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A Survey on Peak to Average Power Reduction Techniques for OFDM Systems

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier communication technique that has found its applications on several wireless technologies due to its bandwidth efficiency. One of the major challenges that OFDM faces is the high value of peak to average power ratio often termed as PAPR. Due to high value of PAPR, it becomes impossible to operate the high power amplifiers in linear region thereby creating non-linear distortion and hence degraded BER. Hence it is of primary importance to reduce the peak to average power ratio in OFDM systems. This paper focuses on different PAPR reduction techniques along with their pros and cons. It is expected that this paper will pave the path for deciding which PAPR reduction technique is the best suited for high number of sub-carriers for ever increasing number of users in present times.

***Key Words*: Bit Error Rate (BER), Clipping, Filtering SLM, High Power Amplifier, Interleaving, OFDM, PAPR, PTS.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a standout amongst the most effective adjustment methods being utilized today where high information rates are required both in wired and remote frameworks. The real preferences of this procedure are high ghastly effectiveness and productive advanced usage. The downside lies in the way that the sufficiency varieties of OFDM signals is expansive, which requires extensive back-off in the transmitter speaker and thus HPAs are not productively utilized. Keeping in mind the end goal to lessen the mutilation caused by a HPA without setting it to vast back-offs, a few methods have been presented that breaking point the pinnacle of the envelope of the flag (clipping)[1],[5], an issue that is generally alluded to as crest to-normal power proportion (PAPR) decrease. These procedures have changing PAPR-lessening abilities, power, and transmission capacity and unpredictability prerequisites. PAPR is an exceptionally surely understood measure of the envelope changes of a multicarrier (MC) communication system and assumes a conclusive part in the reception of a specific strategy. The issue of lessening the envelope changes with the extent to build the framework execution (diminish both BER and the out-of-band radiation) has come down to decreasing PAPR. In this paper we acquaint the fundamental ideas related with OFDM, the essentialness of

PAPR and different procedures formulated to decrease PAPR in OFDM systems. [1], [5]. Computational multifaceted nature of different PAPR decrease strategies have additionally been broke down and arranged. Likewise their down to earth relevance remembering the frequently restricted vitality necessities of OFDM frameworks has been specified

II.OFDM THEORY

Orthogonal Frequency Division Multiplexing or OFDM is belongs to the fundamental concept of multi carrier communication wherein the overlap or interference between carriers or typically sub-carriers is evaded by satisfying the condition of orthogonality. Mathematically the OFDM signal is given by:

$$X(u) = \Sigma X(i)\, ej2\pi i^{(u/N)}$$

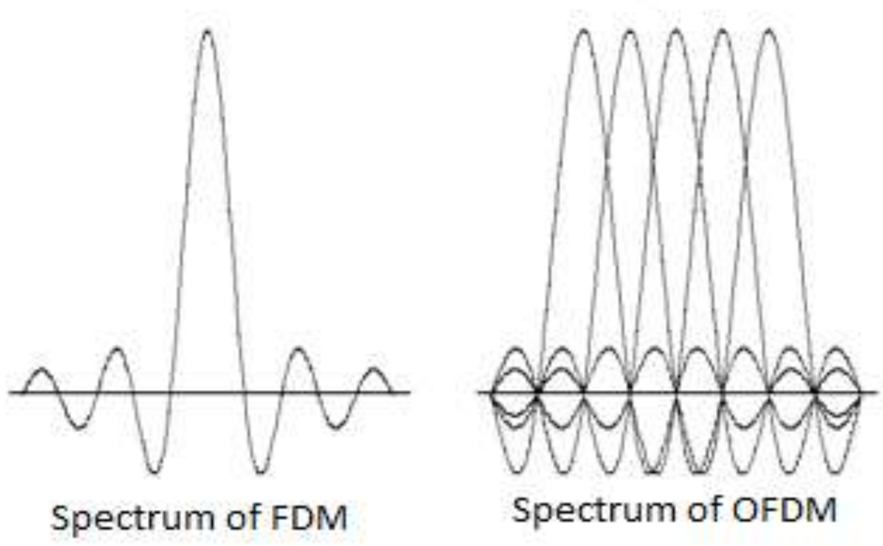

Fig-1:- Spectrum of frequency division multiplexing and Orthogonal frequency division multiplexing

The block diagram for the execution of OFDM is depicted in figure 2. The information source can be a multi-user information source which creates a serial information stream. At that point the information source is adjusted utilizing any coveted balance strategy, wherein many suitable modulation stratergy is utilized for modulating the sub carriers using the serial data bits. At that point the information is changed over from serial to parallel shape and in this way connected to the IFFT obstruct whose intention is to produce mutulally orthogonal sub-transporters on which the created sinusoidals are superimposed. As information is transmitted serially through the channel, in this way the information is changed over from parallel to serial and connected to the transmit channel which band constrains the data transfer capacity of transmission. At that point the OFDM signal is transmitted through the channel whose which may be frequency selective in nature and thereby can create distortions in the signal. Moreover the non-linear distortions in high power amplifiers becomes even more

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severe as the peak to average power attains higher values. For the sake of convenience, quadrature amplitude modulation (QAM) is shown as the modulation technique which by no means is a binding condition.

