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PAPR REDUCTION OF OFDM BASED ON ADAPTIVE ACTIVE CONSTELLATION EXTENSION

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ABSTRACT

One of the main disadvantages of Orthogonal Frequency Division Multiplexing (OFDM) is its high peak-to- average power ratio (PAPR). As the simplest approach to reducing the PAPR, Clipping based Active Constellation Extension (CB-ACE) exhibits good practicability, and the repeated clipping-and-filtering (RCF) algorithm proposed by Jean Armstrong provides a good performance in PAPR reduction and out-of-band power's filtering. However, its way of filtering in frequency-domain requires RCF operations to control the peak regrowth, which degrades the bit error rate (BER) performance and greatly increases the computational complexity. Therefore, this paper put forward a new method of utilizing Adaptive Active Constellation extension to reduce PAPR by controlling both clipping level and the convergence factor at each step and thereby minimize the peak power signal. The simulation results show that, this method can still limit the out-of-band power to meet the requirement of transmit spectrum mask specified in the IEEE802.11a standard. Moreover, it dramatically reduces the PAPR as well as provides lower BER and computational complexity.

KEYWORDS

CB-ACE, OFDM, PAPR, RCF.

INTRODUCTION

As a promising technique, OFDM has been widely used in many new and emerging broadband communication systems, such as digital audio broadcasting (DAB), high-definition television (HDTV), wireless local area network (IEEE 802.11a and HIPERLAN/2). However, as the OFDM signals are the sum of signals with random amplitude and phase, they are likely to have large PAPR that requires a linear high-power- amplifier (HPA) with an extremely high dynamic range, which is expensive and inefficient. Furthermore, any amplifier nonlinearity causes intermodulation products resulting in unwanted out-of-band power. A number of approaches have been proposed to deal with the PAPR problem, including clipping, clipping-and-filtering (CF), coding, companding transform, active constellation extension (ACE), selected mapping (SLM), partial transmit sequence (PTS), and so on [1]. Compared with other methods, clipping is the simplest and of good practicality. In particular, Jean Armstrong has proposed a RCF Algorithm which is also called Clipping Based Active Constellation Extension, which dramatically reduces the PAPR and limits the out-of band power to a low level , but excessively increases the computational complexity as well. Based on Jean Armstrong's method, this paper describes an improved approach which can provide good performance and lower complexity.

DEFINITION OF OFDM SIGNALS AND PAPR

In OFDM, a block of N symbols, {*Xk*, k=0, 1, … , N-1}, is formed with each symbol modulating one of a set of subcarriers, $\{f_n, n = 0, 1, \ldots, N-1\}$ with equal frequency separation 1/T, where T is the original symbol period. An inverse discrete Fourier transform (IDFT) can efficiently generate the multicarrier symbols. The IDFT of vector $X[k] = [X_0, X_1, \ldots, X_{N-1}]$ results in T/N spaced discrete time signal $x[n] = [x_0, x_1, \ldots, x_{N-1}]'$. Thus, the transmitted signal is

$$x_n = \frac{1}{\sqrt{N}} \int_{k=0}^{N-1} \exp j \frac{2\pi nk}{N} \qquad 0 \le k \le N-1 \tag{1}$$

The PAPR of the transmitted signal can be written as

$$PAPR = \frac{\max\limits_{0 \le n \le k-1} |x_n|}{E\{|x_n|^2\}} \tag{2}$$

The complementary cumulative distribution function (CCDF) is one of the most frequently used performance measures for PAPR reduction techniques, which denotes the probability that the PAPR of a data block exceeds a given threshold z. The CCDF of the PAPR of a data block of N symbols with Nyquist rate sampling is derived as

$$P(PAPR > z) = 1 - P(PAPR \le z) = 1 - (1 - e - z)N \tag{3}$$

THE CB-ACE ALGORITHM

The basic principle of Clipping-Based Active Constellation Extension (CB-ACE) algorithm involves switching between the time domain and the frequency domain. Filtering and applying the ACE constraint in the frequency domain, after clipping in the time domain, both require iterative processing to suppress the subsequent regrowth of the peak power [3].The CB-ACE algorithm is first used to clip the peak amplitude of the original Orthogonal Frequency Division Multiplexing (OFDM) signal. The clipping sample obtained after clipping the peak signals, denoted by $c_n^{(i)}$, is given by

$$c_n^{(i)} = \begin{cases} \left(|x_n^{(i)}| - A\right)e^{j\theta_n}, & |x_n^{(i)}| > A \\ 0, & otherwise \end{cases} \tag{4}$$

where $C_n^{(i)}$ is the Clipping sample of ith iteration, $x_n^{(i)}$ is the oversampled OFDM signal, A is predetermined clipping level. The equation (4) says that the clipping sample is reduced to a value equal to zero when the peak amplitude of the original OFDM signal is less than or equal to the predetermined clipping level, A. If the peak amplitude of the original OFDM signal is greater than the predetermined clipping level, then the clipping sample is given by $(|x_n^{(i)}| - A)e^{j\theta_n}$, where the predetermined clipping level is subtracted from the oversampled OFDM signal an is then multiplied by an exponential value [3]. The predetermined clipping level, denoted by A, is related to the target clipping ratio, γ and is given by the equation 5 [3].

