

Various Techniques for PAPR Mitigation in OFDM System: A Survey

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Abstract: High peak-to-average power ratio of the transmit signal is a major drawback of multi-carrier transmission such as Orthogonal Frequency Division Multiplexing, which causes power inadequacy in Radio Frequency section of the transmitter. This paper describe some of the important PAPR reduction techniques for multi-carrier transmission including amplitude clipping and filtering, partial transmit sequence, selected mapping, and active constellation extension. Among various PAPR reduction techniques, neural network is the most powerful techniques in reducing the PAPR due its good generalization properties with flexible modelling and learning capabilities.

Keywords: OFDM; PAPR; Amplitude clipping and filtering; Partial transmit sequence (PTS); Selected Mapping (SLM); Tone Reservation (TR); Tone Injection (TI); Active constellation extension (ACE) and Neural Network (NN).

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) [1] is a multi-carrier modulation technique in which a single highrate data-stream is divided into multiple low rate data-streams and is modulated using sub-carriers which are orthogonal to each other. Another significant advantage is that the modulation and demodulation can be done using IFFT and FFT operations, which are computationally efficient. Due to many desirable properties such as high spectral efficiency, simple channel estimation, and robustness against multipath fading, therefore it is used in broadband wireless networks. OFDM has standards such as DAB/DVB (digital audio/video broadcasting), IEEE 802.11x, third Generation, fourth generation, and Worldwide Interoperability for microwave access. One of the main disadvantage of OFDM is its high peak-to-average power ratio (PAPR) because it is inherently made up of so many subcarriers. The high peaks are formed by constructively adding sub-carriers. High peak power requires High Power Amplifiers (HPA), A/D and D/A converters. Peaks are distorted nonlinearly due to amplifier flaw in HPA. If HPA operates in nonlinear region, out of band and in-band amplifier distortion in HPA.

There are many methods on PAPR reduction such as Amplitude clipping and filtering, Partial transmits sequence, selected mapping, Active constellation extension and neural network. These techniques achieve PAPR reduction at the expense of transmit signal power increase, bit error rate (BER) increase, data rate loss, computational complications increase, and so on.

In this paper Section I define the introduction of OFDM, Section II describes the PAPR, Section III describes the OFDM system model with PAPR, Section IV explains the various PAPR reduction techniques and Section V summarizes the discussion.

2. PAPR

High PAPR results from the nature of the modulation itself where multiple subcarriers/sinusoids are added together to form the signal to be transmitted[2]. The peak magnitude average might be quite low due to the destructive interference between the sinusoids. High PAPR signals are usually unwanted for it usually strains the analog circuitry. High PAPR signals would require a large range of dynamic linearity from the analog circuits which usually results in expensive devices and high power consumption with lower efficiency.

Effect of High PAPR

The linear power amplifiers are being used in the transmitter so the Q-point must be in the linear region. Due to the high PAPR Q-point moves to the saturation region hence the clipping of signal peaks takes place which generates in-band (IB) and out-of-band (OOB) distortion. So to keep the Q-point in the linear region the dynamic range of the power amplifier should be increased which again reduces its efficiency and increases the cost [1]. Hence adjustment exists between nonlinearity and efficiency. And also with the increasing of this dynamic range the cost of power amplifier increases.

Issues and Challenges

The primary factor of selecting PAPR reduction technique is the capability of PAPR reduction [3]. A technique is considered finest if it reduces PAPR largely. OOB radiation and IB distortion are rare considerable factors for selecting a technique. A technique should reduce PAPR also the average power of the signal should not increase from tolerable section. If so it will require a large linear region for operation in HPA, which will escalate the BER rate of the OFDM system. The technique should not surge the complexity of the whole system. Complexity includes both time and hardware needs for implementation of the system. Some techniques increase the bandwidth usage which causes the degradation in the throughput. Some other factors like non-linear devices such as ADC/DAC convertors and HPA should be kept into considerations as PAPR reduction avoid nonlinear distortions due to devices.

3. OFDM SYSTEM MODEL

A multicarrier signal is the sum of many independent signals modulated onto sub channels of equal bandwidth. Let us denote the collection of data symbols $X_n, n = 0, 1, \dots, N - 1$, as a vector $X = [X_0, X_1, \dots, X_{N-1}]^T$ that will be termed a data block. The complex baseband illustration of a multicarrier signal consisting of N subcarriers is given by

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \cdot e^{j2\pi\Delta f t}, 0 \leq t < NT \tag{1}$$

Where $j = \sqrt{-1}$, Δf is the space between subcarriers, and NT denotes the useful data block period. In OFDM the subcarriers should be orthogonal, $\Delta f = 1/NT$.

