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Improving The Performance of OFDM Signal Based on Peak to Average Power Ratio Reduction

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Abstract- One of the problems of OFDM system is the Peak to Average Power Ratio (PAPR) which adversely affects performance efficiency. In this paper, the PAPR of OFDM signal has been reduced by using discrete cosine transform (DCT) precoding with repeated clipping and filtering (RCF) plus A-law companding. The simulations were carried out in MATLAB looking at four different scenarios which are conventional (or uncoded) OFDM system, uncoded OFDM plus RCF, precoded OFDM plus RCF, and precoded with RCF plus A-law. For the uncoded OFDM signal, the PAPR was 10.51dB at CCDF of 0.001. Then RCF algorithm was added and a reduced PAPR of value 6.80dB was obtained which is an improvement of 35.3%. The PAPR was further reduced to 6.68dB after fourth iteration by precoding the OFDM signal before adding the RCF. This is means 36.44 % reduction of PAPR (or improvement of OFDM signal). Inclusion of A-law companding into precoding with RCF scheme in the OFDM system reduced the PAPR much more to a value of 1.71dB. This is 83.73% improvement in OFDM signal performance in terms of PAPR reduction. Generally, the proposed solution was able to reduced the PAPR to a level sufficiently enough to improve the PAPR performance.

Indexed Terms- A-law companding, DCT precoding, OFDM, PAPR, RCF

I. INTRODUCTION

In Orthogonal Frequency Division Multiplexing (OFDM) system, a single data stream is transmitted over a number of lower rate orthogonal subcarriers using multicarrier advance modulation technique. The word “orthogonal” as used, indicates that there exists a given mathematical correlation between the multicarrier frequencies in the system [1]. The basic principle of OFDM involves splitting a high-data rate sequence into a number of low-rate sequences that are transmitted at the simultaneously over several subcarriers. In the case of low rate parallel subcarriers, the symbol duration is increased so that the multipath delay spread induced dispersion is reduced. To overcome the effect of ISI due to multipath, guard interval is added to isolate successive OFDM symbols. Also, cyclic prefix, which is the cyclical extension of guard interval, is used in the guard interval to eliminate inter-carrier interference (ICI). This results to a transformation of highly frequency selective channel into a large set of flat fading, narrowband channels, and non-frequency selective. The use of an integrated circuit (IC) eliminates need for complete collection of separate transmitters and receivers for the implementation of Inverse Fast Fourier Transform (IFFT) or Discrete Fourier Transform (DFT). The Fast Fourier Transform (FFT) method is employed to take away collections of sinusoidal generators and coherent demodulation required in parallel data systems and guarantees reduced cost of implementation.

Orthogonal Frequency Division Multiplexing (OFDM) is one of the most popular methods used in the transmission data in several wireless communication systems. This can be as a result of the numerous advantages it provides like bandwidth efficiency, robust multipath fading, high data rate, inter-symbol interference (ISI) mitigation, and low implementation complexity [2][3]. Therefore, the application of OFDM as a multicarrier system has attracted much attention in Wireless Local Area Networks (WLAN) standards such as HiperLAN/2 and IEEE802.11a/g, Wireless Metropolitan Area Networks (WMAN), Long Term Evolution (LTE) standards, Worldwide interoperability for Microwave Access (WiMAX), Digital Audio Broadcasting (DAB), Digital Video Broadcast (DVB), Asymmetric Digital Subscriber Line (ADSL) and power line communication [4-6]. In spite of the benefits of OFDM technique, it is still associated with some challenges such as sensitivity to carrier offset and drift, receiver complexity, and high Peak to Average Power Ratio (PAPR). However, study of PAPR is the focus of this paper.

The effect of high PAPR is as result of the output of OFDM system being a superposition of many subcarriers which can cause a large increase in some instantaneous power output and thereby making them to become much higher than the average power of the system when these carriers are in the same phase [7]. Thus, by transmitting OFDM signals with high PAPR causes nonlinear distortion of power amplifier (PA) that can reduce the efficiency of the system.

