A Novel Iterative Clipping and Filtering Technique for PAPR Reduction of OFDM Signals: System Using DCT/IDCT Transform

Sroy Abouty, Li Renfa, Zeng Fanzi and Fall Mangone

[1] *College of Information Science and Engineering of Hunan University*
410082, Changsha, China
s_abouty@yahoo.com, lirenfa@vip.sina.com, zengfanzi@126.com,
mangone.fall.ch@gmail.com

Abstract

The drawbacks of high peak to average power ratio (PAPR) can outweigh all the potential benefits of Orthogonal Frequency Division Multiplexing (OFDM) signals. In this Paper, a sophisticated PAPR reduction technique, named Iterative Clipping and filtering (ICF) with DCT/IDCT transformation, is proposed for OFDM system. By considering the example of OFDM, with Quadrature Phase-Shift Keying (QPSK) mapping, simulation results under Matlab environment show that the new proposed method performs well in reducing PAPR.

Keywords: *OFDM, High Peak to Average Power Ratio, Iterative Clipping and Filtering, DCT/IDCT*

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is the promising technology for future broadband wireless communication system especially based on multicarrier modulation which make good use of available bandwidth by allocation sub-carriers. The recent interest advances in this technique is mainly due to the recent advances in digital signal processing technology. International standards making use of OFDM for high-speed wireless broadband communication are already established or being established by IEEE 802.11 as well known as wireless local area networks (WLAN), IEEE 802.16 also known as worldwide interoperability for microwave access (WIMAX), IEEE 802.20, and European Telecommunications Standards Institute (ETSI) Broadcast Radio Access Network (BRAN) committees. For wireless applications, an OFDM-based system can be of interest because it provides greater immunity to multipath fading and impulse noise, and eliminates the need for equalizers, while efficient hardware implementation can be realized using Fast Fourier transform (FFT) techniques.

In Orthogonal Frequency Division Multiplexing system the signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier. The OFDM has many significant advantage such as high bandwidth efficiency, robustness to the selective fading problem, use of small guard interval, and its ability to combat the Inter Symbol Interference (ISI) problem [1]. However, though OFDM has many advantages there are still leak some obstacles in transmission of OFDM communication system. The main of disadvantages is that the OFDM signal exhibits a very high Peak to Average Power Ratio (PAPR), which means that some of transmitted signal could be much larger than typical values. PAPR make any amplifier in non-linearity because of unwanted out-of-band power. To prevent spectral growth of the OFDM signal in the form of intermodulation among subcarriers and out-of-band radiation, the transmit amplifier must be operate in its linear region [2].

There are many techniques to resist with the problem of PAPR to achieve the good result of PAPR reduction such as clipping, filtering [3], Partial Transmit Sequence (PTS) algorithm is introduced to offer considerable PAPR reduction by partitioning the input data block into subblocks [4, 5, 6], Selected Mapping (SLM) is one of the popular techniques for achieve minimize of PAPR reduction, where the signal with the lowest peak power is selected for transmission without side information (SI), [7, 8, 9], Tone Reservation (TR), in this technique a small number of unused subcarriers called Peak Reduction Carriers is reserved to reduce the PAPR [10, 11].

One of the effective techniques available to provide a high efficiency in PAPR reduction is to clip the high amplitude peak, clipping and filtering clips the peak value of OFDM signal waveform. So by clipping the signal, the spectral efficiency of the multicarrier signal is reduced [12, 13]. Hence, clipping could be effective technique with a very low complexity for PAPR reduction and filtering is done after clipping in order to eliminate unwanted frequencies by the clipping process.

X. Li, R. Ow'Neill proposed technique for PAPR reducing and L.N. Lopes has been described clipping technique to reduce the PAPR [14, 15]. A lot of work for PAPR reduction has been done by references [16-20]. It could be noted that most of the methods are certainly based on the same idea which mean, selecting the time domain signal to be transmitted from a set of different representations with the constraint of minimization of PAPR which would degrade the performance of system.