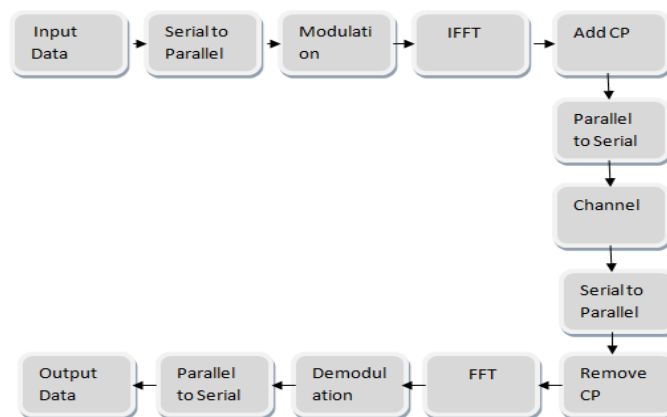


Fig.1. OFDM System

The PAPR of the transmit signal is,

$$PAPR = \frac{\max_{0 \leq t \leq NT} |x(t)|^2}{1/NT \cdot \int_0^{NT} |x(t)|^2 dt} \tag{2}$$

4. PAPR REDUCTION TECHNIQUES

In this section we focus more on the PAPR reduction techniques for multicarrier transmission.

A. Amplitude Clipping And Filtering

The amplitude threshold value is set in this process and any subcarrier having amplitude more than that value is clipped or that subcarrier is filter to bring out a lower PAPR value [4].

$$C(x) = \begin{cases} x, & |x| \leq A \\ Ae^{j\phi(x)}, & |x| > A \end{cases} \quad (3)$$

Where,

$\phi(x)$ = Phase of x .

$C(x)$ = Amplitude value after clipping.

x = the initial signal value

A = the threshold set by the user for clipping the signal.

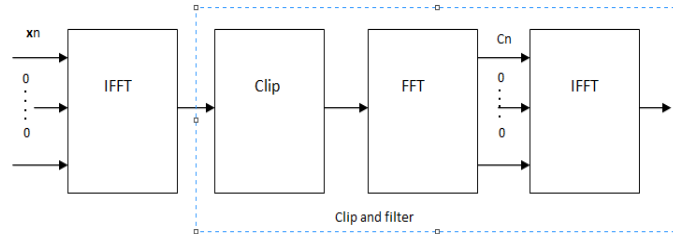


Fig.2. Clipping and Filtering

The problem in this case is that due to amplitude clipping distortion is observed in the system which can be viewed as another factor of noise. This distortion exists in both IB and OOB regions. Filtering cannot be applied to reduce the IB distortion and error performance degradation is detected here. The spectral efficiency is hampered by OOB radiation. OOB radiation can be reduced by filtering after clipping but this may result in some peak re-growth. A recurring filtering and clipping operation can be implemented to solve this problem. The preferred amplitude level is only achieved after several iteration of this process.

B. Partial Transmit Sequence

In the PTS technique, [5] an input data block X is partitioned in M disjoint sub-blocks $X_l = [X_{l,0}, X_{l,2}, \dots, X_{m,N-1}]^T, l = 1, 2, \dots, L$, such that $\sum_{l=1}^L X_l = X$ and the sub-blocks are combined to minimize the PAPR in the time domain. The Wintervals over sampled time domain signal of $X_l, l = 1, 2, \dots, L$ is obtained by taking the IDFT of length NW on X_l concatenated with $(W - 1)N$ zeros.

