

OFDM PAPR reduction for image transmission using improved tone reservation

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ABSTRACT

High peak to average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) is an important problem, which increase the cost and complexity of high power amplifiers. One of the techniques used to reduce the PAPR in OFDM system is the tone reservation method (TR). In our work we propose a modified tone reservation method to decrease the PAPR with low complexity compared with the conventional TR method by process the high and low amplitudes at the same time. An image of size 128×128 is used as a source of data that transmitted using OFDM system. The proposed method decrease the PAPR by 2dB compared with conventional method with keeping the performance unchanged. The performance of the proposed method is tested with several numbers of subcarriers; we found that the PAPR is reduced as the number of subcarriers decreased.

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1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a technique used to transmit a high speed data. The concept of OFDM is the spreading of the high speed transmitted data over a large number of subcarriers [1]. The OFDM system covers the requirements for wireless image and video communication services. The image has big size and needs long time to transmit over wireless channel in OFDM system, the transmitted image is needed to be coded by two types of coding, the first is the source code to reduce redundant data in the image, decreasing the image size and transmission time, the second is the channel code, which is helpful for error detection and correction [2-4].

The peak to average power ratio (PAPR) provides a measure for the variation range of signal power. The PAPR is high in OFDM because the nature of modulation, where multiple subcarriers are added together to form the transmitted signal. These large peaks increase the probability of leakage energy to the neighbor channel, which lead to signal distortion in the output of power amplifier and degrade the error rate performance due to the system constraint to a limited peak power of dynamic range in transmitter amplifiers. Thus, a large power amplifier has needed. However, increasing the large power in amplifier not only reduces the power efficiency but also increase the amplifier cost significantly [5, 6].

Several approaches have been introduced to reduce PAPR, but, these methods increase the expense of transmitted signal power, degrade the bit error rate, increase the computational complexity, and lead to loss of data rate, so, a system trade-off is predicted [7]. One can divide the methods used to reduce the PAPR of an OFDM signal to four categories: i) signal distortion, ii) coding methods, iii) probabilistic (scrambling) techniques and iv) pre-distortion methods [8, 9]. The pre-distortion methods attempt to reorient or spread

the energy of data symbol. The pre-distortion schemes include the DFT spreading, pulse shaping or pre-coding and constellation shaping. The tone reservation (TR) is one example of constellation shaping methods [10].

Tone Reservation technique has based on reserving some tones to reduce PAPR. The PAPR reduction amount depends on the number of the reserved tones and their position. The performance of TR also depends on the amount of complexity and reserved tones power. This technique can be applied to every type of OFDM system. In this method, transmission of side information is not necessary at the receiver [11]. In this paper an image is used as a source of data, good quality received image with PAPR reduction is the aim of this paper. TR method is used for PAPR reduction, new proposal is introduced to improve the clipping based TR method, by clipping the high amplitudes and amplifying the low amplitudes, the method aims to decrease the number of iterations with parameters changeable at each iteration.

Many papers work on TR method improvement, where Horvath and Botlik made optimization for TR by changing clipping ratio in each iteration to make limits for the peak values. In our work, we make clipping for the maximum values and amplification for minimum values, the PAPR reduction in this work increases with increasing the number of iterations but in our work the increasing of number of iteration is not useful [12]. Ali *et al.* decrease the complexity of TR technique. The PAPR reduction in this work is less than that in our work [13]. Antonov *et al.* decrease TR complexity, by randomly generation of different combinations of manipulation symbols, which lead to the additional subcarriers, equally spaced over the signal bandwidth. They need one hundred iterations in their work, but in our work, we need three iterations [14]. Abdelali *et al.* make combination of TR method and clipping method to improve PAPR reduction. They need high number of iterations and the bit error rate is more than that in our work [15]. Shixian Lu *et al.* suggest a sliding window, tone reservation PAPR reduction technique. They need fifty iterations to reach to good results but we need three iterations [16]. The modification of Tone Reservation method to reduce PAPR ratio with multicarrier non-orthogonal signal is introduced in [17].

The organization of this paper is as follows: an overview of OFDM system and PAPR definition has introduced in section 2. In section 3 an explanation for tone reservation method will be presented. Section 4 presents the proposed algorithm. Performance measurements in section 5. In section 6 the simulation results for the used technique will be presented and discussed. Finally, the conclusions for the used technique has shown in section 7.

