Comparison of Peak to Average Power Reduction Techniques in OFDM

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Abstract: Orthogonal frequency division multiplexing (OFDM) is a type of multicarrier modulation technique in which entire bandwidth is divided into large number of small sub-carriers and each subcarrier is transmitted parallel to achieve higher data rates. It is used in various applications like Digital audio broadcasting (DAB), Digital video broadcasting (DVB) & wireless LAN. OFDM is a attractive modulation scheme with strongly efficient in bandwidth usage, immunity against multipath fading environment. It has less ICI and ISI and provides better spectral efficiency. Although it has various advantages but still certain disadvantages are: high Peak to average Power ratio, high bit error ratio (BER) & synchronization problem. This paper will focus on various PAPR reduction techniques and conclude with comparison between various techniques.

Keywords: Orthogonal Frequency division multiplexing (OFDM), Wireless LAN, Bit Error ratio (BER), Peak to average power ratio (PAPR), Multipath fading.

I. INTRODUCTION

Due to the advances in communication technology, there is a demand for very higher data rate, the efficient modulation technique is used which is known as OFDM. OFDM stands for orthogonal frequency division multiplexing which is multicarrier modulation technique and have efficient use of bandwidth.

The basic idea of OFDM is to divide a high-rate data stream into a number of lower rate streams which are transmitted simultaneously over a number of subcarriers. These parallel subcarriers are overlapped with each other. The problem of Inter- symbol interference (ISI) is also eliminated by introducing a guard time in every OFDM symbol [7]-[8].

OFDM faces several problems. The first problem is ISI which is due to multipath. It has large peak to average ratio which results in non-linearity's of amplifier. It also has phase noise problems of oscillator, OFDM also deals with synchronization problem both in terms of timing & frequency High peak-to-average power (PAP) ratio results in the distortion of signal if the transmitter contains nonlinear components such as power amplifiers (PAs). The nonlinear effects on the transmitted OFDM symbols results in large dynamic range of the high power amplifier which results in distortion. The nonlinear distortion causes both in-band and out-of-band

The remainder of this paper is organized as follows. In section II, deals with the PAPR problem in OFDM. Section III describes various effects of PAPR. Section IV describes various PAPR reduction techniques. Section V describes comparison between various PAPR reduction techniques. Section VI describes the Conclusions.

II. PAPR PROBLEM IN OFDM

In this section, we review the basics of OFDM system and the definition of PAPR. OFDM (Orthogonal Frequency Division Multiplexing) is being widely used for wireless applications as it provides high data rate and helps to improve spectral efficiency [1]-[3]. OFDM is a multicarrier digital communication scheme where the whole available bandwidth is divided into many streams of low data rate and then modulated with various sub-carriers. One major shortcoming of OFDM is high PAPR (peak to average power ratio) [5]. To obtain efficient output power, we operate the high power amplifier (HPA) near to the saturation region. The high PAPR causes nonlinearity in the amplifier behavior. Due to which it has to work in the linear part with large head-room and this leads to very inefficient amplification. So, it becomes a necessity to reduce the PAPR for making the system efficient. To understand PAPR, we describe it as the ratio of maximum power at an instant to the average power. Here, we only consider baseband PAPR.

OFDM signal may be generated by an N point Inverse Fast Fourier Transform (IFFT) in the transmitter, and the Fast Fourier Transform (FFT) is employed at the receiver to restore the signal. Let us define input complex-valued data of N subcarriers as: $X_N = X_K, K = 0,1,2 \dots\dots N-1$ is formed with each symbol modulating the corresponding subcarrier from a set of chosen orthogonal, discrete-time OFDM symbol can be written as:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j\frac{2\pi}{NL}kn}, 0 \le n \le NL-1$$

Where; X_K is the symbol carried by the K^{th}sub-carrier, L is the oversampling factor. An OFDM signal consists of an "N" number of independently modulated subcarriers, which can give a very large PAPR when added up coherently.