Many techniques have been presented and implemented to address the problem of high PAPR associated with OFDM of signal. A hybrid scheme that combines an enhanced partial transmit sequences (PTS) and Mu-law companding algorithms to reduce PAPR was proposed by Ibraheem et al.[8] A Generalized Oppositional Biogeography Based Optimization (GOBBO) algorithm enhanced by Oppositional Based Learning (OBL) scheme was used by Goudos [9] to solve the problem of PTS. In Sudha and Kumar [10] time domain signals available at the output of IFFT were separated into subsequences comprising real odd, real even, imaginary odd and imaginary even using the properties of Fourier transformation to reduce the computational complexity of selected mapping (SLM) for improved PAPR minimization. Peak to average power ratio (PAPR) reduction using precoded OFDM signal with repeated clipping and filtering (RCF) and Mu-law companding was proposed by Agwah et al. [11]. Discrete Fourier transform (DFT) precoding in combination with RCF was applied in OFDM system of LTE standard to minimize PAPR by Agwah et al. [12]. A significant reduction in PAPR for an OFDM system was achieved using RCF and SLM by Manjula and Muralidhara [13]. Dubey and Gupta [14] combined different precoding schemes including, DFT, DCT, DHT, and discrete sine transform (DST) with RCF to mitigate the effect of PAPR in OFDM system. The use of DCT-RCF plus Mu-law technique to reduce PAPR in OFDM system has been presented [7].

So far, recent studies on the reduction of PAPR of OFDM signal have been briefly presented. This paper proceed to present a technique that uses DCT precoding combined with repeated clipping and filtering plus A-law companding to effectively reduce PAPR of OFDM signal in LTE standard.

II. OFDM AND PAPR PROBLEM

The OFDM signal for N subcarriers is formed by several blocks of data symbols $X = \{X_k, k = 0,1,\cdots\cdots, N-1\}$ [8] that can be effectively implemented by an IFFT operation with an output given by [15]:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi\Delta f t}, \quad 0 \le t \le NT$$

(1)

where NT is the duration of the OFDM symbol, Δf is the frequency interval between the subcarriers, $X(k)$ represents the data symbol on the K^{th} subcarrier. Thus the PAPR of OFDM signal can be defined as [10]:

$$PAPR = \frac{\max 0 \le t \le NT \left| x(t)^2 \right|}{P_{av}}$$

(2)

where P_{av} denotes the average power, and $x(t)$ is the continuous time signal. Nevertheless, the PAPR of a continuous time signal with Nyquist rate sampling is inaccurate such that getting an accurate value, $x(t)$ given by Eq. (1) is oversampled by a factor L. Therefore, the oversampled form denoting the discrete time domain OFDM signal is given by:

$$x(n) = \frac{1}{(LN)^{1/2}} \sum_{k=0}^{LN-1} X(k) e^{\frac{j2\pi nk}{N}}, \quad 0 \le n \le LN-1$$

(3)

For the discrete time OFDM symbol, the PAPR is defined by:

$$PAPR = \frac{\max 0 \le n \le LN-1 \left| x(n) \right|^2}{P_{av}}$$

(4)

The most frequently used measure of performance in PAPR reduction evaluation is the Complementary Cumulative Distribution Function (CCDF), and it is given by Ali and Hamza [16]:

$$P_r(PAPR \geq PAPR_0) = 1 - P_r(PAPR \geq PAPR_0)$$
$$= 1 - \left(1 - e^{PAPR_0}\right)^N$$
(5)

III. METHODOLOGY

The configuration of the proposed scheme for OFDM signal performance improvement via PAPR reduction is shown in Fig. 1. The structure comprises DCT precoding, RCF and A-law companding algorithms. The various algorithms are briefly discussed as follows.

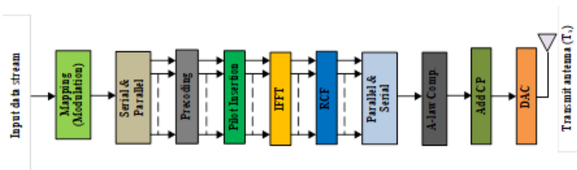

Fig. 1 Transmit structure of OFDM system

A. Precoding Method

The precoding algorithm uses a precoding matrix to multiply the frequency domain modulated OFDM signal before IFFT operation is implemented as shown in Fig. 1. The reverse process takes place at the receive end where inverse of the precocding matrix is used after FFT operation. In this paper, the focus is on minimizing PAPR of OFDM signal and this

takes place on the transmit end of OFDM system. Hence, only the transmit end is considered. The baseband-modulated stream of data is grouped into blocks of length $(N - N_p)$ symbols each [12]. A precoding matrix **P** defined by $N \times (N - N_p)$ is used to multiply each block of symbols and it is given by Eq. (6):

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

where $P_{n,m}$ denotes the elements of the precoding matrix, N is the number of subcarriers, and $(N - N_p)$ represents the data block length before precoding with $0 \leq N_p < N$. P becomes matrix when $N_P = 0$ and the rate loss reduces to zero [16][17].