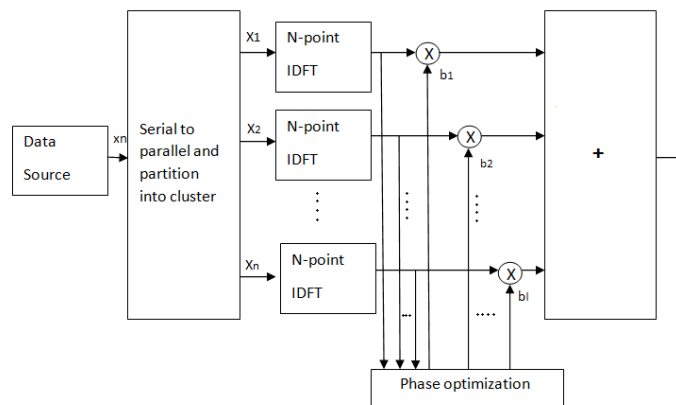


Fig.3. Partial Transmit Sequence

These are called the partial transmit sequences complex phase factor, $b_l = e^{j\phi_l}, l = 1, 2, \dots, L$, are introduced to combine the PTS. The set of phase factors is represents a vector $b = [b_1, b_2 \dots, b_l]^T$. The time domain signal after combining is given by

$$x'(b) = \sum_{l=1}^L (b_l \cdot x_l) \quad (4)$$

where $x'(b) = [x'_0(b), x'_1(b), \dots, x'_{NW-1}(b)]^T$. The objective is to find the set of phase factors that minimizes the PAPR. Reduction of PAPR is related to the reduction of $\max_{0 \leq k \leq NW} |x'_k(b)|$.

C. Selected Mapping

The main objective of this technique is to generate a set of data blocks at the transmitter end which represent the original information and then to choose the most favorable block among them for transmission [6]. Let us consider an OFDM system with N orthogonal sub-carriers. A data block is a vector $X = (x_n)_N$ composed of N complex symbols x_n , each of them representing modulation symbol transmitted over a sub-carrier. X is multiplied element with U vector $Z_u = (z_{u,n})_N$ composed of N complex numbers $z_{u,n}$ $u \in \{0,1, \dots, U - 1\}$, defined so that $|z_{u,n}| = 1$, where $|\cdot|$ denotes the modulus operator. Each resulting vector $X_u = (x_{u,n})_N$, where $x_{u,n} = (b_{u,n} \cdot x_n)$, produces after IDFT, a corresponding OFDM signal $s_u(t)$ given by

$$s_u(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_{u,n} e^{j2\pi n \Delta f t}, 0 \leq t \leq T, \tag{5}$$

Where T is the OFDM signal duration and $\Delta f = 1/T$ is the sub-carrier spacing.

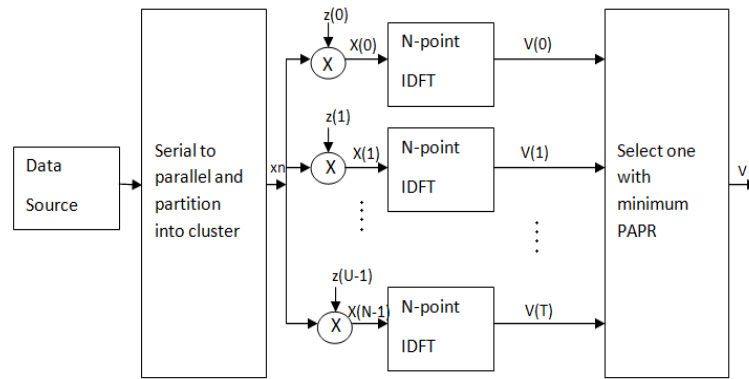


Fig.4. Selected mapping

Among the modified data blocks, the one with the lowest PAPR is selected for transmission. The value of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences.

D. The Tone Reservation Technique

Tone reservation (TR) and tone interjection (TI), [10] explained below, are two efficient techniques to reduce the PAPR of a multicarrier signal. These methods are based on adding a data-block –dependent time domain signal to the original multicarrier signal can be easily computed at the transmitter and detected at the receiver.

For the TR technique, the transmitter does not send data on a small subset of subcarriers that are optimized for PAPR reduction. The objective is to find the time domain signal to be added to the original time domain signal x such that the PAPR is reduced. If we add a frequency domain vector $F = [F_0, F_1, \dots, F_{N-1}]^T$ to X, the new time domain signal can be represented as $x + f = IDFT\{X + C\}$, where f is the time domain signal due to F. The TR technique restricts the data block X and peak reduction vector F to lie in disjoint frequency subspaces (i.e. $X_n = 0, n \in \{i_1, i_2, \dots, i_L\}$ and $F_n = 0, n \notin \{i_1, i_2, \dots, i_L\}$). The L non-zero positions in F are called peak reduction carriers (PRC). Since the subcarriers are orthogonal, these additional signals cause no distortion on the data bearing sub-carriers. To find the value of $F_n, n \in \{i_1, i_2, \dots, i_L\}$, we must solve a convex optimization problem that can easily be cast as a linear programming (LP) problem. To decrease the computational complication of LP, a simple gradient algorithm is also proposed [9].

