PAPR Reduction in an OFDM system using Recursive Clipping and Filtering Technique

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Abstract: - An Orthogonal Frequency Division Multiplexing (OFDM) scheme is expected as an efficient technique for next generation wireless communications. However, high Peak to Average Power Ration (PAPR) of OFDM system is the main drawback which degrades the transmitter power efficiency causes poor performance of the system. To reduce PAPR of OFDM signal, several works on clipping technique have been proposed. This paper is incorporated the improvement of the PAPR and Bit Error Rate (BER) performance using clipping method. It has been shown from the result that by employing the recursive clipping and filtering, 11.45 dB of PAPR of original OFDM signal is reduced down to 4.77 dB. Hence, BER is also increased significantly. This research is carried out through MATLAB simulation and gradually measured the effect of PAPR on BER under AWGN channel for 16QAM scheme with 256 points OFDM. Moreover, it is studied the effect of OFDM signal while passing through High Power Amplifier (HPA). Finally, the PAPR reduction technique such as recursive clipping and filtering (RCF) is implemented.

Key-Words: - AWGN, HPA, OFDM, PAPR, QAM, Recursive Clopping and Filtering (RCF)

1 Introduction

Orthogonal frequency-division modulation (OFDM) is a popular multicarrier modulation technique in modern communication systems. Today, OFDM schemes are used for terrestrial digital video broadcasting (DVB-T), digital audio broadcasting (DAB-T), wireless local area networks (IEEE 802.11a, ETSI Hiperlan2) and wireless metropolitan area networks (IEEE 802.16d). However, a well-known disadvantage of OFDM is the occasional occurrence of high peak-to-average power ratio (PAPR) in the time-domain signal [1, 2].

Several techniques have been proposed in the literatures to reduce the PAPR. These techniques can mainly be categorized signal scrambling techniques and signal distortion techniques. Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR. Coding techniques can be used for signal scrambling. Golay complementary sequences, Shapiro-Rudin sequences, M sequences, Barker codes [3] can be used efficiently to reduce the PAPR. However with the increase in the number of carriers the overhead associated with exhaustive search of the best code would increase exponentially. More practical solutions of the signal scrambling techniques are Block coding, Selective Level Mapping (SLM) and Partial Transmit Sequences (PTS) [3]. Signal scrambling techniques with side information reduces the effective throughput since they introduce redundancy. The signal distortion techniques introduce both In-band and Out-of-band interference and complexity to the system. The signal distortion techniques reduce high peaks directly by distorting the signal prior to amplification [3]. Clipping the OFDM signal before amplification is a simple method to limit PAPR. However clipping may cause large out-of-band (OOB) and in-band-interference, which results in the system performance degradation. More practical solutions are peak windowing, peak cancellation, Peak power suppression, weighted multicarrier transmission, companding etc. Basic requirement of practical PAPR reduction techniques include the compatibility with the family of existing modulation schemes, high spectral efficiency and low complexity [3].

This paper is based on repeatedly clipping and filtering method to reduce PAPR and also evaluate the system performance. The simplest

PAPR reduction method is to employ clipping in the time domain signal. This results in band distortion and high out-of-band spectrum [4]. By repeating clipping and filtering several times [5], both low PAPR and low out-of-band spectrum can be achieved. Such a method is called recursive (or repeated) clipping and filtering (RCF). By increasing the number of recursions in RCF, PAPR can be reduced [12]. However, the associated error rate will also be increased, which is due to the increase of in-band distortion (clipping noise) [1], [5]. This can be mitigated by clipping the oversampled version of OFDM signal. The oversampled (L>1) approach has the advantages of reducing in band distortion and peak reform to some extent, but inevitably generates out of band radiation. The conventional solution to this problem is to pass the clipped samples through a low pass filter (LPF) [6].

