International Journal of Academic Pedagogical Research (IJAPR)
ISSN: 2643-9123
Vol. 7 Issue 4, April - 2023, Pages: 60-64

A Technique for Peak-to-Average Power Ratio Minimization in Orthogonal Frequency Division Multiplexing Based Wireless Network

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Abstract: *Peak-to-Average Power Ratio (PAPR) reduction in Orthogonal Frequency Division Multiplexing (OFDM) based wireless network has been presented. An OFDM system that uses Discrete Fourier Transform (DFT) precoding algorithm to code the OFDM signal and after which Clipping and Filtering process was performed repeatedly for four times in or der to effectively reduced the PAPR effect on the signal. Simulations were performed in MATLAB environment using Quadrature Phase Shift Keying (QPSK) modulation. The results from the simulations carried out using optimum parameters revealed that the PAPR o f OFDM signal was reduced to 2.80 dB, which is 73.4% improvement from the original or conventional OFDM signal.*

Keywords—Discrete Fourier Transform; OFDM signal; PAPR; Clipping and Filtering

1. INTRODUCTION

In order to exploit the numerous benefits channel fading robustness, diversity in multipath fading environment, high data rate, spectral efficiency and energy efficiency, systems with Orthogonal Frequency Division Multiplexing (OFDM) (multicarrier) modulation and Multiple Input Multiple Output (MIMO) plus OFDM (simply referred to as MIMO-OFDM) are now being increasingly adopted in wireless communication networks such as Digital Audio Broadcasting (DAB), Worldwide interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE), Digital Video Broadcasting (DVB), high speed Wireless Local Area Network (WLAN) and many other applications. In fact, in many wireless networks such as Digital Video Broadcasting Terrestrial (DVB-T) DVB-T2, Integrated Services Digital Broadcasting (ISDB) for Microwave Access, (ISDB-T), LTE and etc, OFDM has been accepted [1, 2]. A very important advantage of OFDM is that it can overcome the effect of severe channel conditions such as interference, attenuation and multipath fading without complex equalization filters [1].

Despite the observed significant improvement in the performance of OFDM systems, intensive research in MIMO-OFDM is still being performed [3]. These areas of research interest include carrier offset and drift sensitivity, high Peak-to-Average Power Ratio (PAPR), receiver complexity and the use of complex computational scheme [4]. However, the interest of this paper is on PAPR reduction. With several techniques already proposed and implemented in literature resulting in considerable reduction in PAPR of OFDM signal, the problem of computational complexity due to the sub-blocks associated with signal scrambling schemes such as selective level mapping (SLM) and partial transmit sequence (PTS), and also the in-band noise associated with signal distortion methods is still being addressed. In this study, a combination of signal distortion schemes with finest simulation parameters is employed for minimizing PAPR in OFDM system.

With several techniques proposed in literature, recent approaches are geared towards using hybrid algorithms that combine two or more different techniques. This can be by integrating scrambling scheme such PTS and signal distortion techniques such as Mu-Law companding ($\mu-\text{Law}$ companding) as in [5]. Also, to reduce PAPR in OFDM, conventional SLM and clipping algorithm has been combined in [6]. Another approach can be the combination of distortion techniques such as repeated clipping and filtering (RCF) and $\mu-\text{Law}$ companding as in [7]. The choice of the hybrid scheme is to exploit the individual strength of each technique while overcoming their individual weaknesses. Another approach is the use of optimization algorithm as genetic algorithm or any other evolutionary algorithm such as particle swam optimization (PSO) with PTS in OFDM system to reduce PAPR. For instance, in addressing the effect of PAPR, social spider optimization (SSO) and adaptive artificial bee colony (AABC) has been implemented with SLM [8].

However, the use of optimal parameters in validating the effectiveness of most of the proposed schemes was not considered. Hence, these parameters are used in this study to

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performed simulation analysis of a PAPR minimization technique for OFDM system.

