

Improving Peak to Average Power Ratio of OFDM Signal Using DCT Precoding with Combined Distortion Techniques

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Abstract –This paper has presented Peak to Average Power Ratio (PAPR) reduction improvement in Orthogonal Frequency Division Multiplexing (OFDM) system using discrete cosine transform (DCT) precoding with repeated clipping and filtering plus Mu-law companding techniques. Recent studies have shown the use of evolution algorithms and combination of two or more algorithms to reduce PAPR in OFDM system. The algorithms of DCT, RCF and Mu-law were studied and presented in form of mathematical equations. MATLAB codes were developed for PAPR analysis in OFDM system. The MATLAB codes for DCT, RCF and Mu-law companding were implemented and incorporated into the OFDM system to enhance the PAPR performance. Simulations were conducted considering uncoded (or conventional) OFDM, uncoded OFDM with RCF, precoded OFDM with RCF, and precoded OFDM with RCF plus Mu-law. Using the PAPR value of 10.43dB at CCDF of 10⁻³ for the uncoded OFDM signal as reference value, it was observed that the introduction of RCF into the uncoded OFDM provided a PAPR value of 6.834dB which is 34.48% improvement. Also, for the precoded OFDM with RCF, the PAPR was reduced to 6.799dB with 34.81% improvement. Finally, the proposed scheme using precoded OFDM with RCF and Mu-law provided an efficient reduction in PAPR with a value of 2.048dB and 80.36% improvement. Thus, the implemented scheme has shown to be effective based on MATLAB simulations conducted.

Keyword –DCT, Mu-law, OFDM, PAPR, RCF

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has become one of the most famous techniques used in the transmission of data for a number of wireless communication systems. This can be attributed to the various benefits it offers such as high bandwidth efficiency, robustness to multipath fading, high data rate, mitigation of inter-symbol interference (ISI) and low implementation complexity [1,2]. Thus the use of OFDM as a multicarrier system has become attractive in application like Wireless Local Area Networks (WLAN) standards (e.g. HIPERLAN-2, IEEE 802.11a/g), Wireless Metropolitan Area Networks (WMAN), LTE standards, Worldwide Interoperability for Microwave Access (WiMAX), Digital Audio Broadcasting (DAB), Digital

Video Broadcasting (DVB), Asymmetric Digital Subscriber Line (ADSL) and power line communication [3-5]. Despite these advantages offered by OFDM technology, there are certain shortcomings that are still associated with its use and one of such disadvantages is the high Peak to Average Power Ratio (PAPR).

High PAPR occurs due to the fact that the output of OFDM system is the superposition of multiple subcarriers such that some instantaneous power output might largely increase and become much higher than the average power of the system when these carriers are in the same phase. Hence, transmitting OFDM signals with high PAPR causes nonlinear distortion of power amplifier (PA) which is capable of degrading the performance efficiency of the system.

Several methods have been proposed and implemented to overcome the problem of high PAPR. Recently, the application of evolutionary algorithms such as particle swarm optimization (PSO), artificial bee colony optimization algorithm (ABCOA), cuckoo search algorithm (CSA) and so on as well as hybrid technique for reducing PAPR of OFDM signal has become increasing popular in literature. The use of reduced computational complexity partial transmit sequence (PTS) technique with help of swarm intelligent algorithm called fire work algorithm (FWA) was proposed by Amhaimar et al. [2] to reduce PAPR. Agwah et al. [6] proposed a hybrid scheme that combines repeated clipping and filtering (RCF) and Mu-law companding with precoded OFDM signal to optimize the performance of PAPR. Application of discrete Fourier transform (DFT) precoding with Repeated Clipping and Filtering (RCF) was implemented by Agwah et al. [7] for the reduction of PAPR in OFDM. Anoh et al. [8] proposed discrete Hartley transform (DHT) precoded root-based Mu-law companding (RMC) to reduce PAPR in OFDM system and to address the limitations of conventional mu-law companding caused by computational complexity and energy inefficiency. A scheme using selected mapping (SLM) and RCF was proposed by Majula and Muralidhara [9]. In order to improve the computational complexity and sub-block partitioning of usual PTS scheme, a Mu-law compound was introduced into the PTS-OFDM scheme by [10]. To reduce PAPR in turbo coded OFDM system, Bindal and Gupta [11] implemented a selected mapping (SLM) incorporating genetic algorithm (GA). Sudha and Kumar [12] combined conventional SLM and clipping technique to form a hybrid scheme for the reduction of both complexity and PAPR in OFDM system. Addressing the computational complexity for searching optimum phase factors using SLM approach and reducing PAPR, VijayaLakshmi and Reddy [13] incorporated two optimization algorithms called social spider optimization (SSO) and adaptive artificial bee colony algorithm into SLM MIMO-OFDM system. Shiragapur and Wali [14] used coding and hybrid scheme combining SLM and Mu-law companding to reduced PAPR in OFDM system and maintained that the hybrid technique provided better performance compared to conventional and modified SLM scheme. Enhancing generalized oppositional biogeography based optimization (GOBBO) with oppositional based learning (OBL) incorporated into PTS OFDM system, Goudos [15] was able to effectively reduce PAPR and reduce PTS search intricacy.