In Section 2, some basics about OFDM, PAPR reduction, and the operation of RCF are provided. Section 3 describes the system model. Section 4 describes the simulation results and discussions. Conclusion is given in Section 5

2 OFDM and PAPR

Consider an OFDM system with N subcarriers. Each OFDM block (OFDM symbol), $s(t)$, $0 \leq t \leq T$, consists of N complex baseband data $X_0, X_1, \ldots, X_{N-1}$ carried on the N subcarriers respectively for a symbol period of T. The OFDM symbol $s(t)$ is

$$s(\mathrm{t}) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\,jk2\pi\Delta f t} \quad ; \quad 0 \leq t \leq T \tag{1}$$

where $\Delta f = 1/T$ is the subcarrier spacing and X_k is the complex baseband data modulating the k-th subcarrier for $s(t)$. For the OFDM symbol $s(t)$, the peak instantaneous power is,

$$P_{max} = \max_{0 \leq x \leq 1} (|s(t)|^2) \tag{2}$$

An OFDM symbol sequence can be represented by . . . , $s(t)$, $s(t + T)$, ... , $s(t + mT)$, ... We define the average power of the OFDM symbol sequence following the approach in [7], [8] as follows

$$\mathrm{P_{av}}(X_0, X_1 \ldots\ldots X_{N-1}) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} (\mathrm{E}|X_k|^2) \tag{3}$$

where $\mathrm{E}[|X_k|^2]$ is the expected value of $|X_k|^2$. The peak to average power ratio (PAPR) of the OFDM symbol $s(t)$ is,

$$PAPR(s(t)) = \frac{\overset{P}{max}(s(t))}{\mathrm{p_{av}}(X_0, X_1, \ldots\ldots X_{N-1})} \tag{4}$$

OFDM systems are usually implemented by discrete Fourier transform (DFT). Consider the OFDM signal of Equation (1) sampled at time instant $n\Delta t$, the associated discrete-time output is $s[n] = s(n\Delta t)$. When the signal is sampled by interval $\Delta t = T/LN$, where L is the oversampling factor (OSF). The associated discrete-time output becomes,

$$\mathrm{s_L}[n] = s\left(n\frac{T}{nL}\right) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} Xk^{ejk2\pi\frac{n}{LN}},\ 0 \leq n \leq LN - 1 \tag{5}$$

The oversampled signal can be obtained by padding $LN - N$ zeros in the frequency domain and taking the LN-point inverse discrete Fourier transform (IDFT). The symbol-wise peak power definition in Equation (2) can be approximated by $P_{max}(s(t)) \approx \max_{0 \leq n < LN} |\, s_L[n] \,|^2$ for a large enough L.

To alleviate the problem of the occasional occurrence of symbols with high PAPR, many methods have been proposed. Among them, oversampled digital clipping and filtering [7], [9] is a simple and effective method. The basic operations for the oversampled digital clipping and filtering (OCF) are shown in Fig. 1. Complex baseband data $(X_0, X_1, \ldots, X_{N-1})$ are used as input and are converted to time domain data ($s_L[0]$, …, $s_L[N-1]$, $s_L[N]$, …, $s_L[LN-1]$) by LN-point IDFT, which are then clipped by the soft limiter model [10]. The input and output of the soft limiter model are respectively

$$input: x = \rho e^{j\varphi}, \rho = |x| \tag{6}$$

And

$$output: g(x) = \begin{cases} x & for\ \rho \leq A \\ Ae^{j\varphi} & for\ \rho > A \end{cases} \tag{7}$$

where A is the clipping threshold. Then ($g(s_L[0])$, $g(s_L[1])$,. . . , $g(s_L[LN-1])$) are converted to $(\hat{X}_0, \hat{X}_1 \dots, \hat{X}_{N-1} \dots, \hat{X}_{NL-1})$ by using the LN-point DFT, i.e.,

$$\hat{X}_k = \frac{\sqrt{N}}{LN}\sum_{n=0}^{NL-1} g(s_L[n])e^{-j2\pi\frac{nk}{NL}}, \quad 0 \le k \le LN-1 \quad (8)$$