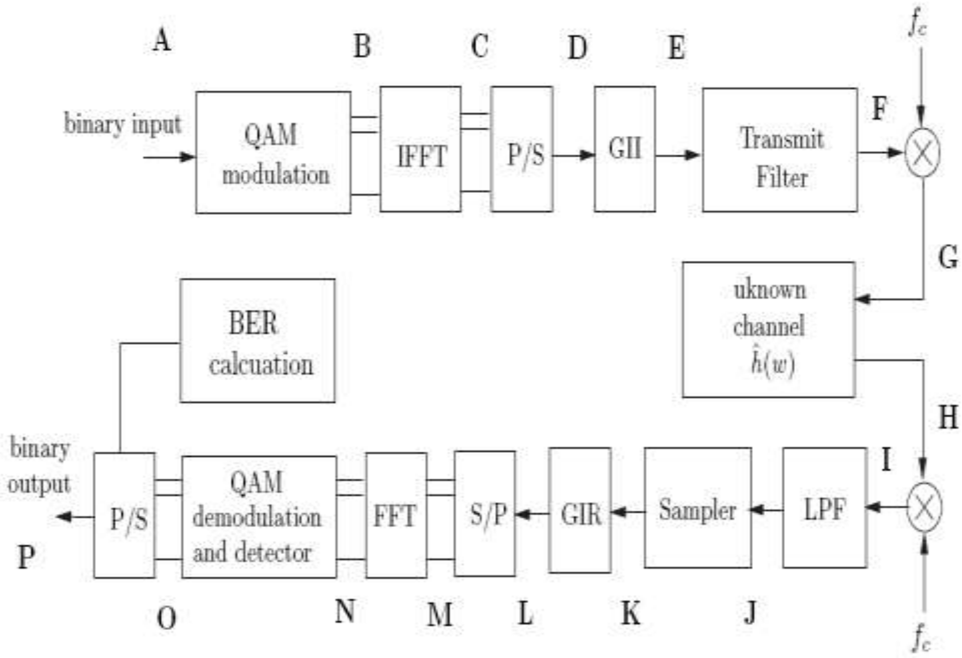

Fig-2:- OFDM Transceiver Structure

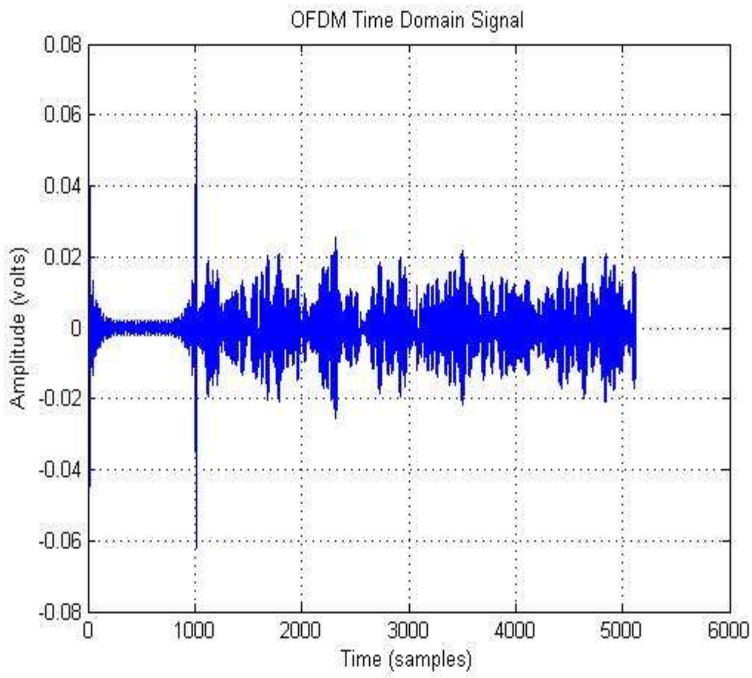

Fig-3: OFDM Time Domain Signal

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2.1 PEAK-TO-AVERAGE POWER RATIO (PAPR)

