Analysis of Various PAPR Reduction Techniques in OFDM System

Mohammad Abdul Raqeeb

Abstract— ORTHOGONAL Division Multiplexing (OFDM) is a modern transmission technique used widely in many digital communications. It utilizes multiple carriers that are modulated simultaneously. Though they overlap, owing to the orthogonality of sub-carriers they can be demodulated using correct time windowing at the receiver. OFDM is very effective against inter symbol interference and frequency selective fading providing high spectral efficiency. The major drawback of this system which reduces its efficiency is the distortion of the signal caused at the High Power Amplifier (HPA) of a transmitter called as Peak-to-Average-Ratio (PAPR). In this paper we are going to analyze various techniques used to reduce the PAPR in OFDM system. Simulations are used to analyze the efficiency of the techniques used which signifies Weighted OFDM to be providing much better PAPR reduction and a better Bit Error Rate (BER).

Keywords--- OFDM, PAPR, Clipping OFDM, Weighted OFDM, Partial Transmit Scheme (PTS), BER, SNR.

I. INTRODUCTION

ORTHOGONAL Division Multiplexing (OFDM) is a technique widely used in many digital communication systems such as digital broadcastings, WLANs and 4G Mobile communication. Due to its resilience to multi path fading and high spectral efficiency it provides high and better bit rate. It also accommodate large number of sub carriers subjected to orthogonality as when compared to conventional Frequency Division Multiplexing. It utilizes multiple carriers that are modulated simultaneously. Though they overlap, owing to the orthogonality of sub-carriers they can be demodulated using correct time windowing at the receiver. OFDM is very effective against inter symbol interference and frequency selective fading providing high spectral efficiency Conventional modulation schemes such as Quadrature Amplitude Modulation (QAM) and Phase shift keying at low symbol rates are used to modulate each sub carrier. Data rates in accordance with the conventional single carrier modulation schemes in the same bandwidth are maintained. The major drawback of this system which reduces its efficiency is the distortion of the signal caused at the High Power Amplifier (HPA) of a transmitter called as Peak-to-Average-Ratio (PAPR). PAPR causes performance degradation. HPA non-linearity causes in band distortion giving rise to high BER, leading to inter channel interference. Based upon the significant performance degradation of the system, various techniques have been employed to reduce the PAPR as clipping, Partial Transmit Scheme(PTS) and Weighted OFDM Section II discusses the reasons for PAPR and benchmarks to be considered for the selection a PAPR reductin technique. Weighted OFDM, Clipping and Partial Transit Scheme are proposed and a comparative analysis of these techniques are described in section III, followed by simulation results and conclusion in section IV and section V respectively

II. PEAK TO AVERAGE POWER RATIO

PAPR is caused when the phase of different sub-carriers of an OFDM system combines at the transmitter and results in the formation of large peaks causing in band distortion. PAPR is defined for each OFDM signal on a time interval [n, n+Ts] by the following formula:

For continuous signals

$$\chi_n = \frac{\max_{t\in[n,n+T_s]} |x(t)|^2}{\int |x^2(t)| \mathrm{d}t}$$

For sampled signals

$$\chi_n = \frac{\max_k |x_n[k]|^2}{E\{|x_n[k]|^2\}}$$

Certain sets of inputs in OFDM can result in large values of PAPR which overloads the non linear characteristics of a system. This results in out of band radiation and adjacent interference[2].

PAPR reduction techniques are employed based on the requirements of the system as data rate loss, spectral efficiency, computational complexity etc.

In Orthogonal Frequency Division Multiplexing sub-carriers overlapping each other are placed orthogonally. Since they are orthogonal to each other, the integral of the product of two signals is zero. The orthogonality condition for continuous time signal can be written as

$$\int_0^T \cos(2\pi n f_0 t)\cos(2\pi m f_0 t)\mathrm{d}t = 0$$

For discrete time signal condition is

$$\sum_{k=0}^{N-1} \cos(2\pi knN)\cos(2\pi knN) = 0$$

Where n and m are two different integers of the different signals, f_0 is the fundamental frequency of the subcarriers and T is the time period over which we have taken integration. Figure 1 shows the block diagram of an OFDM system with convolution scheme.