2. OFDM SIGNAL MODEL AND PEAK TO AVERAGE POWER RATIO (PAPR)

An OFDM systems use orthogonal and independent subcarriers, where the modulation process can be easily implemented using simple N-point inverse fast Fourier transform (IFFT) operation, the output signal is a summation of modulated complex harmonics [12] that can be expressed as [13, 18]:

$$x(t) = \frac{1}{N} \sum_{k=0}^{N-1} s_k e^{j2\pi f_k t} \quad 0 \leq t \leq T_s \quad (1)$$

where s_k is the data symbol transmitted on the k^{th} sub carrier f_k , the subcarrier index is denoted by k and T_s is the symbol duration.

OFDM systems introduce high PAPR due to the use of a large number of subcarriers [19], for a continuous time baseband OFDM signal, the definition of PAPR of any signal is the proportion of the maximum instantaneous power of the signal to its mean power. If $x(t)$ represents a baseband transmitted OFDM signal, then

$$PAPR[x(t)] = \frac{\text{MAX}_{0 \leq t \leq T_s} |x(t)|^2}{P_{av}} \quad (2)$$

where, P_{av} is the average power of $x(t)$ which can be computed in frequency domain because IFFT is a unitary transformation. T_s represents the useful duration of an OFDM symbol [8].

The complementary cumulative distribution function (CCDF) has used to describe a distribution of a random variable [11]. The distribution of PAPR may be expressed in terms of (CCDF), which is represents the probability that the PAPR of an OFDM symbol exceeds a given threshold $PAPR_0$, which is denoted as [1, 20].

$$CCDF(PAPR_0) = P(PAPR > PAPR_0) = 1 - P(PAPR_0) \quad (3)$$

The CCDF has also used to evaluate the performance of PAPR reduction in OFDM systems [1, 20]. Tone reservation method is one of the many techniques, which have introduced in the literatures to reduce the PAPR of an OFDM signal.

3. TONE RESERVATION METHOD

In TR schemes, some of the total number of tones N are reserved as a peak reserved tones (PRTs) and stored in the reserved tones vector $PRT = \{p_0, p_1, \dots, p_{z-1}\}$, where z is the size of the PRT set. With TR methods, the OFDM k th data block X_k^{TR} configured from two parts, the peak reserved tones that are stored in the PRTs and denoted by X_k^{tr} and the unreserved tones X_k , i.e., [13, 21].

$$X_k^{TR} = X_k + X_k^{tr} \quad k = 0, 1, 2, \dots, N - 1 \quad (4)$$

There are different methods for tone reservation technique, kernel based and clipping based TR methods have explained below.

3.1. Kernel based (TR-K) method

This method creates a reference kernel vector p_n , which is an impulse function has FFT size, in the kernel vector the reserved tones positions will set to one, and all other values are updated to zero. The kernel will update with a single peak and all the other samples would be zero, but this is impractical because of the limited bandwidth. In every iteration i the maximum amplitude A^i of OFDM signal x^i and its position m^i has to be found. The position of the maximal amplitude of the kernel vector is circularly shifting to the position m^i , the adding of kernel vector to the original input reduces the peak to a previously determined wanted clipping level. The following equations will explain the method:

$$x^{i+1} = x^i - \alpha^i p_n(m^i) \quad (5)$$

$$\alpha^i = \frac{x^i(m^i)}{A^i} (A^i - A_{max}) \quad (6)$$

where A_{max} is the clipping amplitude and $p_n(m^i)$ is the circularly shifted kernel, then the PAPR value is calculated [12, 22].

3.2. Clipping based (TR-C) method

This method is shown in Figure 1. In clipping method, a generated signal r_n is subtracted from the original OFDM symbol x_n :

$$b_n^i = x_n^i - r_n^i \quad (7)$$

where

$$r_n = \begin{cases} x_n, & |x_n| < A_{max} \\ A_{max} e^{j\phi(x_n)}, & |x_n| \geq A_{max} \end{cases} \quad (8)$$

r_n is the clipped signal and the maximum clipped signal is A_{max} , $\phi(x_n)$ is the phase of x_n . In the frequency domain:

$$B_k = FFT(b_n) \quad (9)$$

$$B'_k = \begin{cases} B_k, & k \in PRT \\ 0, & k \notin PRT \end{cases} \quad (10)$$

where PRT is the matrix of the positions of clipped signals ($b_n \neq 0$). B'_k is the same as B_k matrix in the clipped signal position and will be zero in the other positions.

$$b'_n = IFFT(B'_k) \quad (11)$$

$$x_n^{i+1} = x_n^i + \mu b_n^i \quad (12)$$

The clipped signal b'_n is added to the original OFDM signal x_n with weight parameter μ and this operation is repeated for several iterations until minimum PAPR is obtained for the resulting signal y_n , the symbol i denotes for each iteration [12, 22].