2. MATERIAL AND METHODS

This section presents the approaches taken to realizing the objective of this paper. The material or tool used in this paper is the MATLAB. The mathematical descriptions are presented to describe OFDM and PAPR problem.

2.1 Model of OFDM System

The model of the system used for the PAPR reduction in OFDM system is shown in Figure 1. In the model, the OFDM is initially coded using precoding discrete Fourier Transform precoder before the RCF algorithm scheme is applied. It should be noted that the block diagram as shown in Fig. 1, represents the transmit side of OFDM system because it is the transmitter that PAPR occurs.

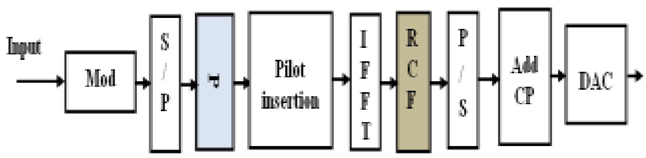

Fig. 1 PAPR reduction model for OFDM system

- Precoding Scheme

In Figure 1, the input data binary data stream are grouped and mapped into multi-amplitude-multi-phase signals. Precoding scheme based on DFT is applied after parallel conversion. Pilot carrier insertion is performed and after that the modulated and DFT coded complex band OFDM signal with N subcarriers is performed.

The precoding matrix P of $N \times N$ dimension that is implemented prior to Inverse Fast Fourier Transform (IFFT) is given by [9, 10]:

$$P = \begin{bmatrix} P_{00} & P_{01} & \cdots & P_{0(N-1)} \\ P_{10} & P_{11} & \cdots & P_{1(N-1)} \\ \vdots & \vdots & \ddots & \vdots \\ P_{(N-1)0} & P_{(N-1)1} & \cdots & P_{(N-1)(N-1)} \end{bmatrix} \quad (1)$$

Adding the P matrix to the OFDM system results in complex band OFDM signal with N subcarriers given by:

$$x(t) = \sqrt{\frac{1}{N}} \times \sum_{k=0}^{N-1} P.X_k e^{j2\pi k \Delta f t} \qquad 0 \le t \le NT$$

(2)

where Δf is the subcarrier spacing and NT is the useful block period.

The modulated OFDM vector signal with N subcarriers can be expressed given by:

$$x_N = IFFT\{P.X_N\} \quad (3)$$

The PAPR of OFDM signal in can be expressed given by:

$$PAPR = \frac{\max |x(t)|^2}{E[|x(t)|^2]}$$

(4)

The DFT of a sequence of length N and IDFT can be expressed given by [10]:

$$X(k) = \sum_{n=0}^{N-1} x(n).e^{-j2\pi nk}, \quad k = 0,1 \ldots N-1$$

(5) $$x(n) = \frac{1}{N} \sum_{n=0}^{N-1} x(n).e^{j2\pi nk}, \quad k = 0,1 \ldots N-1$$

(6)

where, $p_{mn} = e^{-j2\pi mn/N}$, m and n are integers from 0 to N-1.

- Clipping and Frequency Filtering

With the operation of IFFT performed, next stage is clipping and filtering process performed repeatedly, which is simply called repeated clipping and filtering (RCF). This process is repeated depending on the number of iterations, which is often chosen between 1 and 4. Flow chart of RCF technique is shown in Figure 2. In RCF, the original signal is clipped in the time domain [11]. Mathematical description of the clipping is given by:

$$C = \begin{cases} \sqrt{CR * E[|x|^2]} * \frac{x}{|x|} & |x|^2 > C_m \\ x & |x|^2 \le C_m \end{cases} \quad (7)$$

where C represents the time domain signal of the output, $|x|^2$ is the signal absolute power, $E[|x|^2]$ is the mean signal power, CR is the clipping ratio, which is the defined as the ratio of the clipping level to the mean power of the unclipped baseband signal, and C_m is the threshold clipping level is given by:

$$C_m = CR * E[|x|^2] \quad (8)$$

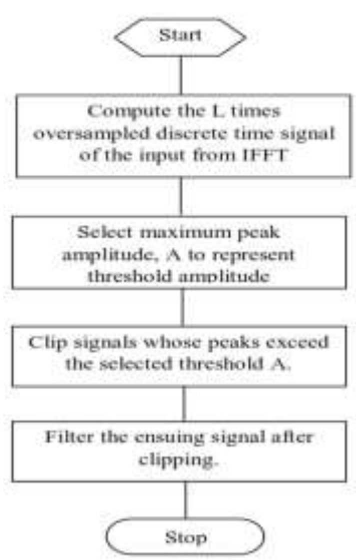

Fig. 2 Flow chart of RCF technique

2.2 Simulation Parameters

The parameters for the simulation conducted in MATLAB environment are shown in Table 1.

Table 1 LTE Simulation Test Parameter

Parameter	Description /value
Modulation	QPSK
FFT Size	256
Spacing	15KHz
Band Width (BW)	1250KHz
Cyclic Prefix (CP)	1/4 of FFT Size
Number of Symbol (nsym)	1×10^3
Sampling Frequency (f_s)	192MHz
Sampling Period (T_s)	192µs
Max. Doppler Frequency Shift (F_{Dmax})	0.01Hz

The selection of optimal values for clipping ratio (CR), number of iteration, oversampling factor (OF), and the $\mu-$Law companding is based on previous reports in literature.

i. Oversampling factor L: The fact that at Nyquist sampling rate, OFDM symbols may not show equivalent PAPR as the continuous time signals is the essence of the L. Therefore, the time domain signal must meet this criteria, $L>2$ (or $L\geq4$) [14-17] with L = 4 usually considered to be sufficient to reach the peaks [18].

ii. Clipping ratio (CR): The CR can be any positive value from 0.8 to 4. However, in practical system, by setting CR = 1.2, the system performance will be nearly optimal [14].

iii. $\mu-$Law: The value of μ can be assigned any positive value. Increasing it will increase compression and average power with increasing PAPR reduction gain, however this leads to deteriorating bit error ratio (BER) [19]. The effect of varying μ on both PAPR and BER shows that at low μ values, the PAPR decreases moderately fast and then drops at high values while the BER changes almost constantly with μ [17]. Thus the best results for OFDM signal should target small values of μ [12] such that a better and optimum value of 2 was obtained for $\mu-$Law companding [12, 19].

iv. Number of iteration: The number of iteration is chosen based on the fact that with 4 iterations, the best performance of CF is achieved as shown from simulations carried out by [7, 20].

3. Results and Discussion

Simulations were conducted in MATLAB considering uncoded OFDM signal, OFDM signal with RCF technique, coded OFDM signal with RCF, OFDM signal with $\mu-$Law companding, and coded OFDM signal with RCF and $\mu-$Law companding.

- Uncoded OFDM Signal

In this case, the OFDM system is simulated assuming no algorithm was included as part of the transmit process. This was done to enable easy understanding of how the system was performing when no technique was included in the transmit end to reduce the effect of PAPR. The value of the PAPR as shown in Figure 3 is 10.51 dB at CCDF of 10^{-3} and it is taken as the reference value for PAPR of OFDM signal.

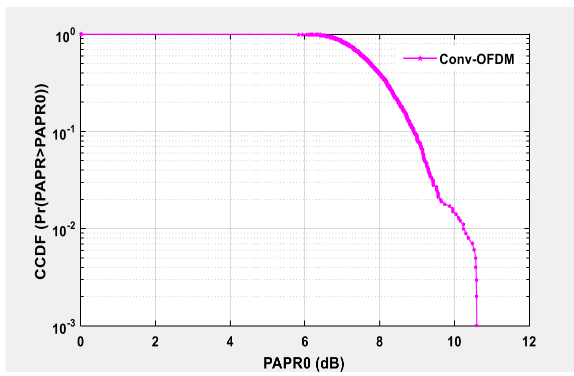

Fig. 3 PAPR of conventional OFDM signal

- Uncoded OFDM signal with RCF

Simulation is carried out in this case by enhancing the PAPR performance of OFDM signal with RCF scheme as shown in Figure 4. The essence of this simulation is to show the effectiveness of the RCF technique when combined alone with OFDM system. The performance analysis is shown in Table 2.