The mathematical definition of the DCT precoding scheme which is a $(N \times N)$ is as follows:

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

B. Repeated Clipping and Filtering

Repeated clipping and filtering (RCF) algorithm is one of the distortion based scheme. Figure 2 is a block diagram illustration of clipping and filtering process.

The process is as follows:

- Computation of the input of the RCF block which is the OFDM symbol and represents the out of IFFT.
- Maximum peak amplitude **A** is selected, which represents threshold value.
- Signals peaking further than the threshold value are clipped.
- Filtering of the resulting signal is carried out.

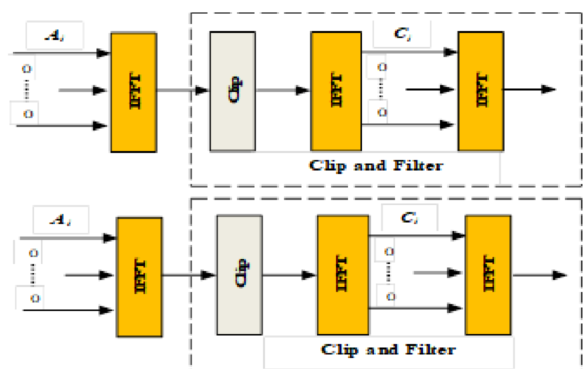

Fig. 2 Illustration of clipping and filtering

The mathematical expression of the amplitude clipping is given by Jolania and Toshniwal [18]:

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

where A is predefined clipping level and it is a positive real number [18].

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

C. A-Law Companding Technique

A-law is a companding technique that is used to compress OFDM signal at the transmitter and expansion at the receiver [19]. This technique just like the Mu-law, applies a logarithmic quantization function to adjust the resolution of the data in proportion to the level of the input signal [20]. The A-law companding algorithm is used for pulse code modulation (PCM) telephone system. The mathematical definition of A-law is given by Sonawane and Khobragade [19]:

$$y(x)=\begin{cases} y_{max}=\dfrac{A\dfrac{|x|}{x_{max}}}{(1+A)}\operatorname{sgn}(x); & 0<\dfrac{|x|}{x_{max}}\leq\dfrac{1}{A} \\ y_{max}=\dfrac{\left|1+\ln\left(A\dfrac{|x|}{x_{max}}\right)\right|}{(1+\ln A)}\operatorname{sgn}(x) ; & \dfrac{1}{A}<\dfrac{|x|}{x_{max}}\leq 1 \end{cases}$$

(9)

where x is the input signal, y is the output signal, $\operatorname{sgn}(x)$ is sign of the input (positive or negative), $|x|$ is the absolute value of x, A is assigned a value of 87.6 by Consultative Committee for International Telephony and Telegraphy (CCITT) [19].

So far, the algorithms combined in this study to reduce PAPR in OFDM system have been presented. The simulation parameters used in this paper to determine the efficiency of the proposed solution are presented in Table 1.

TABLE 1 PARAMETERS OF THE OFDM SYSTEM [7]

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
A	87.6

IV. RESULTS AND DISCUSSION

This section presents the simulation results of the proposed solution for PAPR reduction in OFDM system. Four iterations were performed to ensure efficient PAPR reduction. Simulation results are provided for four separate scenarios considered namely, a) uncoded or conventional OFDM system shown in Fig. 3, b) uncoded OFDM system plus RCF shown in Fig. 4, c) coded or precoded OFDM plus RCF plus A-law companding as shown in Fig. 5.