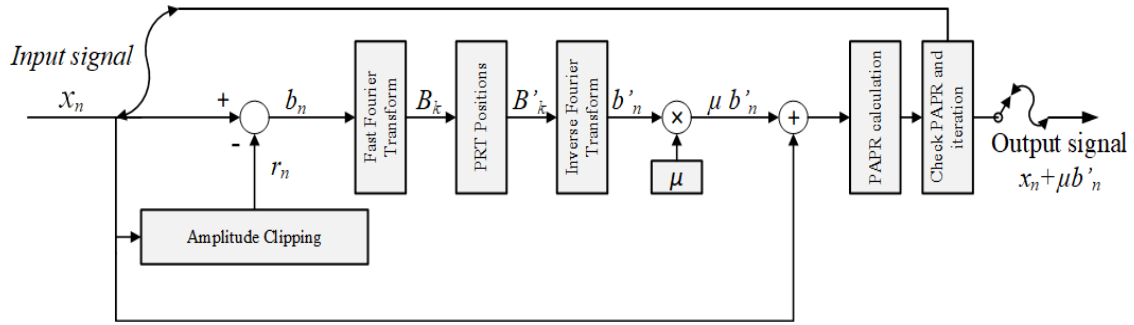


Figure 1. Block diagram of TR-C original method

4. PROPOSED ALGORITHM

The proposed work does not need any processing at the receiver as the original TR, but we improve the TR_C method by clipping the maximum peaks of original signal which exceed a limited A_{max} level and amplify the lowest values of original signal which are lower than a limited level A_{min} , see Figure 2.

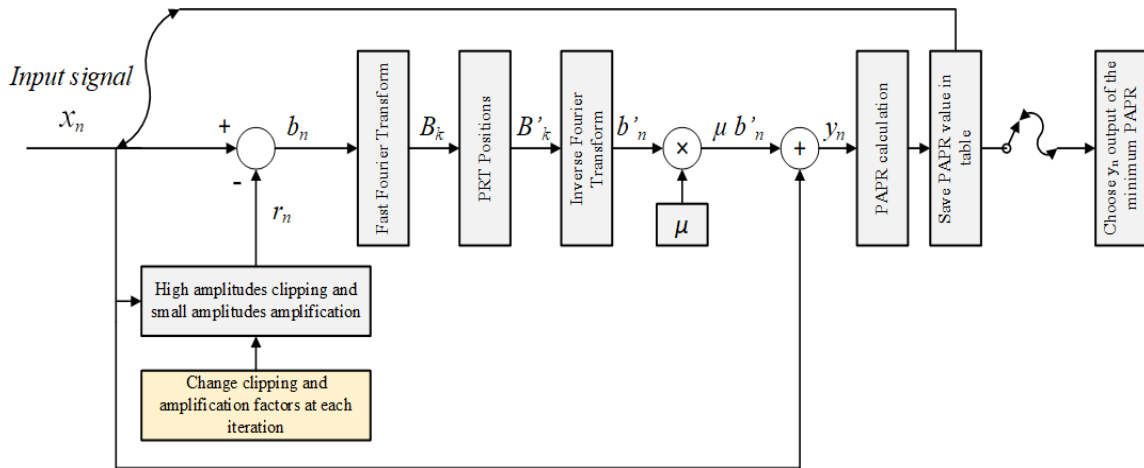


Figure 2. Block diagram of proposed TR-C

$$r_n = \begin{cases} x_n, & \text{if } A_{min} < x_n < A_{max} \\ \alpha x_n, & \text{if } x_n < A_{min} \\ \beta x_n, & \text{if } x_n > A_{max} \end{cases} \quad (13)$$

Where α is a factor more than one multiplied with the original signal to amplify the low levels, β is a factor less than 1 multiplied with the original signal to minimize the high levels of signal, by this method the maximum is minimized with keeping the average value of the overall messages close to the original value and minimizing PAPR, see (2). In this technique A_{max} and A_{min} are changed in each iteration, their values are ratio of the largest signal x_n , which is called x_{nmax} . The values of α and β are also changed in each iteration. Four cases can be obtained by changing A_{max} , A_{min} , α and β :

- 1) Case1: decreasing α by $(1 + 0.1Mi - 0.1i)$ with increasing A_{min} by $((0.1i)x_{nmax})$, in the other side decreasing β by $(1 - 0.1i)$ with increasing A_{max} by $((0.5 + 0.1i)x_{nmax})$.
- 2) Case2: increasing α by $(1 + 0.1i)$ with decreasing A_{min} by $((0.5 - 0.1i)x_{nmax})$, in the other side decreasing β by $(1 - 0.1i)$ with increasing A_{max} by $((0.5 + 0.1i)x_{nmax})$.
- 3) Case3: decreasing α by $(1 + 0.1Mi - 0.1i)$ with increasing A_{min} by $((0.1i)x_{nmax})$, in the other side increasing β by $(0.5 + 0.1i)$ with decreasing A_{max} by $((1 - 0.1i)x_{nmax})$.
- 4) Case4: increasing α by $(1 + 0.1i)$ with decreasing A_{min} by $((0.5 - 0.1i)x_{nmax})$, in the other side increasing β by $(0.5 + 0.1i)$ with decreasing A_{max} by $((1 - 0.1i)x_{nmax})$.