The main objective of this research is design an efficient algorithm for OFDM communication systems that will be reduced for PAPR, with an improvement over other algorithms and a very reasonable complexity. In this paper, we propose new efficient scheme, Iterative clipping and filtering technique by using DCT/IDCT for significant PAPR reduction while maintaining low error rate in OFDM communication system. In the first iteration of this work, the new OFDM symbol enters the ICF block with DCT/IDCT technique. Then clipping and filtering is iteratively performed. In the final iteration, the output is produced. The simulation results demonstrate the effectiveness of our proposed approach.

The rest of this paper is organized as follow. In Section 2 present the OFDM system description and the PAPR problems. Section 3 describes the new iterative clipping and filtering technique with proposed block diagram using DCT/IDCT technique and proposed method. Simulation results with discussion are presented in Section 4. Finally, the conclusion is given in Section 5.

2. System Description

2.1 OFDM Signal Basics

Let denote the collection of all data symbols as X_k where $n = 0, ..., N-1$, to create a complex value symbol vector $X = [X_0, X_1, ..., X_{N-1}]^T$ in the frequency domain, where X_k the complex value is carries by the k_{th} subcarrier and assume N is the number of subcarriers. The symbol vector is also called the input symbol sequence. The OFDM signal is generated by summing all the N modulated subcarriers each of which is separated by $1/NTs$ in the frequency domain, where Ts is the sampling period and then $x(t)$ continuous time baseband. The OFDM signal can be written as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}, \qquad 0 \le t \le NTs \tag{1}$$

Where $f_k = k\Delta f$ and $\Delta f = 1/NTs$

Where N the subcarrier of an OFDM system is, A_k is the modulated data carried by the k_{th} subcarrier, $x(t)$ is the n_{th} sample of a time-domain symbol. Actually, the equation above can be realized conveniently by using the inverse Fast Fourier Transform (IFFT).

$$x(t) = IFFT(X(t)) \tag{2}$$

We can see that:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t} \tag{3}$$

2.2 PAPR of an OFDM Signal

High Peak-to-Average Power Ratio has been recognized as one of the major practical problem involving OFDM modulation. Generally, the PAPR of OFDM signals $x(t)$ is defined as the ratio period between the maximum instantaneous power and its average power during an OFDM symbol.

The PAPR can be defined as

$$PAPR = 10\log_{10} \frac{P_{peak}}{P_{av}} \tag{4}$$

Where P_{peak} and P_{av} can be compute as:

$$P_{peak} = \max\left|x(t)\right|^2 \text{ and } P_{av} = \frac{1}{T}\int_0^T \left|x(t)\right|^2 dt \tag{5}$$

Hence, the PAPR is expressed as:

$$PAPR = 10\log_{10} \frac{\max|x(t)|^2}{\frac{1}{T}\int_0^T |x(t)|^2\, dt} \tag{6}$$

When N sinusoids add, the peak magnitude would have a value of N, where the average might be quite low due to the destructive interference between the sinusoids. High PAPR signals are usually undesirable for it usually strains the analog circuitry. For *e.g.* power amplifier has High PAPR, signals would require a large range of dynamic linearity from the analog circuits which usually results in expensive devices and high power consumption with lower efficiency (operate with larger back-off to maintain linearity).

In OFDM system, some input sequences would be resulted in higher PAPR than others. Which mean, input sequence that requires all such carriers to transmit their maximum amplitudes would certainly result in a high output PAPR. Thus by limiting the possible input sequences to a smallest sub set, it should be possible to obtain output signals with a guaranteed low output PAPR.

High PAPR could cause problems when the signal is applied to transmitter which contains non-linear components such as High Power amplifier (HPA) in the Transmitter chain. The PAPR has the worst case value PAPRWC which depends on the no of subscribers N. The non-linear effects on the transmitted OFDM symbols are spectral spreading, inter-modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals.