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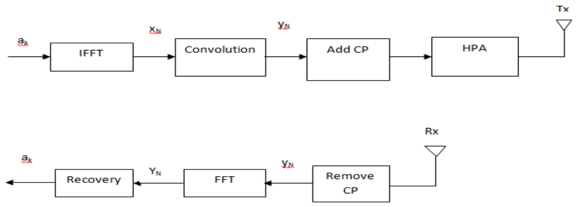

Fig.1. Block diagram of an OFDM system motivated by a convolution scheme

Figure.1shows the block diagram of convolutional OFDM system.

III. PAPR REDUCTION TECHNIQUES

A. WEIGHTED OFDM

In weighted OFDM, a special kind of a signal is used as a weight. The special signal is chosen in such a way that its fourier transform has no zero on the real line. The weight signal is then convoluted with the modulated signal. The weighted OFDM signal is the given convoluted signal.

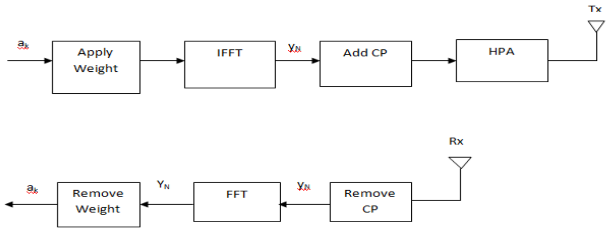

Fig.2. Block diagram of a Weighted OFDM system

The block diagram of proposed work is shown in Fig. 2. It clearly describes step by step procedure and the functional blocks of proposed system.

The idea used here is a convolution process. The modulated signal is convoluted with a special kind of signal Φ. The Fourier transform of this signal has no zero on the real line. The weighted OFDM signal is the given convoluted signal. In this proposed scheme the weighted modulated signal is given to the IFFT block[2]. It converts the signal from frequency domain to time domain. Then cyclic prefix is added to reduce ISI. Then For discrete data $\sum_{k=0}^{N-1} a_k$ modulated signal is given by X(t)= $\frac{\sum_{k=0}^{N-1} a_k * e^{-j*2*\pi*f*k*t}}{N}$

N denotes independent signals modulated onto subchannels of equal bandwidth, Δf=1/N T ,and fk=k*Δf, k=0,...,N−1. Here both real and imaginary part are uncorrelated and orthogonal. Therefore the distribution of both real and imaginary approaches Gaussian with zero mean according to Central Limit Theorem.

When added weights are non uniform , it causes degradation to bit error performance. So to avoid that in this scheme a positive constant is added to the original weight[10][4]. This constant is taken randomly. Convoluted signal is the weighted OFDM signal and is expressed as

- $\frac{\sum_{k=0}^{N-1} a_k * \varphi(2*\pi*f_k) * e^{-j*2*\pi*f*k*t}}{\sqrt{N}}$
- $\varphi_a(x) = \varphi(x) + \frac{a}{logN}$
- Z(t) = $\frac{\sum_{k=0}^{N-1} a_k * \varphi_a(2*\pi*f_k) * e^{-j*2*\pi*f*k*t}}{\sqrt{N}}$

The weighted OFDM signal'sPAPR is given as $Z_n = \frac{\max_k |Z_n[k]|^2}{E\{|Z_n[k]|^2\}}$

x

TABLE I Simulation Parameters

Parameters	Values of parameters
Size of OFDM Symbol N	64
Number of OFDM symbols to be simulated m	32
Size of Alphabet M	16
Up-sampling factor L	1.5
Type of Mapping	QAM
Constellation Phase Offset	Zero
Constellation Symbol Order	Gray
Size of cyclic prefix samples Ncp	< N
Channel	Additive White GaussianNoise(AWGN)

The input parameters for the proposed work are shown in Table I.

B.CLIPPING

Of all the PAPR reduction techniques , clipping is the most simplest and least computational to implement. In clipping, the signal's high parts which are outside the allowed threshold region are clipped. Though, this technique is simple . It has several disadvantages:

- Clipping causes in-band distortion which could effect the Bit Error Rate.
- Out-of-band radiation caused by clipping leads to adjacent channels interference.

To reduce the out-of-band distortion, filtering operation is introduced. Clipping and filtering technique for PAPR reduction is used in Fig4. N represents the number of subcarriers and L is the oversampling factor.In thediagram,The signal generated by IFFT ,$x'[m]$ is L-times oversampled signal. The FFT-IFFT filter is applied which allows the signal to pass through a band-pass filter (BPF) then through a low-pass filter (LPF).When the signal passes through the LPF there is a regrowth of the peak power. For efficient reduction of the peak power the oversampling factor is set such that the OFDM should be oversampled (L>3).The applied filter reduces the out-of-band radiation and thus reduces adjacent channels interference providing less degraded BER performance[9][6].