Where the maximum number of iterations is Mi and i is the iteration number ($i = 1, 2, \dots, Mi$). At each iteration the output y_n is obtained as in (14), it is saved in table with its PAPR value, then the output with minimum value of PAPR is taken in this technique.

$$y_n^i = x_n^i + \mu b_n^i \quad (14)$$

5. PERFORMANCE MEASUREMENTS

The transmitted data in this paper is image. Measurements for checking the received image quality has often used, peak signal to noise ratio (PSNR) and mean squared error (MSE) of the decoded received image are measured with respect to the transmitted one as follows:

$$MSE = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N |X_1(i, j) - X_2(i, j)|^2 \quad (15)$$

where M and N are the image vertical and horizontal dimensions, X_1 and X_2 are the transmitted and received images respectively, MSE is a metric used to measure the amount of errors in the received image with respect to the transmitted one. PSNR measures the precision of image decoding, better image quality PSNR is greater than 20dB [23-25].

$$PSNR = 10 \log_{10} \left(\frac{255^2}{MSE} \right) \quad (16)$$

6. SIMULATION AND RESULTS

In this work colored image of Lenna with size 128×128 is used, the image is coded using Huffman source code and BCH channel code, and transmitted over OFDM system with parameters shown in Table 1, under additive white Gaussian noise (AWGN) channel. Mat-lab 2018a is used in the simulation.

Table 1. Parameters used in simulation

Name of Parameters	Value
System	OFDM
Modulation	16QAM
Num. of subcarriers	64 to 1024
Band width	20MHz
Num. of symbols	49152
Value of μ	-1

CCDF is computed for the transmitted OFDM signal without any PAPR reduction and is compared with CCDF of OFDM signal with conventional TR technique and the CCDF of signal with the four cases of proposed TR technique (FFT size=256), see Figure 3, from this figure the PAPR is reduced about 2dB for proposed TR with respect to the PAPR of FFT signal without any PAPR reduction, the PAPR is similar among the four cases of proposed TR, it is clear that the proposed TR PAPR with $Mi=3$ reduce the PAPR more than for conventional TR with $Mi=10$.

In the other side the CCDF and bit error are computed and compared for the signal with different subcarriers number, the first case of proposed TR is computing with $Mi=3$. The CCDF of the signal with different number of subcarriers is shown in Figure 4, from this figure we find that the PAPR reduced as the number of sub carriers increased. The bit error for them is shown in Figure 5, from this figure we find that the larger number of subcarriers has the less BER at the same signal to noise ratio (SNR).

The CCDF of the OFDM signal with proposed TR first case and FFT size=256 are shown and compared in Figure 6 for two different maximum number of iterations, for $Mi=3$ and $Mi=5$, from the figure we can see that the PAPR reduction with $Mi=5$ is more than the PAPR reduction with $Mi=3$ by a small value, at the same time the BER=1.0173e-05 at SNR=10dB for $Mi=3$, but the BER=3.0518e-05 at SNR=10dB for $Mi=5$, the BER for $Mi=5$ is worse than that for $Mi=3$ by a small value.

The proposed TR (first case and $Mi=3$) is used to reduce the PAPR for Lenna image which is transmitted with OFDM. The original and the received image are shown in Figure 7 for different numbers of subcarriers with SNR=10dB. The received image with FFT size=256, but for different values of SNR are shown in Figure 8. From Figure 7, we found that image transmitted with higher number of sub carriers has the better peak signal to noise ratio (PSNR), and from Figure 8 we show that the image at smallest SNR has the smallest PSNR.