The filtering operation removes the out-of-band components and gets $(\hat{X}_0, \hat{X}_1 \dots, \hat{X}_{N-1} \dots, \hat{X}_{NL-1}, 0 \dots, 0)$. After the filtering operation, the time domain signal becomes

$$\hat{s}_L[n] = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} \hat{X}_k e^{jk2\pi\frac{n}{NL}} \;;\quad \text{for } 0 \le n \le LN-1 \quad (9)$$

which exhibits the problem of peak power reform. That means the peak power $P_{max}(s(t)) \approx P_{max}(\hat{s}_L[n])$ $=\max 0 \le n < LN$ $|\hat{s}_L[n]|^2$ will be greater than A^2 again. The average in-band power in Equation (3) now becomes

$$P_{av}(\hat{X}_0, \hat{X}_1, \dots, \hat{X}_{N-1}) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}\left(E|\hat{X}_k|^2\right) \quad (10)$$

which is lower than the original P_{av} $(X_0, \dots, X_{N-1})$ due to the clipping and filtering operation. Since a single round of the OCF operation encounters the problem of peak power rebuild, it is proposed in [11] to repeat the OCF operation several rounds to suppress the final peak power. We call such a method recursive clipping and filtering (RCF).

3 SYSTEM MODEL

The system model considered in this paper consists of two clipping processes. One is simple clipping and the other is recursive clipping with filtering. Both former and later are used for PAPR reduction and to test the bit error rate (BER) condition over AWGN channel. For this consideration, the clipping threshold is denoted as A. We also use same oversampling factor, i.e. L =4 for both the investigations. L = 4 is used in the proposed clipping process since it can achieve effective PAPR reduction with the least complexity compared to less oversampling factor, e.g. L=1, 2 and 3. It is (L=4) also used to approximate the analog signal and the nonlinear behavior of the power amplifier in this paper. Although larger L can achieve more accurate results, L = 4 is commonly used to demonstrate the performances of PAPR reduction methods [10].

The performance of a PAPR reduction technique for the OFDM system can be evaluated by the complementary cumulative distribution function (CCDF) of peak power, bit error rate (BER) and effects of the OFDM subcarriers after HPA. This work is drawn out considering the 16 QAM 256-OFDM system (N = 256). Simulation results using RCF scheme is figured out in terms of PAPR and BER. Numbers of recursion clipping and filtering are tested throughout the work. It is shown from the simulation results that the only first and the fourth clipping and filtering are included in this paper to compare the reductions of PAPR and its effects on BER. It is observed that while the number of recursions increases, the probability of the occurrence of high PAPR decrease but the error rate increases. The drawback of the increased error rate is due to the increased distortion caused by the recursive clipping operations. Figure 1 shows the system model of the proposed work.

Figure 1: See Bottom of the Page

3. Results and Discussions

Simulation results of 16QAM 256 points OFDM systems for Recursive Clipping and Filtering with four recursion times under additive white Gaussian noise (AWGN) channel and are presented in 2, 3 and 4 respectively. Firstly, the Fig. 2: (a), (b) and (c) reflect the original OFDM signal, effect on OFDM signal while passing through High Power Amplifier (HPA) and effect of RCF of OFDM signal respectively.

Figure 2: Bottom of the Page

Secondly, in Figure 3, the PAPR **11.45 dB** of the OFDM signal is reduced down to **5.28 dB** by using first clipping and filtering, then the PAPR is down to **4.77 dB** due to further recursion of clipping and filtering. Moreover, in Fig. 4, the performance in terms of BER is evaluated with the reduction of PAPR. From the work, it is observed that some of the OFDM signals peak reaches high while it passes through HPA which causes poor efficiency of HPA and leads to clip the high amplitudes to retain the operating point in the linear region. Using the PAPR reduction RCF technique, it is also observed that for the first RCF the PAPR is reduced by **6.17 dB** and again it is improved by **6.68 dB** using 4th RCF from the original one. But for both the cases BER is increased significantly as shown in Figure 4.

Figure 3: Bottom of the Page
Figure 4: Bottom of the Page

4 Conclusion

The proposed RCF scheme achieves significant PAPR reduction while keeping the distortion of the data carried on the subcarriers passing through HPA under control. Such a scheme points out the first RCF provides low BER and PAPR compare to the fourth RCF. The simulation results show that RCF is more robust against PAPR reduction than BER. So the conclusion can be revealed that while the number of recursions increases, the probability of the occurrence of high PAPR decrease but the error rate increases.