E. The Tone Injection Technique

In this technique the constellation size so that each of the points in the original basic constellation can be mapped into several equivalent points in the expanded constellation. Since each symbol in a data block can be mapped into one of several equivalent constellation points, these extra degrees of freedom can be used for PAPR reduction. This technique is called tone injection because substituting a point in the basic constellation is equivalent to injecting a tone of the appropriate frequency and phase in the multicarrier signal.

Assume that M-ary square quadrature amplitude modulation (QAM) is used as a modulation scheme and the minimum distance between constellation points is d . Then the real part of X_n, R_n , and the imaginary part, can take values $\{\pm d/2, \pm 3d/2, \dots, \pm(\sqrt{M}-1)d/2\}$ where \sqrt{M} is equal to the number of levels per dimension. Assume that $X_n = d/2 + j.3d/2$. Modifying the real and imaginary part of X_n could reduce the PAPR of transmit signal. Since we want the receiver to decode X_n correctly, we must change X_n by an amount that can be estimated at the receiver.

F. The Active Constellation Extension Technique

Active constellation extension (ACE) [7] is a PAPR reduction technique similar to Tone injection. In this technique, some outer signal constellation points in the data block are dynamically extended towards the outside of the original constellation such that the PAPR of the data block is reduced. The main idea of this scheme is easily explained in the case of a multicarrier signal with QPSK modulation in each subcarrier. In each subcarrier there are four possible constellation points that lie in each quadrant in the complex plane and are equidistant from the real and imaginary axes. Assuming white Gaussian noise the maximum likelihood decision regions are the four quadrants bounded by the axes; thus, a received data symbol is observed. Any point that is farther from the decision boundaries than the nominal constellation point (in the proper quadrant) will offer increased margin, which guarantees a lower bit error ratio. Which allow modification of constellation points within the quarter-plane outside of the nominal constellation point with no degradation in performance.

G. The Trained Neural Network

In this scheme, the PAPR is reduced by the use of two stage neural network architecture based on time domain neural network (TNN) for time domain processing and frequency domain neural network (FNN) for frequency domain processing [8]. Both TNN and FNN are based on the multilayer feedforward network with two layers and neurons per layer with triangular activation function. The TFNN is trained using the ACE signal as the desired signal with the Levenberg-Marguardt algorithm as the learning algorithm. The time domain OFDM signal X is used as training input signal to the TNN. The time domain ACE signals X_{ace} is used as the desired signal [11].

H. Table of various PAPR Reduction Techniques

Many of the PAPR reduction techniques do not consider the effect of the components in the transmitter such as the transmit filter, digital-to-analog (D/A) convertor, and transmit power amplifier. In practice, PAPR reduction techniques can be used only after careful performance and cost analyses for realistic environments.

In Table we conclude the PAPR reduction techniques.

Table I. *PAPR Reduction Techniques*

PAPR Reduction Techniques	PARAMETERS		
	<i>Distortion less</i>	<i>Rise in Power</i>	<i>loss of Data Rate</i>
Clipping and filtering	NO	NO	NO
PTS	YES	NO	YES
SLM	YES	NO	YES
TR	YES	NO	YES
TI	YES	YES	NO
ACE	YES	YES	NO
NEURAL N/W	YES	NO	NO

5. SUMMARY

Multicarrier transmission is a very attractive technique for high-speed transmission over a dispersive communication channel. The PAPR problem is one of the main issues to be addressed in developing multicarrier transmission systems. In this article we describe some PAPR reduction techniques for multicarrier transmission. Many promising techniques to reduce PAPR have been recommended, all of which likely to provide substantial reduction in PAPR at the cost of loss in data rate, transmit signal power increment, Bit error Rate increment, computational complication increment, and so on. No specific PAPR reduction technique is the best solution for all multicarrier transmission systems. Rather, the PAPR reduction technique should be carefully chosen according to various system requirements. In practice, the effect of the transmit filter, D/A convertor, and transmit power amplifier must be taken into consideration to choose an appropriate PAPR reduction technique.

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