Further, we can define PAPR for continuous time and discrete-time signals [5]. For a continuous-time OFDM signal, we can define PAPR as the ratio of the maximum power at an instant to the average power which is defined below:

$$PAPR\ [s(t)] = \frac{t \in \max\limits_{[0,T_S]} |s(t)|^2}{E\{|s(t)|^2\}}$$

Where s (t) is the continuous–time OFDM signal. In case of a discrete-time signal, sampling is done at Nyquist-rate in order to estimate true PAPR. But these samples need not necessarily overlap with the continuous time signal peaks. To correctly estimate the PAPR, we need to do oversampling of the OFDM signal. PAPR with oversampling factor L is given in [5]

$$PAPR[oversampling] = \max_{k\in[0,NL]} \frac{|x(k/L)|^2}{E\{|x(k/L)|^2\}}$$

Where E [ ] denotes the expected value, representing the average power of the signal and x (k/L) are samples of the OFDM signal with oversampling and defined as:

$$x[k/L] = \sum_{n=0}^{N-1} s_n e^{i2\pi kn/N}$$

Where k=0, 1,……, LN-1. For the value L=1, the samples are called Nyquist-rate samples. PAPR with Nyquist-rate sampling is:

$$PAPR[Nyquist - sampling] = \max_{k\in[0,NL]} \frac{|x(k/l)|^2}{E\{|x(l)|^2\}}$$

The CCDF of PAPR for different values of oversampling factor has been shown in [5]. This also suggests that as L increases above value 4, there is not much variation in the results. So, it is adequate to keep oversampling factor of 4 to get accurate results. In this paper, we present a survey of various PAPR reduction techniques and also a theoretical and simulated comparison of these techniques.

The rest of this paper is presented as follows. Section II illustrates various PAPR reduction techniques. Section III theoretically compares different PAPR reduction techniques including the advantages and disadvantages of these techniques. Section IV concludes and briefs about the future possibilities to this work.

Statistically it is possible to characterize the PAPR using Complementary Cumulative Distribution Function (CCDF). CCDF is the most common way to evaluate the PAPR by estimating the probability of PAPR when it exceeds a certain level. The CCDF expression of the PAPR of OFDM signals with relatively small subcarriers can be written as:

$$CCDF = P(PAPR > PAPR_0)$$
$$= 1 - (1 - exp(PAPR_O))^N$$

This equation can be interpreted as the probability that the PAPR of a symbol block exceeds some threshold level $PAPR_O$.
PAPR is a measure of the envelope fluctuations of a Multicarrier signal and it is used as figure of merit. As OFDM signal consists of a number of independently modulated symbols. The sum of independently modulated subcarriers can have large amplitude variations which results in a large peak-to-average power ratio (PAPR).

III. EFFECTS OF PAPR

As PAPR increases it results in the following effects [21]:

- It results in a **large dynamic range** of the D/A and A/D converters will be required; if the dynamic range is not increased then the peak values could be clipped, which results in signal distortion.
- If A/D and D/A converters with large working ranges are chosen, **quantization noise** will increase and the system performance will degrade.
- In addition, the choices of power amplifier and up-converters will also be crucial when PAPR problem occurs. The working range of Power amplifier & up converters is required, so that the nonlinear distortion would not be introduced which results in decreasing the **power efficiency** of Power amplifier. For example, the maximum power efficiency of a Class B power amplifier drops from 78.5% to 4.6%, when the PAPR increases 0dB to 17dB, as stated in the IEEE 802.11a standard.

IV. PAPR REDUCTION TECHNIQUES

PAPR reduction techniques can be divided into two types. These are signal scrambling techniques and signal distortion techniques [24].

The signal scrambling techniques are classified as:

- Block Coding Techniques
- Selected Mapping (SLM)
- Partial Transmit Sequence (PTS)
- Interleaving Technique
- Tone Reservation (TR)
- Tone Injection (TI)

The Signal Distortion Techniques are classified as:

- Peak Windowing
- Envelope Scaling
- Clipping

Signal Scrambling Technique Block Coding Technique

It is a type of signal scrambling techniques. In this technique PAPR is reduced by using different block coding & various set of code words. This scheme is most commonly used to reduce the peak to mean envelope power ratio.

Selective Mapping Technique

The input data sequences are multiplied by each of the phase sequences to generate alternative input symbols sequences [1]. Then for the IFFT operation each of these alternative input data sequence is used, and then the one with the lowest PAPR is selected for transmission as shown in Fig. 1.