$$\gamma = \frac{A^2}{E\{|x_n|^2\}} \qquad (5)$$

Where, γ is the target clipping ratio and A is predetermined clipping level.The clipping of the peak signal results to distortion of the original OFDM signal, namely In-Band Distortion and Out-of-Band Distortion . [3], [4]. The in-band distortion results in the system performance degradation and cannot be reduced, while, the out-of-band distortion can be minimized by filtering the clipped signals. The signal obtained after filtering the clipped signal is given by [3].

$$x^{(i+1)} = x^i + \mu\tilde{c}^{(i)} \qquad (6)$$

where , μ is positive real number (μ varies from 0.1 to 1) and $\tilde{c}^{(i)}$ is the anti-peak signal at the ith iteration given by'

$$\tilde{c}^{(i)} = T^{(i)}c^{(i)} \qquad (7)$$

where , $T^{(i)}$ is transfer matrix at the ith iteration which is given by

$$T^{(i)} = \hat{Q}^{*(i)}\hat{Q}^{(i)} \qquad (8)$$

where , $\hat{Q}^{*(i)}$ is conjugate of constellation order and $\hat{Q}^{(i)}$ is the constellation order

Though, the process of filtering completely eliminates the distortions caused by the clipping process, it introduces peak regrowth at some of the peak signals of the OFDM signal. The peak regrowth can be reduced by repeating the filtering process, which may again introduce some distortions. Therefore, the clipping and filtering processes are to be repeated until the peak signals are completely reduced. Hence, the Clipping-Based Active Constellation Extension (CB-ACE) Algorithm is also named as the Repeated Clipping and Filtering (RCF) process [3]

THE PROPOSED ALGORITHM

The main objective of the Adaptive Active Constellation Extension (Adaptive ACE) algorithm for reducing the Peak-to-Average Power Ratio (PAPR) is to control both the clipping level and the convergence factor at each step and thereby minimize the peak power signal whichever is greater than the initial target clipping level [3]. The Adaptive Active Constellation Extension (Adaptive ACE) algorithm can be initialized by selecting the parameters namely the target clipping level, denoted by A and the number of iterations, denoted by i. In the first step, the iteration is taken as two i.e., i = 2 and the initial target clipping level is to be taken as A [3]. The predetermined clipping level, denoted by A, is related to the target clipping ratio, γ and given is by the equation (5) [3].

$$\gamma = \frac{A^2}{E\{|x_n|^2\}} \qquad (9)$$

where, γ is the target clipping ratio and A is predetermined clipping level .The clipping of the peak signal results to distortion of the original OFDM signal, namely In-Band Distortion and Out-of-Band Distortion . [3]. The in-band distortion results in the system performance degradation and cannot be reduced, while, the out-of-band distortion can be minimized by filtering the clipped signals. The signal obtained after filtering the clipped signal is given by [3].

$$x^{(i+1)} = x^i + \mu\tilde{c}^{(i)} \qquad (10)$$

The Convergence Factor (CF), denoted by μ can be estimated by using the equation

$$\mu = \frac{R[\langle c^{(i)}, \tilde{c}^{(i)} \rangle]}{\langle \tilde{c}^{(i)}, \tilde{c}^{(i)} \rangle} \qquad (11)$$

Where R is the real part, $c^{(i)}$ is the peak signal above the predetermined level, $\tilde{c}^{(i)}$is the anti-peak signal at the ith iteration, $\langle , \rangle$ is complex inner part. the anti-peak signal at the ith iteration given by

$$\tilde{c}^{(i)} = T^{(i)}c^{(i)} \qquad (12)$$

where , $T^{(i)}$ is transfer matrix at the ith iteration which is given by

$$T^{(i)} = \hat{Q}^{*(i)}\hat{Q}^{(i)} \qquad (13)$$

where , $\hat{Q}^{*(i)}$ is conjugate of constellation order and $\hat{Q}^{(i)}$ is the constellation order. The original Orthogonal Frequency Division Multiplexing (OFDM) signal, denoted by xn, is to be clipped in order to reduce the peak signals. The clipping signal is given by the equation