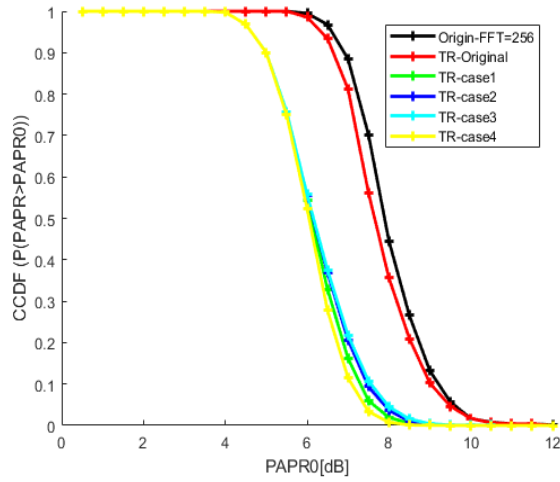


Figure 3. CCDF of PAPR for OFDM signal with four cases of proposed TR PAPR reduction, original OFDM signal without PAPR reduction and with original TR-C method

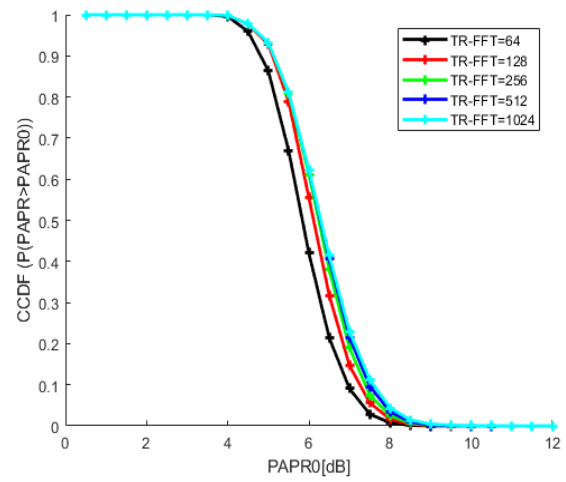


Figure 4. CCDF of PAPR for OFDM signal with proposed TR first case and different number of subcarriers

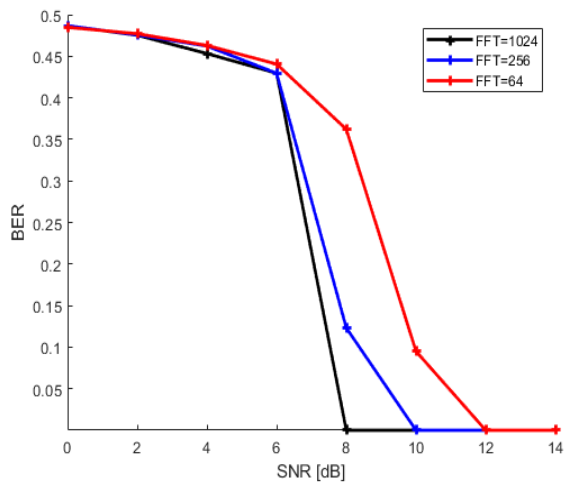


Figure 5. BER of the OFDM signal with proposed TR for different number of carriers

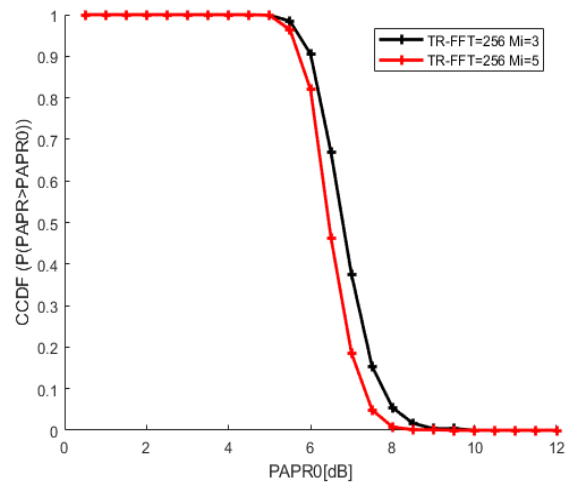


Figure 6. CCDF of PAPR for OFDM signal with proposed TR for two different maximum number of iterations



Figure 7. Lena image: original and received image with different FFT size, (a) Original image, (b) SNR=10 dB, FFT size=64, PSNR=46, (c) SNR=10 dB, FFT size=128, PSNR=71.5



Figure 8. The received Lenna image with different SNR, (a) SNR=10 dB, FFT size=256, PSNR=71.5, (b) SNR=8 dB, FFT size=256, PSNR=20.7147, (c) SNR=6 dB, FFT size=256, PSNR=13.5189

7. CONCLUSION

From the simulation results, one can conclude that clipping the high amplitudes and amplifying the low amplitudes lead to reduce the number of iterations compared with the conventional TR method and enhance the overall system performance. The proposed method is applied in this paper on the image transmission; this method can also be applied on another data such as speech or video transmission.

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