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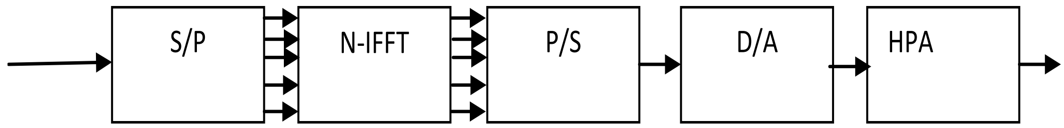
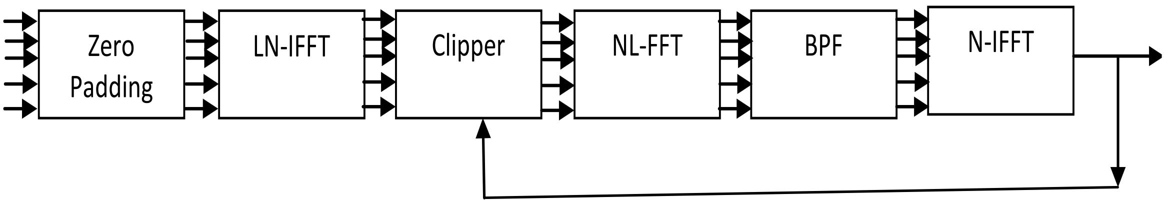
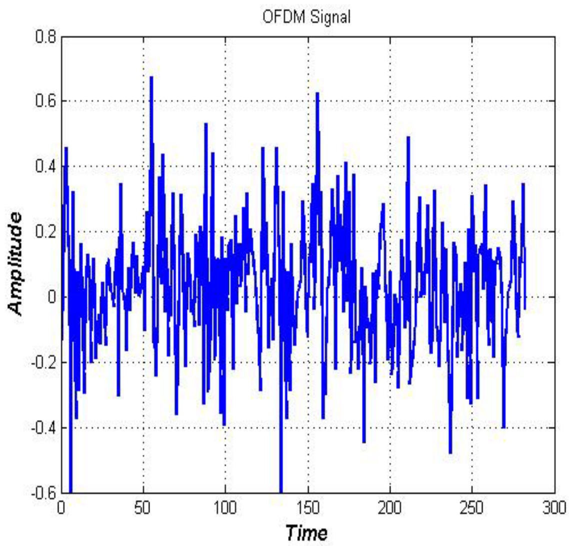


(a)

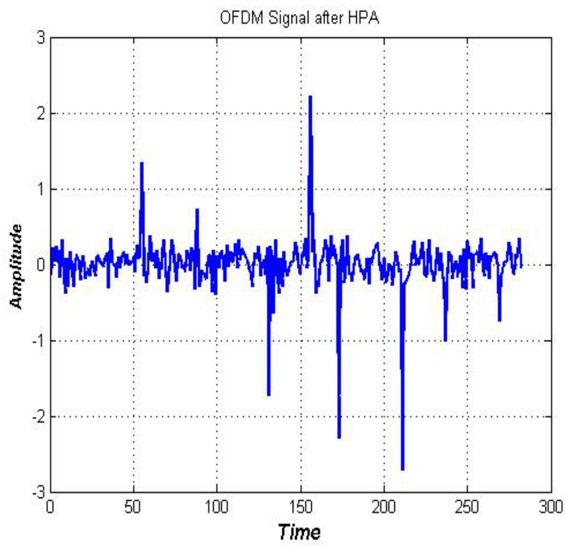


(b)

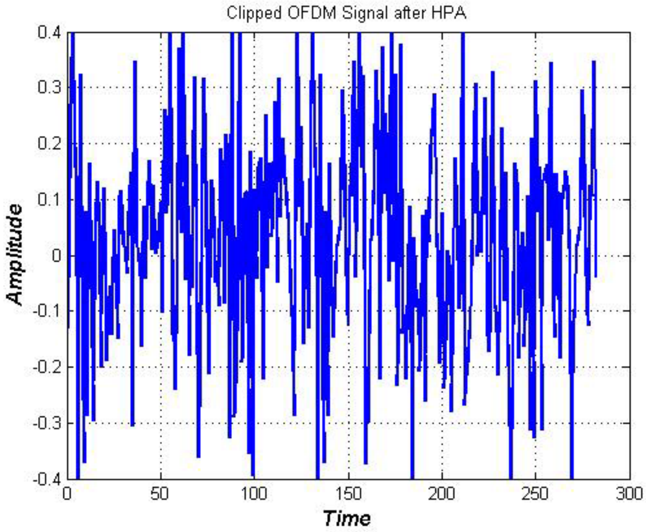
Figure 1: OFDM Transmitter Block Diagram: (a) Original, and (b) With Recursive Clipping and Filtering