PAPR is defined as the ratio of the maximum power to the average power of the OFDM signal. Mathematically it is defined as:

$$PAPR = \max\{x^2(t)\} / mean\{x^2(t)\}$$

Where $x(t)$ denotes the time domain OFDM signal. The Complementary Cumulative Distribution Function (CCDF) is often used to analyze the magnitude of PAPR in an OFDM system, which is mathematically defined as:

$$\text{Probability}(\text{PAPR}\{x\} > Y) = 1 - (1 - e^{-y})^N$$

Here N is the number of sub-carriers, Y is any arbitrary value of PAPR above which the possibility of attaining PAPR is evaluated. The CCDF plot clearly indicates the possibility of attaining PAPR greater than a particular PAPR value. Increase in the value of PAPR increases the back off in high power amplifiers which is the root cause of not being able to maintain the amplifier characteristics in the piece-wise linear range. This causes non-linear distortions in the OFDM signal obtained at the receiver side. The following situation is depicted in the following diagram which clearly illustrates the back off causing non-linearity. In this graph shown below, the input power is indicated by P_{in} while the output power by P_{out}. It can be seen that utilizing a large part of the transfer characteristics of the non-linear amplifier, forces the non-compliance of the piecewise linear model corresponding to high input back off. (IBO)[5], [9]

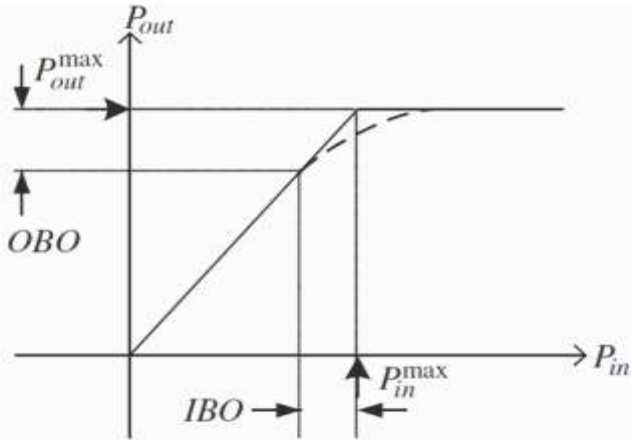

Fig-4:- Graph showing linearity between output and input power

Because of the cutoff forced on the most extreme pinnacle of the OFDM motion by the HPA, an expansion is experienced in both the in-band and out-of-band mutilations. The second causes bothersome increment in the energy of the side projections of the sudden spikes or surges in the power spectral density (PSD) of the OFDM signal. This impact is alluded to as ghastly spreading or ghostly re development. As showed in the figure, when the nonlinearity of the HPA is higher, IBO is littler, and the spreading is higher. High peaks is a result of constructive interference between the sub groups of the OFDM signal, unless the recurrence partition between adjoining subcarriers is additionally expanded to keep up orthogonally. Hence different PAPR reduction techniques are needed.

2.2 DIFFERENT TECHNIQUES FOR PAPR REDUCTION AND THEIR

COMPARISON:[9],[16],[27],[11],[13],[14]

Different PAPR reduction techniques can be broadly categorized as:

2.1.1 Signal Distortion Techniques: These can be further divided into 4 categories: [1], [5], [7]

a) Clipping and Filtering: One of the simplest signal distortion methods is the method of clipping the high peaks of the OFDM signal prior to passing it through the PA. This method employs a clipper that limits the signal envelope to a predetermined *clipping level* (CL) if the signal exceeds that level; otherwise, the clipper passes the signal without change.

$$T(x[n]) = x[n] \text{ if } |x[n]| \leq CL$$

$$CL\, e^{j\angle x[n]} \text{ if } |x[n]| > CL,$$

b) Peak Windowing: Unlike peak clipping where the peaks that exceed a predetermined threshold are hard-limited, peak windowing limits such high peaks by multiplying them by a weighting function called a window function. Many window functions can be used in this process as long as they have good spectral properties good spectral properties window functions include Hamming, Hanning and Kaiser Windows. To reduce PAPR, a window function is aligned with the signal samples in such a way that its valley is multiplied by the signal peaks while its higher amplitudes are multiplied by lower amplitude signal samples around them are multiplied by lower amplitude signal samples around the way compared to hard clipping, resulting in reduced distortion.

c) Companding [2]: Companding transforms are number of bits per sample. Since OFDM and speech signals behave similarly in the sense that high peaks occur infrequently, same companding transforms can be used to reduce PAPR. Companding has lesser complexity and also doesn't depend on the number of sub-carriers, but does degrade the BER.

d) Peak Cancellation: In this technique, a peak cancellation waveform is generated, scaled, shifted and subtracted from those sections of the OFDM signal which exhibit spectral peaks.