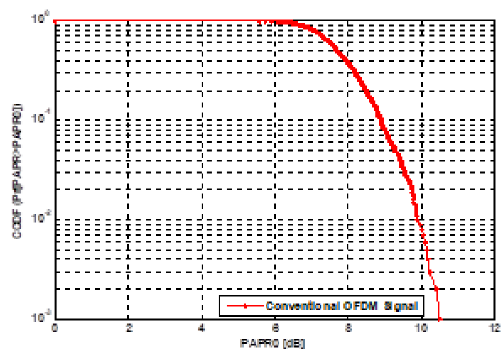

Fig. 3 PAPR of uncoded OFDM signal

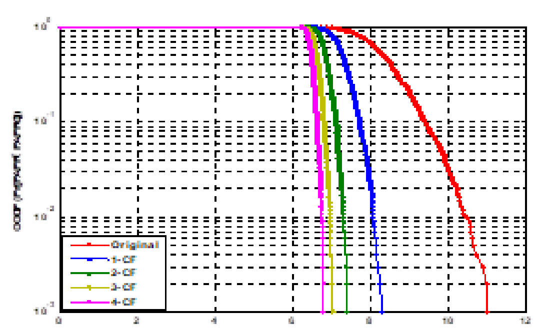

Fig. 4 PAPR of Uncoded OFDM signal plus RCF

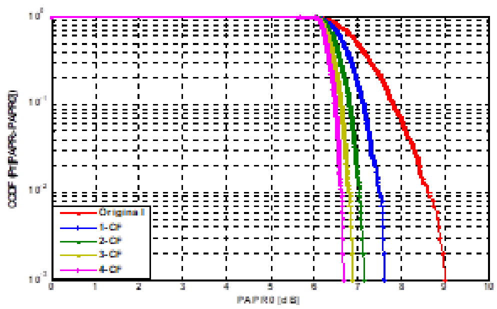

Fig. 5 PAPR of precoded OFDM signal plus RCF

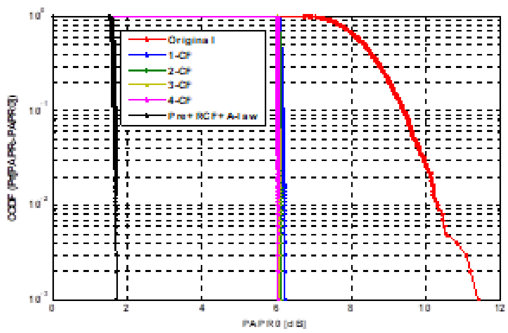

Fig. 6 PAPR of coded OFD signal plus RCF plus A-law

The analysis of the performance of the proposed solution from the simulation plots are presented in Table 2 to 4. However, the PAPR value of the uncoded OFDM signal is chosen as a reference value in determining the efficiency of DCT precoder with RCF plus A-law technique presented in this paper. From Fig. 3, the value of the PAPR of the uncoded OFDM signal is 10.51 dB at CCDF of 10^{-3}. Therefore, evaluating the performance the expression in Agwah et al. [12] is used and it is given by:

$$\%PAPR_{improvemet} = \frac{PAPR_{OFDM\_Without} - PAPR_{OFDM\_With}}{PAPR_{OFDM\_Without}} \times 100$$

(10)

TABLE 2 PERFORMANCE ANALYSIS OF UNCODED OFDM WITH RCF

Plot	PAPR Value (dB)	Percentage reduction in PAPR
Original	10.98	-4.47
One clipping and filtering (1-CF)	8.30	21.03
Two clipping and filtering (2-CF)	7.39	29.69
Three clipping and filtering (3-CF)	7.03	33.11
Four clipping and filtering (4-CF)	6.80	35.30

TABLE 3 PERFORMANCE ANALYSIS OF PRECODED OFDM WITH RCF

Plot	PAPR Value (dB)	Percentage reduction in PAPR
Original	8.99	14.46
One clipping and filtering (1-CF)	7.60	27.69
Two clipping and filtering (2-CF)	7.15	31.97
Three clipping and filtering (3-CF)	6.88	34.54
Four clipping and filtering (4-CF)	6.68	36.44

TABLE 4 PERFORMANCE ANALYSIS OF PRECODED OFDM WITH RCF+A-LAW

Plot	PAPR Value (dB)	Percentage reduction in PAPR
Original	11.40	-8.47
One clipping and filtering (1-CF)	6.23	40.72
Two clipping and filtering (2-CF)	6.11	41.86
Three clipping and filtering (3-CF)	6.06	42.34
Four clipping and filtering (4-CF)	6.04	42.53
Pre +RCF+A-law	1.71	83.73

CONCLUSION

In this paper the performance of OFDM signal based on PAPR performance has been examined through simulations in conducted in MATLAB environment. In order to effectively analyse the proposed solution, simulations were carried out for four iterations. The results obtained indicated that with prcoding plus RCF plus A-law companding, the PAPR of OFDM signal can be effectively reduced.

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