(a)



(b)



(c)

Figure 2: (a) Original OFDM siganl with 256 subcarriers for 16-QAM modulation, (b) Effect on OFDM signal after passing HPA and (c) OFDM signal recovery by amplitude Clipping.

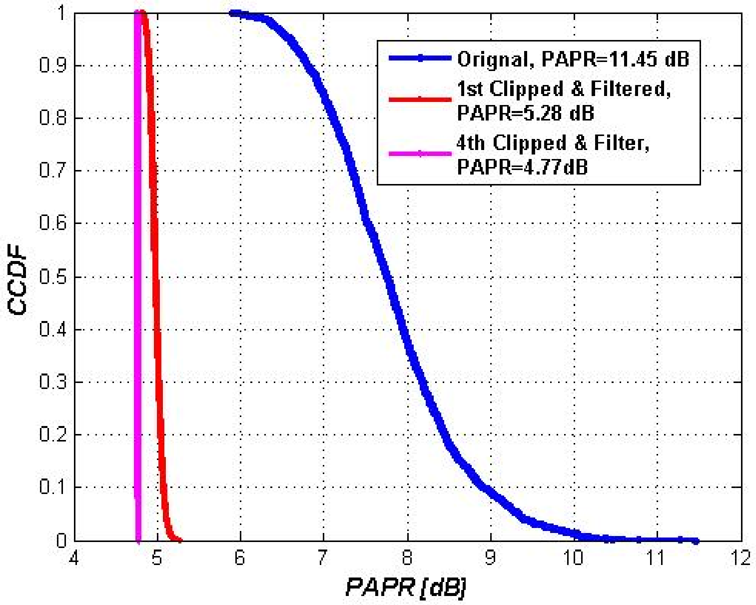


Figure 3**:** PAPR reduction to 6.17 dB and 6.68 dB using 1st & 4th Clipping and Filtering respectively for 16QAM 256-OFDM

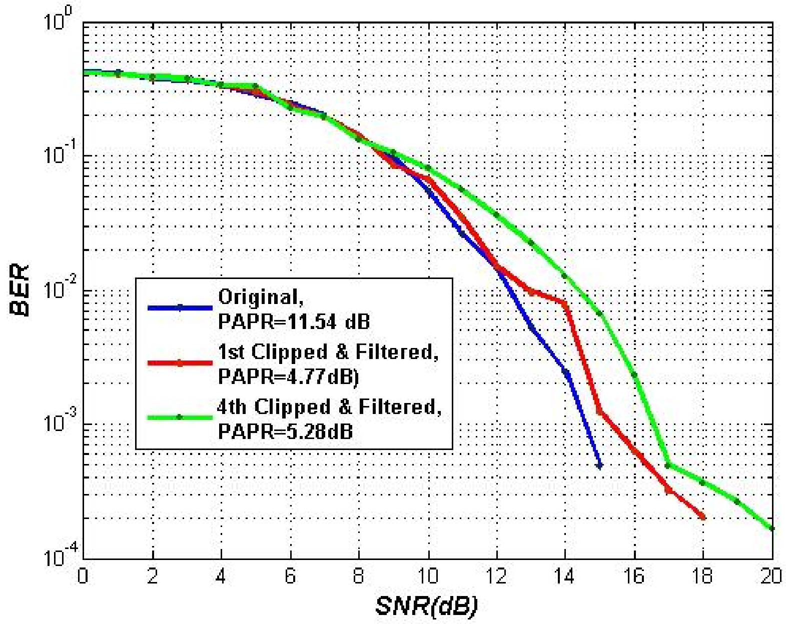


Figure 4: BER performances degrade after RCF for 16QAM 256 OFDM under AWGN channel. At 14 dB of E_b/N_o, BER increases slightly for 4^{th} clipping and filtering