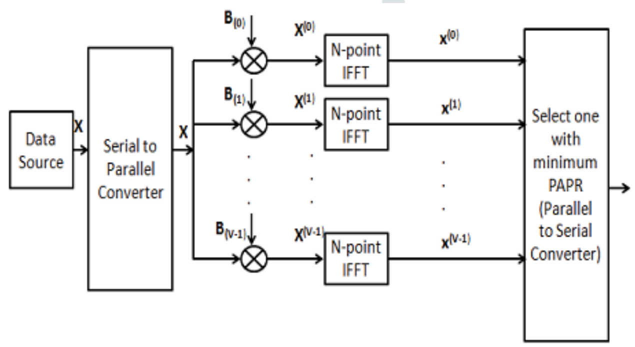

Fig. 1: Selective Mapping Method

Partial Transmit Sequences

It divide the original OFDM sequence into several sub-sequences and then for each sub-sequence is multiplied by different weights until an optimum value is chosen shown in Fig. 2.[6]

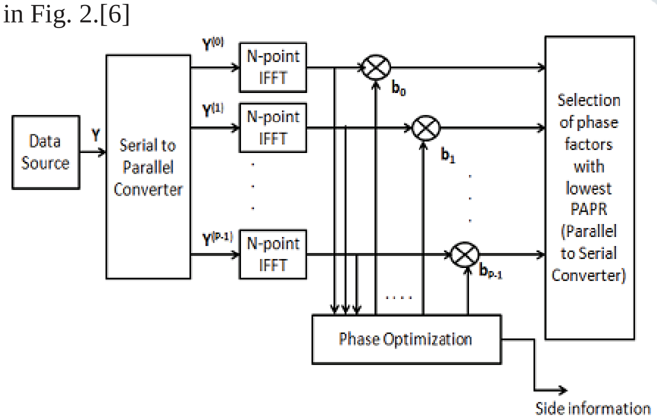

Fig. 2: Partial Transmit Sequence Method

Constant Modulus Algorithm

The Constant Modulus Algorithm (CMA) is stochastic gradient-descent type, which adjusts the equalizer filter coefficients in the direction of the negative gradient. The basic algorithm can be described as given in below equation. The filter coefficients w are updated after every cycle based on error.

$$w(n+1) = w(n) + \mu e(n)x^*(n)$$

The μ is the step size, which can be configured to adjust the convergence rate of adaptive algorithm. The e (n) is the error signal of the algorithm, while (.)* denotes complex conjugation. The iterative computations of filter coefficients w (n+1) from previous cycle coefficient values w (n). The high level block diagram of blind equalizer is given in below figure 3.

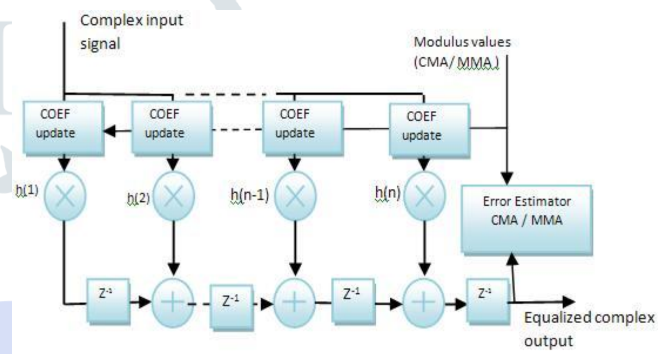

Fig. 3 High Level CMA / MMA Blind Equalizer

Interleaving Technique

It is a type of phase rotation method which is widely used to reduce PAPR (peak to average power ratio) in orthogonal frequency-division multiplexing (OFDM) system. This method reduces the PAPR without spectrum distortion. As it requires many IFFT blocks and the side information must be additional included for the correct data recovery. As the side information is used so the data rate and spectral efficiency decreases which degrades the BER performance.

Tone Reservation

Tone reservation works on the idea of reserving a number of tones to produce a signal that has reduced peak-power. It has few reserved sub- carriers which are not used for transmission purpose. These sub-carriers are termed as reserved tones. If number of tone is small then reduction in PAPR may represent non negligible samples of available bandwidth. In this method there is no requirement of side information and no process is required at the receiver. In this method the data block is added to the time domain signal to reduce the peak leads.

This technique reduces more overhead as compared to PTS and SLM. As there is no need to include the tones information separately to the signal which is ready for transmission. It is sufficient for the receiver to be aware of the positions of these tones and simply ignore them. Mathematically,

$$X = I + T$$

The receiver only needs to be aware of the positions of these tones and ignore where I is the information signal, T is the additive signal such that PAPR of x is minimized. The advantage of this technique is that it is less complex; at the receiver end, no separate processing is needed. Also, there is no need to transmit the tones information beside the data signal. On the contrary, signal power requirement increases as some of the power must be used for reservation of tones.