The complementary cumulative distribution function (CCDF) is the distribution of PAPR and has stochastic characteristics. The CCDF of PAPR is defined as the probability that the PAPR of the OFDM symbols exceeds a given threshold A such as

$$CCDF = 1 - \Pr(PAPR \leq A) \tag{7}$$

3. Proposed Method: Iterative Clipping and Filtering Technique using DCT/IDCT Transformation

3.1 Classic Iterative Clipping and Filtering (ICF) Technique

Iterative clipping and filtering (ICF) is a widely used technique to reduce the PAPR of OFDM signals. However, the ICF technique, when implemented with a fixed rectangular window in the frequency-domain, requires many iterations to approach the specified PAPR threshold in the complementary cumulative distribution function (CCDF).

Figure 1 shows the basic block diagram of the classic ICF PAPR reduction scheme.

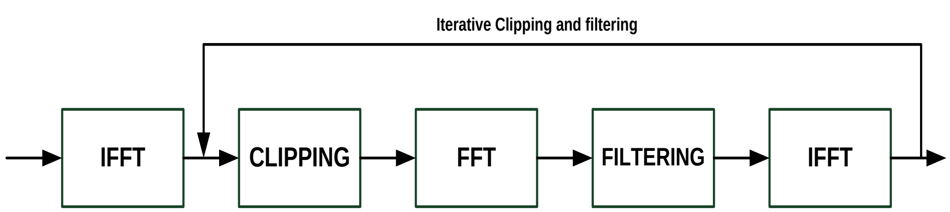

Figure 1. Block Diagram of the Classic ICF Using FFT/IFFT

In the first iteration (i=1), the new OFDM symbol enters the ICF block. Then clipping and filtering is iteratively performed. In the Ith (final) iteration, the output x is produced.

3.2 DCT/IDCT Basics

Like others transformations, such as Hadamard transform, the discrete Cosine transform decorrelates the data sequence. In this section we briefly review the DCT transformation. The one- dimensional DCT of length N can be defined as:

, (8)

for $k = 0, ..., N-1$

Similarly, the inverse transformation of DCT is defined as:

$$x(n) = \sum_{k=0}^{N-1} \alpha(k) X_c(k) \cos\left[\frac{\pi(2n+1)k}{2N}\right] \tag{9}$$

for $n = 0, ..., N-1$

$$\alpha(k) = \begin{cases} \frac{1}{\sqrt{N'}} \; fork = 0 \\ \frac{2}{\sqrt{N'}} \; fork \neq 0 \end{cases} \tag{10}$$

3.3 Proposed Scheme for ICF Using DCT/IDCT

Figure 2 shows the proposed ICF. This new algorithm combines the classic procedure with DCT/IDCT transformation. This new method modifies each OFDM symbol on at a time. In the first iteration (m=1) switch S1 is set to 1 and the OFDM enters the ICF block. Then both S1 and S2 are set to 2 and clipping and filtering is iteratively performed. In the $M-th$ (final) iteration the switches are returned to position 1 and the output signal $\widehat{x'}_m$ is produced. The proposed clipping is performed by

$$\hat{x}_m(k) = \begin{cases} C_m e^{j\theta_m k}, & |x_m(k)| > C_m \\ x_m(k), & |x_m(k)| \leq C_m \end{cases} \tag{11}$$

Where $1 \leq k \leq lN$, θ_m represents the phase of $x_m(k)$, and C_m is the clipping level in the m-th iteration. The clipping level is recalculated in each iteration according to a constant value called the clipping ratio (CR) as follows:

$$CR = \sqrt{PAPR_{\max}} = \frac{C_m}{\frac{1}{\sqrt{N}}\|x_m\|_2} \tag{12}$$

The filtering step is based on a rectangular window with frequency response defined by

$$F_m(i) = \begin{cases} 1, & 1 \leq i \leq N \\ 0, & N+1 \leq i \leq lN \end{cases} \tag{13}$$

The steps for our proposed method are described as:

Step 1: Initialization: Set the clipping ratio (CR) and the number of iteration (M)

Step 2: A new OFDM symbol x^o enters to the proposed ICF block loop.

Step 3: Calculate the clipping level, C_m, using (eq 11) and generate $\hat{x}_m$ by clipping x_m using (eq 10).