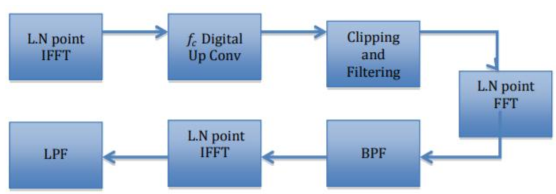

Fig-3 clipping and filtering technique for PAPR reduction

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$x[m]$ denotes the passband modulated signal with carrier frequency f. $xcp\ [m]$ is the clipped pass band modulated signal . The clipped signal is expressed as:

$$x_c^p[m] = \begin{cases} -A & x^p[m] \leq -A \\ x^p[m] & |x^p[m]| < A \\ A & x^p[m] \geq A \end{cases}$$

Iterative Clipping and Filtering operations can be used but it utilizes many iterations to reach a desired amplitude level A.

C PARTIAL TRANSMIT SEQUENCES

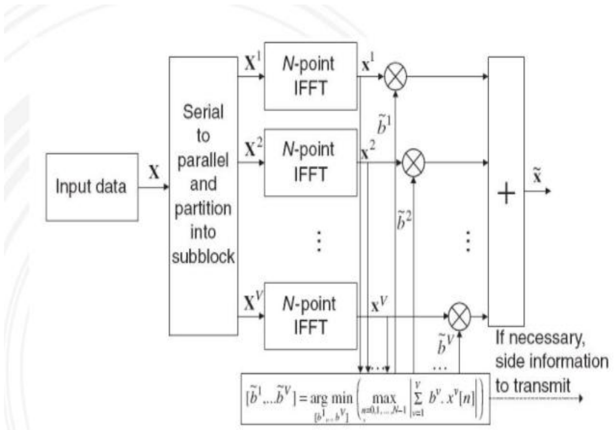

Fig-4

In the Partial Transmit Sequence technique, the frequency domain input data is subdivided into disjoint carrier sub-blocks. Phase weighting factors are selected for sub-blocks. The Phase weighting factors are applied to sub-carriers in each sub-block. Selection of the phase weighting factors are based upon the reduction in PAPR of the combined signal. Fig. 4 describes the block diagram of a Partial Transmit Sequence. Methods used for partitioning sub-blocks are classified into three categories: Interleaved Partition, Adjacent Partition an Pseudorandom Partition.We define the data block as a vector X [8][[11]. The frequency input data block X is sub divided into M disjoint carrier sub-blocks represented as X_i, {i=0,…,M-1}. Then, the sub-blocks $x^{(i)}$are converted into M time domain Partial Transmit Sequence. Data blockX partitioned into *M* disjoint sub-blocks represented by the vector X is:

$$\mathbf{X} = \sum_{i=1}^{M} \mathbf{X}_i$$

These partial sequences are independently rotated by phase factors b = {$b_i = e^{j\theta i}$}. PAPR reduction produced is proportional to optimal phase weighting factors used in the system. The main objective of the PTS method is to choose optimal phase factors. Optimal phase factors are calculated from a comprehensive Simulation of all possible combinations and comparing the PAPR reduction produced[7].This method has a disadvantage of high computational complexity to reach optimal phase factors and ineffective decoding at the receiver.

III .IMPLEMENTATION RESULTS AND DISCUSSION

The input signal used in simulation is 16QAM signal with size 64.

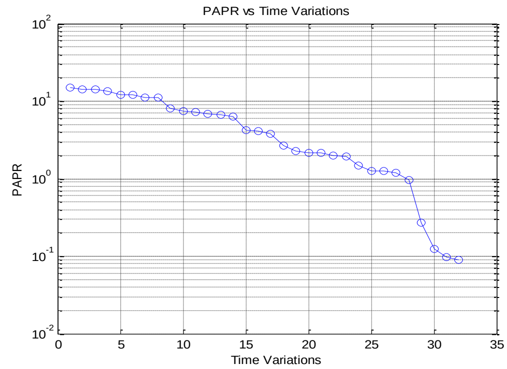

Fig.5.PAPR vs Time Variations

Figure.5 shows the plot between PAPR verses time variations in seconds for Weighted OFDM system. PAPR is reduced due to the increase of time variations.