Having shown the recent trends in PAPR reduction in OFDM system, this paper proceeds to present a technique that

combines discrete cosine transform (DCT) precoding with repeated clipping and filtering (RCF) and Mu-law (or μ -law) companding to efficiently reduce PAPR in OFDM system in LTE standard. This achieved by organizing the remaining part of this paper into four sections namely, overview of OFDM system and PAPR problem, DCT and RCF technique, simulation result and discussion, and conclusion.

II. OVERVIEW OF OFDM SYSTEM AND PAPR PROBLEM

A typical block diagram model of OFDM system is shown in Fig. 1. The diagram shows that incoming data stream is grouped and mapped into multi-amplitude-multi-phase signals. Next is pilot insertion operation which is followed by Inverse Fast Fourier Transform (IFFT). Mathematical description of the OFDM signal and PAPR are presented as follows.

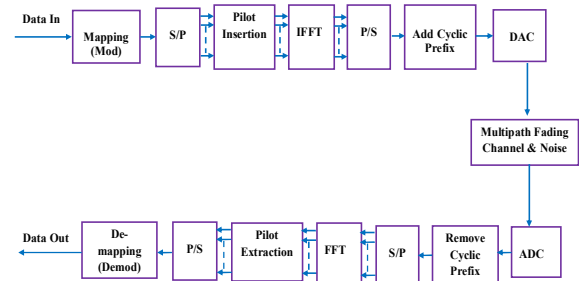


Fig.1. Block diagram of OFDM system [6,7]

2.1. Mathematical Description of OFDM signal

Since OFDM consists of multiple carriers, a mathematical expression of each modulated subcarrier can be represented as a complex waveform given by:

$$x(t) = A_c(t)e^{j[\omega_c t + \phi_c(t)]} \quad (1)$$

where ω_c is the angular frequency of the subcarrier, $A_c(t)$ is the amplitude of the subcarrier, and $\phi_c(t)$ is the phase of the subcarrier.

Considering an OFDM system as having N subcarriers, a block of N symbols, $X = \{X_k, k = 0, 1, \dots, N-1\}$, which is a data block with each symbol modulating on one set of subcarriers can be established. A representation of multicarrier signal that consist of N subcarriers is given by:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j\omega_k t}, \quad 0 \leq t \leq NT \quad (2)$$

where $\omega_k = 2\pi f_k$, X_k is the transmitted symbol on k^{th} subcarrier and NT represents data block period.