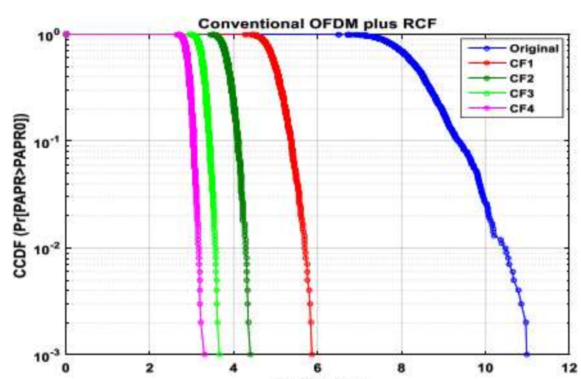

Fig. 4 PAPR of OFDM with RCF

Table 2 Performance analysis of uncoded OFDM signal with RCF technique

Parameter	PAPR Value (dB)	Improvement in PAPR value

Original	10.98	-4.45
CF1	5.86	44.2%
CF2	4.40	58.2%
CF3	3.65	65.2%
CF4	3.30	68.6%

- Coded OFDM signal with RCF Technique

In Figure 5, the simulation performance of PAPR in OFDM system model with precoding and RCF algorithms is presented. This simulation is conducted to show the effectiveness of precoding with RCF technique in reducing PAPR of OFDM signal. Table 3 shows the numerical values

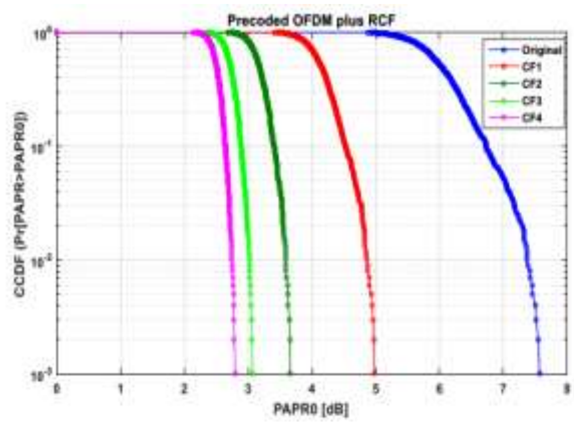

Figure 5 PAPR of OFDM with precoding plus RCF

Table 3 Performance analysis of coded OFDM signal with RCF technique

Parameter	PAPR Value (dB)	Improvement in PAPR value
Original	7.57	28.2%
CF1	4.97	52.7%
CF2	3.65	65.2%
CF3	3.07	70. 8%
CF4	2.80	73.4%

The performance of the coded OFDM system with repeatedly performed clipping and filtering algorithm for PAPR reduction in OFDM signal has been examined using finest parameters. The results obtained showed that the introduction of the algorithm provided reduction in PAPR of OFDM signal. The PAPR of uncoded OFDM signal was initially 10.51 dB. With the addition of RCF, the PAPR value was reduced to 3.30 dB, which is 68.6% reduction. Then, by coding the OFDM signal and adding RCF, the PAPR was reduced to 2.80 dB, which is 73.4% reduction.

4. CONCLUSION

The performance of coded OFDM signal with clipping and filtering process performed iteratively for four times using optimum parameters in litertature has been presented. Simulation results have shown that PAPR was minimized for improved OFDM signal. The performance of the system using optimal values in literature for oversampling factor, clipping ratio, repeated clipping and filtering, with QPSK modulation scheme revealed the effectiveness of the proposed system.

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