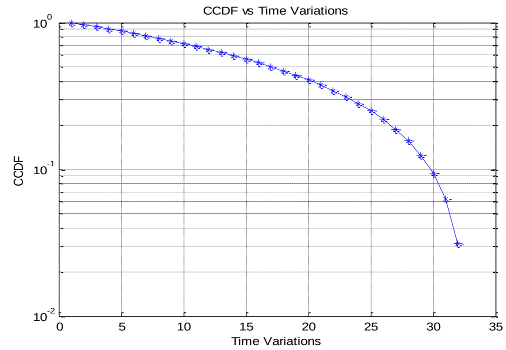

Fig.6.Complementary CDF vs Time Variations

Figure.6 gives plot between CCDF and PAPR with FFT-64 for weighted OFDM.

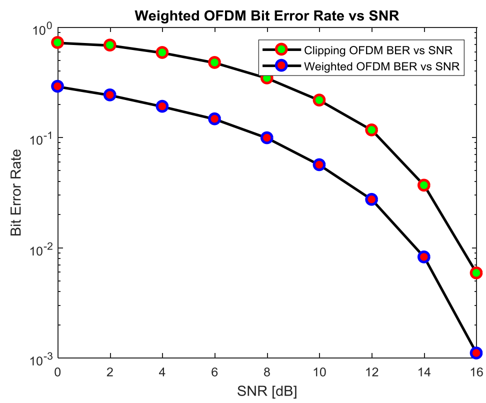

Fig.7 Bit Error Rate vs SNR

The simulation results in figure.7 show that the relation between Bit Error Rate verses Signal to Noise Ratio in terms of decibels. In this paper BER is decreased due to the increase of SNR. Weighted OFDM gives better results than Clipping OFDM.

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TABLE IIi
BER Comparisons between Clipping and WOFDM techniques

SNR in dB	BER	
	Clipping OFDM	Weighted OFDM
0	0.722	0.289
2	0.684	0.241
4	0.586	0.190
6	0.475	0.146
8	0.344	0.098
10	0.216	0.056
12	0.116	0.027
14	0.037	0.008
16	0.005	0.001

Bit Error Rate comparisons for both Clippling and Weighted OFDM(WOFDM) techniques are shown in Table II. In both methods BER is reduced due to the increase of SNR. Compare to first method proposed method BER is better. For example at 0dB BER for clipping method is 0.722 and for weighted OFDM is 0.289.For 10dB SNR first method gives 0.216 and proposed one gives 0.056.

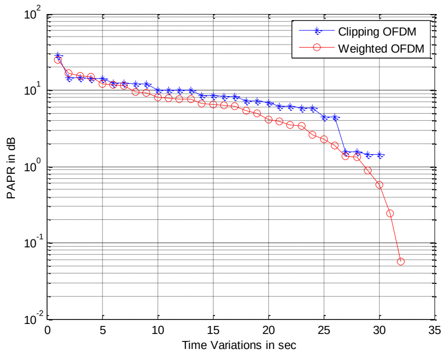

Fig.8.PAPR Comparisons between Clipping and WOFDM

In figure.8 we can see that the PAPR reduction for Weighted OFDM is better than Clipping OFDM for various values of SNR in dB.

TABLE IIIii
PAPR Reduction Comparisons between Clipping and Weighted OFDM techniques

Time Variations	PAPR	
	Clipping OFDM	Weighted OFDM
5	14.23	12.02
10	10.11	8.05
15	8.44	6.44
20	6.86	4.09
25	4.47	2.26
30	1.44	0.57

PAPR for the different time variations are shown in Table III. In both methods PAPR is reduced due to the increase of time variations. Compare to first method proposed method PAPR reduction is better. For example at 5 iterations PAPR for clipping method is 14.23 and for weighted OFDM is 12.02. For 30 iterations first method gives 1.44 and proposed one gives 0.57.Hence, we can clearly observed that the WOFDM outperforms Clipping OFDM.

PAPR reduction using PTS

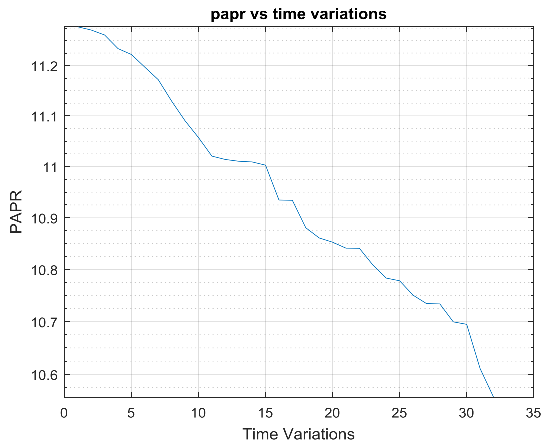

Fig.9.PAPR vs Time Variations

FIGURE.9 SHOWS THE PLOT BETWEEN PAPR VERSUS TIME VARIATIONS IN SECONDS FOR PARTIAL TRANSMIT SEQUENCE OFDM SYSTEM. PAPR IS REDUCED DUE TO THE INCREASE OF TIME VARIATIONS.