2.2. Definition of PAPR

Peak to average power ratio (PAPR) in OFDM system is usually defined as the ratio of the maximum instantaneous power to its mean power. The mathematical definition of PAPR is given by [16,17]:

$$PAPR = 10 \log_{10} \frac{\max[|x_n|^2]}{E[|x_n|^2]} \quad (3)$$

where $E[\cdot]$ represents the expected value, x_n denotes the transmitted OFDM signals. In order to obtain x_n , IFFT operation is carried out on modulated input symbols X_k . Mathematical definition of the discrete time complex envelope of the transmitted OFDM signal is given by Manjula and Muralidhara [9]; Amhaimar et al. [2]:

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j \frac{2\pi n k}{N}}, \quad 0 \leq n \leq N-1 \quad (4)$$

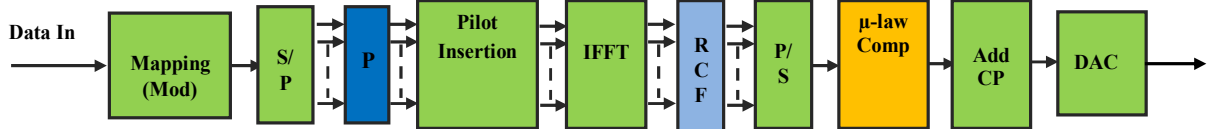


Fig. 2 Transmit structure of OFDM system

3.1. DCT Precoding Technique

Generally, the precoding scheme involves the multiplication of the modulated data of each OFDM block in frequency domain by a precoding matrix $\mathbf{P}$ before the IFFT process. The reverse process takes place at receiver where the inverse of the precoding matrix $\mathbf{P}^{-1}$ is used after FFT operation. However, in this paper, the focus is on the transmitter where PAPR performance needs to be optimized for improved transmitted signal. The baseband modulated data stream is grouped into blocks of length $(N - N_p)$ symbols each [18]. An already established $N \times (N - N_p)$ precoding matrix $\mathbf{P}$ is used to multiply each block of symbols. The $\mathbf{P}$ matrix is given by:

$$P_{n,m} = \begin{cases} \sqrt{\frac{1}{N}}, & n = 0 \quad \text{and} \quad 0 \leq m \leq (N-1) \\ \sqrt{\frac{2}{N}} \cos\left(\frac{2\pi n m + \pi n}{N}\right), & 1 \leq n \leq (N-1) \quad \text{and} \quad 0 \leq m \leq (N-1) \end{cases} \quad (7)$$

2.3. Statistical Expression of PAPR

The statistical tool usually used in the analysis of the peak power of signal in modern communication is Complementary Cumulative Distribution Function (CCDF) measurement [9]. In practice, CCDF is taken as the measurement index for the probability of PAPR greater than a threshold [17] and it is given by:

$$\begin{aligned} P(PAPR > z) &= 1 - P(PAPR \leq Z) \\ &= 1 - f(Z)^N \\ &= 1 - (1 - \text{EXP}(-Z))^N \end{aligned} \quad (5)$$

where N is statistically independent uncorrelated signal samples.

III. SYSTEM CONFIGURATION

The structure of the transmit section of OFDM system is shown in Fig. 2. It consists of DCT precoding, RCF and μ -law companding algorithms. These algorithms are discussed in this section.

$$\mathbf{P} = \begin{bmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,(N-N_p)} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,(N-N_p)} \\ \vdots & \vdots & \cdots & \vdots \\ P_{N,1} & P_{N,2} & \cdots & P_{N,(N-N_p)} \end{bmatrix} \quad (6)$$

where $P_{n,m}$ are the elements of the precoding matrix, N is the number of subcarriers, and $(N - N_p)$ denotes the data block length prior to precoding with $0 \leq N_p < N$. The precoding matrix becomes $(N \times N)$ matrix when $N_p = 0$ and the rate loss reduces to zero [18, 19].

The expression for the DCT precoding technique, which is a $(N \times N)$, is given by:

3.2. Repeated Clipping and Filtering

Repeated clipping and filtering (RCF) is a signal distortion based technique. A block diagram structure of clipping and filtering scheme is shown in Fig. 3. The clipping and filtering algorithm takes the process:

- The input of the RCF block which is the L times oversampled discrete time signal generated by IFFT is computed.
- Selection of maximum peak amplitude A is carried out which represents threshold value.
- Signals peaking beyond the threshold value are clipped.
- Filtering of the resulting signal is carried out.

The amplitude clipping is defined mathematically by Jolania and Toshniwal [20]:

$$C(x)=\begin{cases} x, & x\leq A \\ A, & x>A \end{cases} \tag{8}$$

where A is predetermined clipping level and it is a positive real number[20].