$$C_n^{(i)} = \begin{cases} (|x_n^{(i)}| - A)e^{j\theta_n}, & |x_n^{(i)}| > A \\ 0, & \text{otherwise} \end{cases} \qquad (14)$$

where $C_n^{(i)}$ is the Clipping sample of ith iteration, $x_n^{(i)}$ is the oversampled OFDM signal, A is predetermined clipping level and for the next iteration is given by

$$A^{(i+1)} = A^{(i)} + \mu\nabla_A \qquad (15)$$

where $A^{(i+1)}$ is the next iteration level, $A^{(i)}$ is the present iteration level , μ is the convergence factor and ∇_A is the gradient with respect to A which is given by

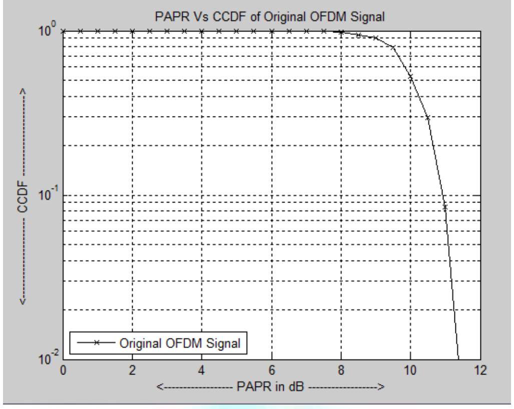
$$\nabla_A = \frac{\sum_{n \in \{i\}_{u} \{i\}} C_n^{(i+1)}}{N_p} \qquad (16)$$

where N_p is the number of peak samples larger than A. The Peak-to-Average Power Ratio (PAPR) is to be calculated to the signal obtained by the equation (10), which reduces the PAPR than the PAPR calculated for the original OFDM signal or PAPR obtained of the OFDM signal obtained by using the Clipping-Based Active Constellation Extension (CB-ACE) algorithm.

SIMULATION RESULTS

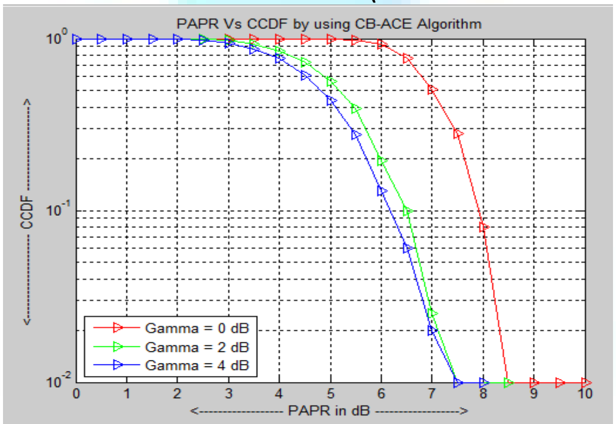
The Peak-to-Average Power Ratio (PAPR) of the original Orthogonal Frequency Division Multiplexing (OFDM) signal i.e., the PAPR is to be calculated by using the equations (1), (2) and (3). From the Figure 1, the Peak-to-Average Power Ratio (PAPR) of the original Orthogonal Frequency Division Multiplexing (OFDM) signal is equal to 11.8 dB with a Complimentary Cumulative Distribution Function (CCDF) of 10-2 or 0.01.The Peak-to-Average Power Ratio (PAPR) of the original Orthogonal Frequency Division Multiplexing (OFDM) signal is very high, which is evident from the Screen Shot 2.1. The high PAPR results to the increase in the complexity of the Analog-to-Digital Convertors (ADCs) and Digital-to-Analog Convertors (DACs), also reduces the efficiency of the power amplifiers.

FIGURE1 – PAPR VS CCDF OF ORIGINAL OFDM SIGNAL



The Peak-to-Average Power Ratio (PAPR) by the Clipping-Based Active Constellation Extension (CB-ACE) algorithm is to be calculated for the Orthogonal Frequency Division Multiplexing (OFDM) signal which is obtained after filtering the clipped signal i.e., the PAPR is to be calculated for the equation (5) by using the equations (1), (2) and (3). The Complimentary Cumulative Distribution Function (CCDF) by the Clipping-Based Active Constellation Extension (CB-ACE) algorithm is to be calculated for the Orthogonal Frequency Division Multiplexing (OFDM) signal which is obtained after filtering the clipped OFDM signal. From the Figure 2, the Peak-to-Average Power Ratio (PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) signal obtained by using the Clipping-Based Active Constellation Extension (CB-ACE) algorithm is equal to 10 dB, 8.5 dB and 8.0 dB for the target clipping ratios of 0 dB, 2 dB and 4 dB respectively with a Complimentary Cumulative Distribution Function (CCDF) of 10^{-2} or 0.01.

