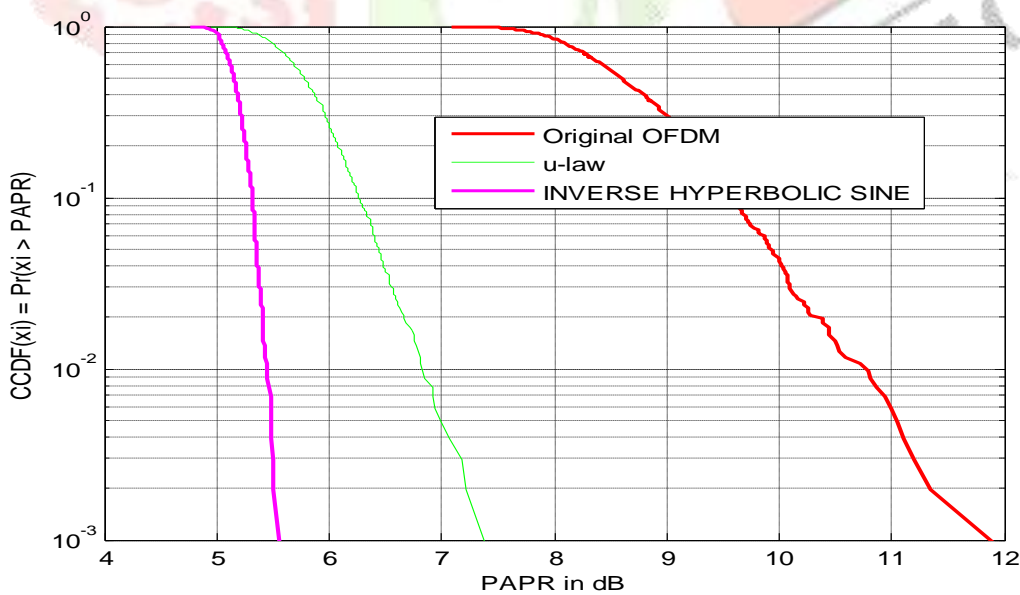

Fig: 8 PAPR vs CCDF comparison among different PAPR reduction (Distortion) techniques.
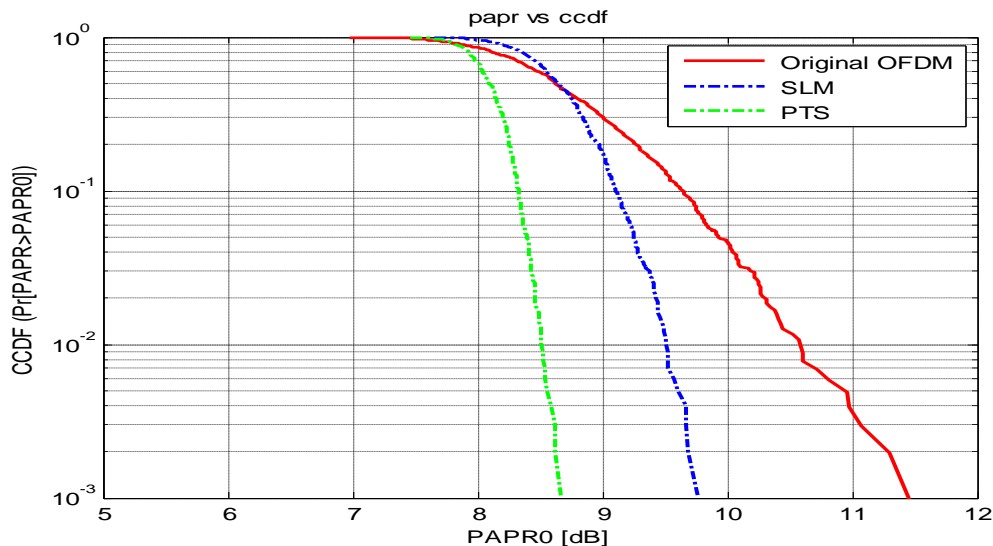
Fig: 9 PAPR vs. CCDF comparison among different PAPR reduction (Non-Distortion) techniques.

Analysis of PAPR reduction Techniques:

By observing the above PAPR reduction techniques we conclude that, distortion techniques (clipping and Companding) are simple and low complexity but non distortion techniques (PTS and SLM) are very complex. But BER performance wise Nondistortion techniques are preferable practically.

VI. CONCLUSION

OFDM plays a very important role in high speed data communication systems. But PAPR is the major problem in OFDM system. In this paper analyzed about different distortion and non-distortion PAPR reduction techniques with simulation results. This paper gives the basic idea about different PAPR reduction techniques and how they can be useful to improve the OFDM system performance by reducing PAPR.

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