Tone Injection

It uses additive method for PAPR reduction .This method leads to less data rate loss. This method used the set of active constellation point for an original constellation point to reduce the PAPR. In this method for each unit, all original constellations is mapped on the several equivalent constellation point & this extra point freedom can be easily used to reduce the PAPR. This method is widely used as the tone injection method because of the newly applying points into basic constellation for the new points for larger constellation. This method deals with injecting tone of appropriate phase and frequency in OFDM symbol. The limitation of this method is the requirement of side information at the receiver side.

Signal Distortion Techniques

Peak windowing

This technique is similar to the clipping technique but it gives better performance by adding some self-interference and increasing in BER (bit error rate& out band radiation) .In this method we multiply different windows with large signal peaks e.gs Gaussian shaped window, cosine, Kaiser etc. OFDM signal is then multiplied with several of these windows, the resulting spectrum which is obtained is a convolution of the original OFDM spectrum with the spectrum of the applied window (as mentioned earlier). Means the windows should be narrow as possible. By using this technique PAPR can be reduced to 4db of each subcarrier.

Envelope Scaling

This technique is related to scaling means before OFDM signals sent to the IFFT, the input envelope for some subcarriers are scaled. This technique uses 256 sub carrier so that all sub carrier will remains equal. In this method the input envelope in some sub carrier is scaled to achieve the smallest amount of PAPR at the output of the IFFT. The receiver does not need any side information at the receiver end for decoding. This method is suitable for the PSK modulation but when it is applied with the QAM high degradation is occurred in terms of BER

Clipping Technique

The Clipping based techniques clips the time domain signal to predefined level. The OFDM signal contains high peaks so it is transferred from the clipping. In this when amplitude crosses the threshold or cut off level, the amplitude is clipped off while saving the phase. It is easier and simpler but it is a cause for decreasing the performance of system [5].

Amplitude clipping is a very basic technique to reduce PAPR. It clips the amplitude of a signal outside the specified region. This method introduces in-band and out-of-band distortion both. Out-of-band distortion reduces spectral efficiency of the transmission. On the other hand, in-band distortion hampers the error performance [6]-[9]. i.e.

$$A(y) = \begin{cases} y, y \leq C \\ C, y > C \end{cases}$$

Where C is the clipping level. It is easy to implement but it degrades the BER performance [6].

V. COMPARISON OF VARIOUS REDUCTIONTECHNIQUES

The comparison of various PAPR reduction techniques is given below in Table 1. The various PAPR reduction technique should be chosen with awareness according to the system requirements. Each method has their own advantages & disadvantages. As Selective Mapping method & Partial transmit method are distortion less methods, so it is more commonly used for PAPR reduction. SLM technique is a very efficient technique for reducing PAPR. SLM can be used for any number of subcarriers and for any signal constellation. It provides significant gain with moderate complexity. In SLM method, Channel coding is needed to protect the side information. While on the other hand PTS is probabilistic method for reducing the PAPR problem. It can be said that PTS method is a modified method of SLM. PTS method works better than SLM method. The main advantage of this scheme is that there is no need to send any side information to the receiver of the system, when differential modulation is applied in all sub blocks. Transmitting only part of data of varying sub-carrier which covers all the information to be sent in the signal as a whole is called Partial Transmit Sequence Technique. Table 1 shows the parameters of different PAPR techniques on which the reduction of PAPR depends. These parameters are distortion, power level, data rate & BER.

Table 1: Analysis of various Reduction Techniques

Reduction Techniques	Distortion Level	Power Rate	Data	BER
Block Coding Technique	Decreases	Decreases	Decreases	Decreases
Selective Mapping Technique	Decreases	Decreases	Decreases	Decreases
Partial Transmit Sequence	Decreases	Decreases	Decreases	Decreases
Interleaving Technique	Decreases	Decreases	Decreases	Decreases
Tone Reservation	Decreases	Increases	Decreases	Decreases
Tone Injection	Decreases	Increases	Increases	Increases
Peak Windowing	Increases	Decreases	Increases	Increases
Envelope Scaling	Decreases	Decreases	Increases	Increases
Clipping Technique	Increases	Decreases	Increases	Increases

VI. CONCLUSIONS

In this paper, we discuss various PAPR reduction methods. Orthogonal frequency division multiplexing technique is high speed modulation technique which provides high data rate and used in both wired and wireless systems. The major problem of OFDM system is PAPR which affects the performance of OFDM. Various techniques are available for improving PAPR and all these techniques have its own advantages and disadvantages. Every technique will minimize PAPR to some level but the best technique will be considered which not only minimize PAPR but also reduce complexity& BER.

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