Step4: Convert $\hat{x}_m$ to frequency domain signal $\hat{X}_m$ using DCT transform ($\hat{X}_m = DCT(\hat{x}_m)$).

Step 5: Generation of $\hat{X}'_m$ by filtering $\hat{X}_m$ using F_m ().

Step 6: Convert $\hat{X}'_m$ into time domain to obtain by using $IDCT\left(\hat{x}'_m = IDCT(\hat{X}'_m)\right)$

Step7: Let, m = m +1, if m > M, reset m = 1 and go to step 2 to process the next OFDM symbol.

Step 1 is performed once for initialization, and then step 2 through 7 are performed M times for each OFDM symbol.

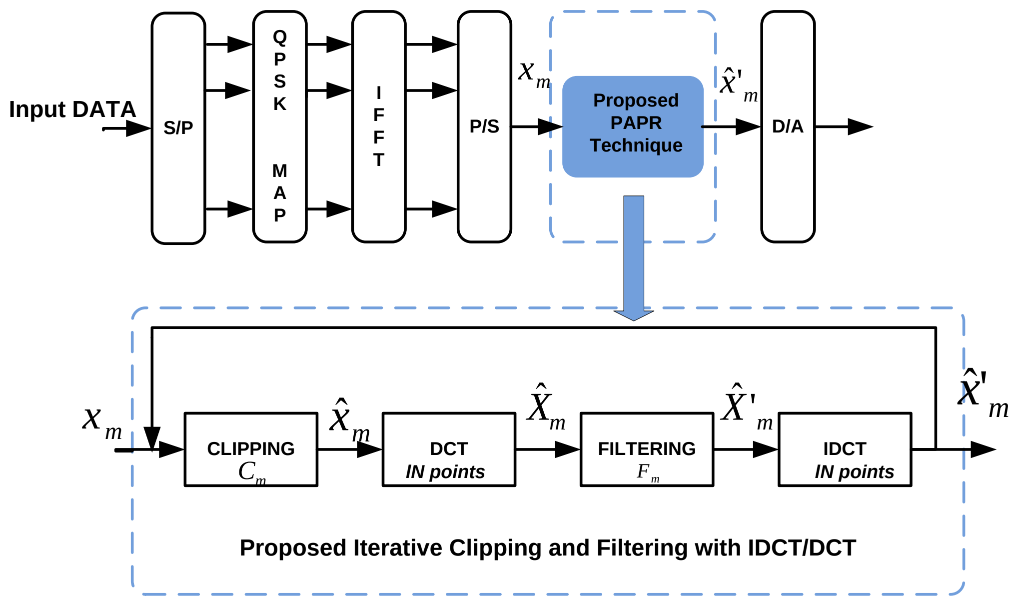

Figure 2. Proposed Block Diagram using DCT/IDCT

4. Simulation and Results

In this section we evaluate the performance of our proposed scheme using simulation under a Matlab environment. Complimentary Cumulative Distribution Function (CCDF) has been used to describe the performance of this scheme. OFDM system is considered with the number of subcarriers N=128, QPSK mapping, Interpolation factor 2, 3 iterations. Data points have been randomly generated by the computer.

Figure 3 shows the CCDF of the iterative clipping and filtering with FFT/IFFT. The original signal is directly obtained from the input sequence while the clipping and filtering signal is derived by using the ICF technique using FFT/IFFT and iteratively performed. It shows that the PAPR performs with the number of iteration.

The CCDF curves between the ICF using DCT/IDCT transformation and the original OFDM signal are in Figure 4. The graph shows better performance than the original OFDM. At the CCDF of 10^{-3}, the PAPR reduction of the ICF with DCT/IDCT and 1 iteration is better than the original OFDM signal, by 0.3 dB, for 2 iterations ICF with FFT/IFFT and 3 iterations ICF with FFT/IFFT, we can achieve a PAPR reduction by 1.2 dB and 1.6 dB respectively.