2.2.2 Multiple Signaling and Probabilistic Techniques:

They can be further classified into 6 categories.

a) Selective Mapping(SLM)[4],[9] : The basic idea is to generate a set of sufficient different OFDM symbols $x(m), 0 \leq m \leq M-1$, each of length N, all representing the same information as the original OFDM, and then transmitting the OFDM signal x having the smallest value of PAPR.

b) Partial Transmit Sequences (PTS) [3], [9]: In this method, an input data block of length N is partitioned into a number of disjoint sub-blocks. The IDFT for each of these sub-blocks is computed separately and then weighted by a phase factor. The phase factors are selected in such a way as to minimize the PAPR of the combined signal of all the sub-blocks.

c) Interleaved OFDM: Another method to generate multiple OFDM signals is to use interleavers, which is similar to the SLM technique but here interleavers are used in place of phase sequences.[27]

d) Tone injection & tone reservation [8], [12]: In this technique, a subset of tones is reserved for reduction of PAPR. Due to their low SNR, they carry no information but reduce PAPR by statistical redistribution.

e) Active Constellation Extension [11], [14]: In this the modulation constellation over active subcarriers in the OFD data block is modified or pre-distorted so that the PAPR is reduced but at the cost of degrading the BER.

f) Constrained Constellation Shaping [11], [12], [13]: In this technique, the modulation points over the data sub carriers in OFDM symbol are modified within an allowed error to reduce the PAPR, again BER is the tradeoff.

2.2.3 Coding Techniques for reduction of PAPR [9]:

Due to the inherent error detection and correction capabilities of different coding techniques viz. Linear Block Codes, golay Complementary Sequences, BCH codes etc, coded OFDM is a natural choice for reduction of PAPR. The coding pattern is modified in such a manner that the codes are not used to reduce BER but to reduce PAPR.

2.3 Comparison of various PAPR reduction techniques [7], [9]

Before selecting a particular PAPR reduction technique, one should bear in mind that the power required is proportional to $\mathbf{N^2}$, [27] where N is the number of sub-carriers of the OFDM system. In earlier OFDM systems, the main focus was on the simplicity of the PAPR reduction method in implementing it on hardware. Therefore, before comparing the various techniques, it becomes mandatory to analyze the computational complexity of the most common PAPR reduction techniques when it comes to hardware implementation. The table below depicts the computational complexities of the common PAPR reduction techniques. The table is critically significant keeping in mind the fact that any process that aims at reducing the PAPR is needed to do so in the time before the next frame of bits arrive, thereby making it mandatory to have a upper limit on the computational complexity of any PAPR reduction technique. The computational complexity can be evaluated in terms of the number of mathematical operations needed to be performed in implementing the algorithm.

III.TABLE

TABLE 1: COMPUTATIONAL COMPLEXITY

It can be seen from table.2 that the least complex strategy to the extent computational many-sided quality is concerned, is by all accounts the Clipping. This simplicity is at the cost of information loss though. The result in the recurrence in BER.[5],[9] Presently different frameworks like Wi-Max, Mobile-Wi-Max, LTE, DVB-T use OFDM with number of sub-carriers typically from 512, 2048 to 8192 . Selective mapping and partially

transmitted sequences seem to be one of the most effective techniques of all with a balanced approach.

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Method	Complexity
Clipping and Filtering	$4NL + 2N$ multiplications, $4NL + 2N$ additions
SLM	$2MN(1 + \log2 N) + M$ multiplications, $3MN(1 + \log2 N) + M(N - 1) - 1$ additions
PTS	$2MN \log2(N) + 2N + 1$ multiplications $3MN \log2(N) + (M - 1)[2N(M + 1) - 1]$ additions

TABLE 2: COMPARATIVE COMPLEXITY ANALYSIS [1], [3], [5], [9]

PAPR Reduction Technique	BER Increase	Implementation Complexity	Power Increase
Clipping and Filtering	Yes	low	No
Companding	Yes	low	No
SLM	No	high	No
PTS	No	high	No
Interleaving	No	high	No
Coding	No	high	Depends on the coding technique used

IV.CONCLUSION

OFDM has emerged as an indispensible technique for multi-carrier modulation. This paper presents the various techniques such as clipping, selective mapping, partial transmitted sequences, companding, interleaving, coding for PAPR reduction in OFDM systems. Also the computational complexity and PAPR reduction capability of the different techniques has been compared. It seems from the comparative analysis that SLM and PTS stand as the topmost contenders for PAPR reduction. While PTS is a slightly higher PAPR reduction capability compared to SLM, yet the computational complexity of the algorithm is a con. Moreover, hybrid techniques can be employed wherein the essence of two or more techniques can be combined to create a more effective technique.

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