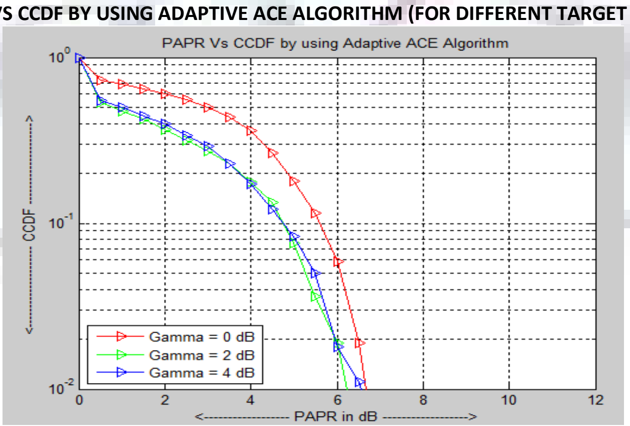
FIGURE 2 – PAPR VS CCDF BY USING CB-ACE ALGORITHM (FOR DIFFERENT TARGET CLIPPING RATIOS)



The Peak-to-Average Power Ratios is increasing as the target clipping ratios is decreasing i.e., minimum PAPR cannot be achieved, when the target clipping level is set below an initially unknown optimum value, which results to low clipping ratio problem.

The other problems faced by the Clipping-Based Active Constellation Extension (CB-ACE) algorithm are Out-of-Band Interference (OBI) and peak regrowth. Here, the Out-of-Band Interference (OBI) is a form of noise or an unwanted signal, which is caused when the original Orthogonal Frequency Division Multiplexing (OFDM) signal is clipped for reducing the peak signals which are outside to the predetermined area and the peak regrowth is obtained after filtering the clipped signal. The peak regrowth results to, increase in the computational time and computational complexity. To evaluate the performance of the proposed method we choose the software MATLAB completing the simulation based on Adaptive Active Constellation Extension (adaptive ACE) is to be calculated for the Orthogonal Frequency Division Multiplexing (OFDM) signal which is obtained after filtering the clipped signal i.e., PAPR is to be calculated for the equation (10) by using the equations (1), (2) and (3).

FIGURE 3 – PAPR VS CCDF BY USING ADAPTIVE ACE ALGORITHM (FOR DIFFERENT TARGET CLIPPING RATIOS)



From the figure 3, the Peak-to-Average Power Ratio (PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) signal obtained by using the Adaptive Active Constellation Extension (Adaptive ACE) algorithm is equal to 6.8 dB for all the target clipping ratios i.e., for γ = 0 dB or γ = 2 dB or γ = 4 dB with a Complimentary Cumulative Distribution Function (CCDF) of 10^{-2} or 0.01.

TABLE 5.1 – COMPARISON OF PAPR (IN DB) AND CCDF FOR DIFFERENT TECHNIQUES

Different Techniques	PAPR (in dB)	CCDF
Original OFDM Signal	11.8	10^{-2} or 0.01
Clipping-Based Active Constellation Extension (CB-ACE) Algorithm	10.0 (For γ = 0 dB) 8.5 (For γ = 2 dB) 8.0 ((For γ = 4 dB)	10^{-2} or 0.01
Adaptive Active Constellation Extension (Adaptive ACE) algorithm	6.8 (For γ = 0 dB, 2 db or 4 dB)	10^{-2} or 0.01

From the table 5.1, the Peak-to-Average Power Ratio of the Orthogonal Frequency Division Multiplexing systems is reduced or minimized by using the existing methods namely Clipping-Based Active Constellation Extension (CB-ACE) and the proposed method namely Adaptive Active Constellation Extension (Adaptive ACE) Algorithm at a Complimentary Cumulative Distribution Function of 10^{-2} or 0.01.

CONCLUSIONS

In this paper, we have proposed a new algorithm based on Adaptive Active Based Constellation Extention to reduce the PAPR of OFDM signal. Compared with the CB-ACE algorithm, this method can dramatically reduce the peak regrowth and the computational complexity by avoiding RCF operations. Moreover, it can still meet the requirement of transmit spectrum mask specified in the IEEE802.11a standard, and greatly improve the BER performance even when the initial target clipping ratio is set below the unknown optimum clipping point. Hence, the proposed algorithm avoids the problem of low clipping ratio, which is caused in the process of reducing the PAPR by using the Clipping-Based Active Constellation Extension (CB-ACE) Algorithm

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