Comparison of PTS vs Weighted OFDM

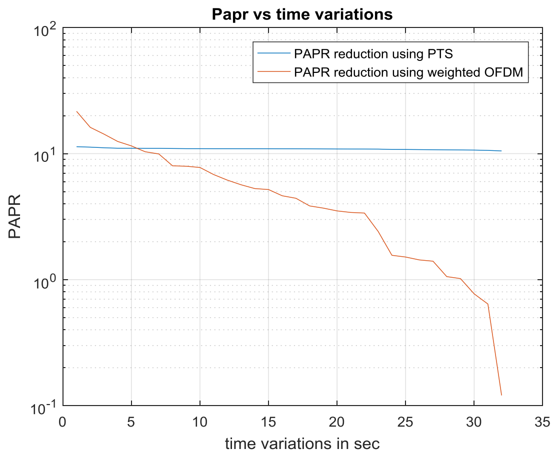

Fig.10.PAPR Comparisons between PTS and WOFDM

In figure.10 we can see that the PAPR reduction for Weighted OFDM is better than PTS for various values of SNR in dB.

TABLE V
PAPR Reduction Comparisons between PTS and Weighted OFDM techniques

Time Variations	PAPR	
	PTS	Weighted OFDM
5	11.09	12.02
10	11.28	8.05
15	10.93	6.44
20	10.86	4.09
25	10.81	2.26
30	10.66	0.57

PAPR for the different time variations are shown in Table V. In both methods PAPR is reduced due to the increase of time variations. Upon comparison, the reduction of the PAPR in PTS technique is less as when compared to the weighted OFDM technique over a period of time variations.

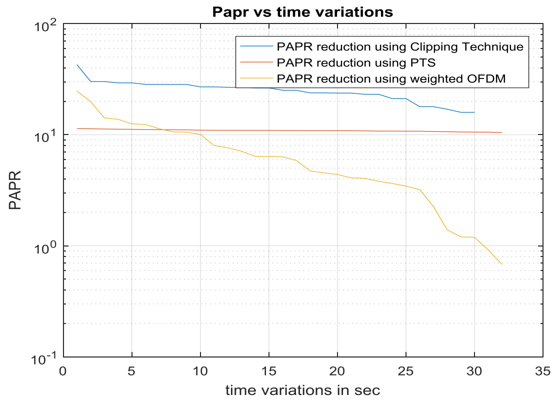

Fig.11.PAPR Comparisons between clipping, PTS and WOFDM

Simulation in the Fig.11. gives a comparison between the PAPR reduction vs Time Variations for Clipping ,PTS and Weighted OFDM PAPR reduction techniques.

TABLE VI
PAPR Reduction Comparisons between Clipping, PTS and Weighted OFDM techniques

Time Variations	**PAPR**		
	Clipping OFDM	**PTS**	**Weighted OFDM**
5	29.30	11.19	12.53
10	26.98	10.06	10.06
15	26.39	10.95	6.388
20	23.71	10.88	4.382
25	21.15	10.76	3.442
30	15.92	10.56	1.191

PAPR for the different time variations are shown in Table VI. The PAPR is reduced along with the time variations in the following PAPR reduction techniques. Upon comparison Weighted OFDM outperforms both Clipping and PTS in terms of PAPR reduction. The PTS provides better PAPR reduction than that of Clipping Technique. The PAPR in clipping technique can be increased by reducing the threshold signal value which can cause signal distortions.

IV. Conclusion

In this paper, the advantages and disadvantages of an OFDM system are analyzed. The symbol-error rate is also plotted against the signal–to–noise ratio to understand the performance for clipping and weighted OFDM system. The simulation results show that, application of the algorithm results in significant reduction in the PAPR values. It was clearly observed that the PAPR reduction in proposed approach better than that of clipping OFDM, and the BER performance is improved and all simulations are carried out using MATLAB

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