The use of repeated clipping and filtering is used in this context to ensure that re-grow effect of filtering is addressed by carrying out the process in a repeated fashion until expected PAPR value is obtained. Also, the use of precoding provides better performance of bit to error ratio (BER) than conventional OFDM with RCF scheme.

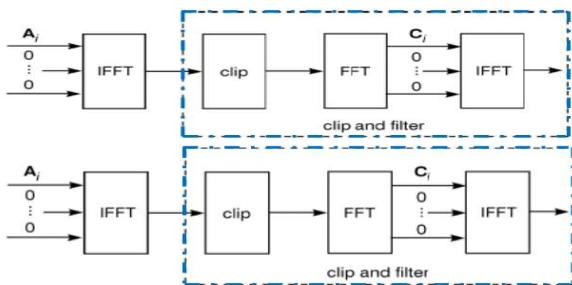


Fig. 3 Block diagram presentation of clipping and filtering

3.3. Mu-Law Companding

The μ -law companding is a logarithm-based nonlinear technique for PAPR reduction [6, 21]. The approach is such that small amplitudes of the signal so the difference between the peaks and small values is reduced [21, 22]. The

mathematical description of μ -law companding technique is given by [6]:

$$C(x)=\frac{v}{\log(1+\mu)}\log\left(1+\frac{\mu}{V}|x|\right)\text{sgn}(x) \tag{9}$$

where x is the baseband OFDM signal, v is the maximum amplitude of the signal x , μ represents the companding level which is chosen as 100 in this paper, and $\text{sgn}(x)$ is the signum function.

3.4. Simulation Parameter

Table 1 shows the simulation parameters for examining the effectiveness of the developed technique for reducing PAPR in OFDM system.

Table 1 Parameters of the OFDM system

Parameters	Values
Modulation	QPSK
FFT size	256
Spacing	15000Hz
Cyclic prefix	¼ of FFT size
Sampling period	192µs
Maximum Doppler frequency shift	0.01
Oversampling factor	4
Clipping ratio (CR)	4
μ	100

IV. RESULT ANALYSIS AND DISCUSSION

With the use of RCF in this paper, 4 iterations were carried out to ensure efficient PAPR performance. Simulations were considered in four conditions namely, a) for conventional (or uncoded) OFDM system shown Fig. 4, b) for uncode OFDM with RCF algorithm shown in Fig. 5, c) for precoded (or coded) OFDM with RCF shown in Fig. 6, and for precoded OFDM with RCF and Mu-law companding shown in Fig. 7.

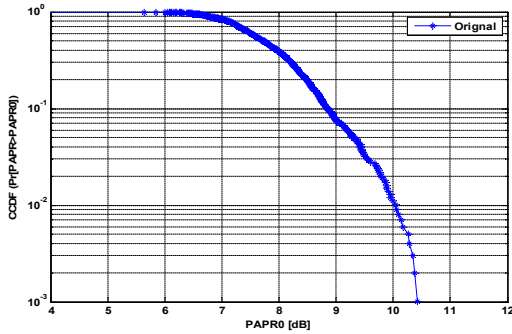


Fig. 4 PAPR plot for uncoded OFDM

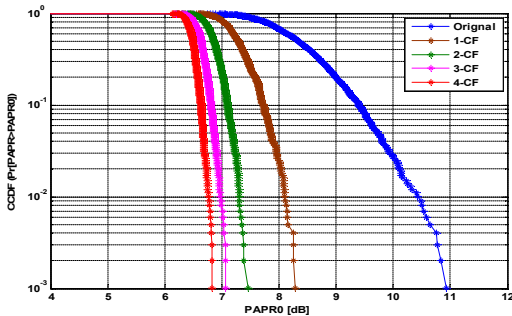


Fig. 5 PAPR plot of uncoded OFDM plus RCF

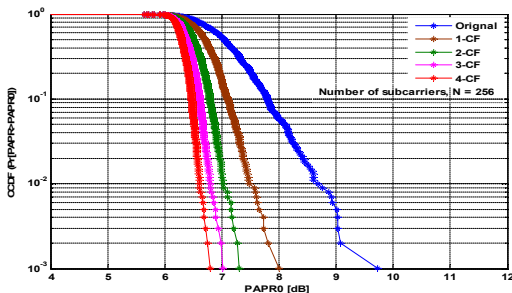


Fig. 6 PAPR plot of precoded OFDM plus RCF

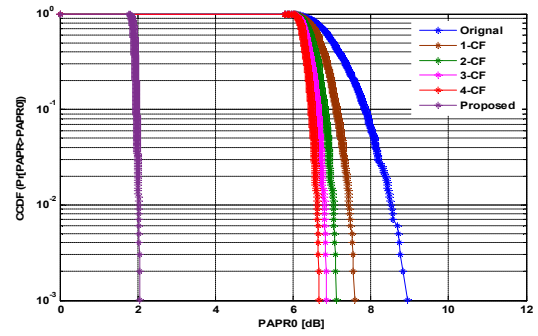


Fig. 7 PAPR plot of precoded with RCF and μ -law

The performances of the various simulation results are presented in Tables 2-4 while the value of PAPR for uncoded OFDM is taken as a reference value to determine the effectiveness of the DCT with RCF plus μ -law scheme presented. The value of the PAPR of the uncoded OFDM system was 10.43dB at CCDF of 10^{-3} . Thus the performance evaluation is carried out using expression given by Agwah et al. [6, 7]:

$$\%PAPR_{improvement} = \frac{PAPR_{OFDM_Without} - PAPR_{OFDM_With}}{PAPR_{OFDM_Without}} \times 100 \quad (10)$$

Table 2 Performance analysis of uncoded OFDM with RCF

Plot	PAPR Value (dB)	Percentage reduction in PAPR
Original	10.93	-4.79
One clipping and filtering (1-CF)	8.288	20.54
Two clipping and filtering (2-CF)	7.455	28.52
Three clipping and filtering (3-CF)	7.072	32.20

Four clipping and filtering (4-CF)	6.834	34.48
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Table 3 Performance analysis of precoded OFDM with RCF

Plot	PAPR Value (dB)	Percentage reduction in PAPR
Original	9.719	6.82
One clipping and filtering (1-CF)	8.004	23.26
Two clipping and filtering (2-CF)	7.299	30.02
Three clipping and filtering (3-CF)	7.021	32.68
Four clipping and filtering (4-CF)	6.799	34.81

Table 4 Performance analysis of precoded OFDM with RCF+ μ -law

Plot	PAPR Value (dB)	Percentage reduction in PAPR
Original	8.951	14.20
One clipping and filtering (1-CF)	7.586	27.27
Two clipping and filtering (2-CF)	7.118	31.75

Three clipping and filtering (3-CF)	6.859	34.24
Four clipping and filtering (4-CF)	6.665	36.10
Proposed	2.048	80.36

It can be seen from Table 2-4 that with the inclusion of each algorithm, a reduction of PAPR in the OFDM system was achieved. The uncoded OFDM signal was seen to have a PAPR value of 10.43dB at CCDF of 10^{-3} . The addition of RCF as shown in Table 2 revealed that value of the PAPR of OFDM signal was reduced to 6.834dB with performance improvement of 34.48%. With the OFDM signal precoded before the introduction of the RCF technique, simulation results looking at Table 3 indicated that the PAPR was reduced to 6.799 dB at the fourth iterative clipping and filtering (4-CF), which corresponds to 34.81% reduction of PAPR. This performance is better than that of uncoded OFDM with RCF scheme. While keeping the OFDM signal precoded, RCF and μ -law algorithms were added to the OFDM system and simulation conducted. The results obtained as shown in Table 4 indicated that an overall reduction of PAPR value to 2.048dB which is 80.36% reduction of PAPR in OFDM system.

V. CONCLUSIONS

This paper has presented a combination of two distortion techniques with precoded OFDM signal to reduce PAPR in OFDM system. Simulations were conducted for four conditions so as to sufficiently analyze the developed method. The simulation results have indicated that the use of DCT precoding with RCF and the companding algorithm is capable of improving the performance of PAPR in OFDM system.

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