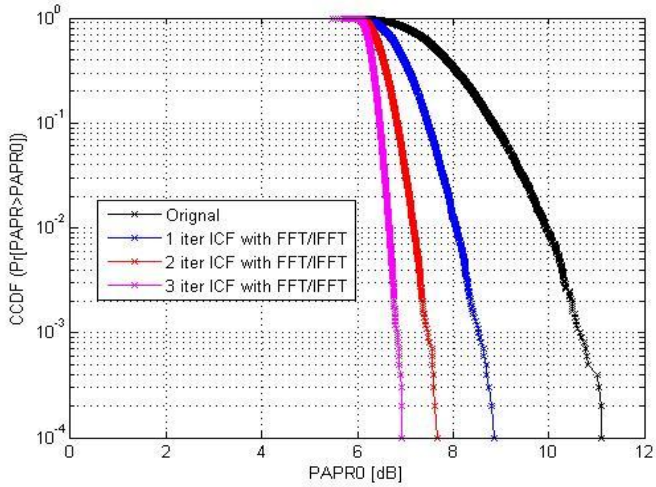

Figure 3. CCDF of PAPR using Iterative Clipping and Filtering with FFT/IFFT

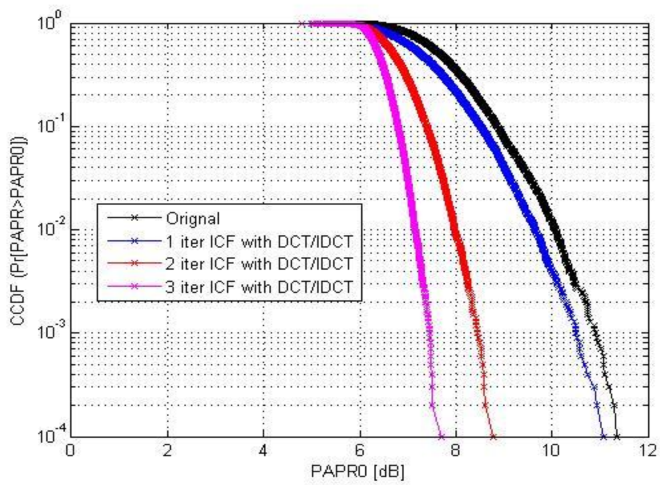

Figure 4. CCDF of PAPR using Iterative Clipping and Filtering with DCT/IDCT

5. Conclusion

In this paper, new Iterative clipping and filtering technique using DCT/IDCT transform for PAPR reduction is proposed. In the first iteration of our proposed scheme, the new OFDM symbol enters the ICF block with DCT/IDCT technique, then clipping and filtering is iteratively performed. In the final iteration, the output is produced.

The performance is seen through CCDF curves. Although we demonstrate that significant PAPR reduction is obtained through Iterative clipping and filtering using FFT/IFFT transform, but better results are observed applying DCT/IDCT in the classical ICF technique.

Acknowledgements

I would like to thank to my supervisor Prof. Li renfa, Zeng Fanzi, and also Mr. FALL mangone who shepherded me during the period of this work, and encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject, their kindly but rigorous oversight of this work constantly giving me motivation to perform my maximum ability.

References

[1] P. Foomooljareon and W. A. C. Fernando, "PAPR Reduction in OFDM Systems", Thammasa Iternational Journal Sc. Tech., vol. 7, no. 3, **(2002)** December.

[2] M. Pauli and H. P. Kuchenbecher, "On the reduction of the out of band radiation of OFDM signals", In Proceedings of IEEE International Conference on Communications, **(1998)**, pp. 1304-1308.

[3] J. Ou, X. Zeng, F. Tian and H. Wu, "Simplified Repeated Clipping and Filtering with Spectrum Mask for PAPR Reduction", JCIT: Journal of Convergence Information Technology, vol. 6, no. 5, **(2011)**, pp. 251-259.

[4] A. S. Rathore and N. Srivastava, "Analysis of Selected Mapping and PartialTransmit Sequence for PAPR Reduction", Journal of Telecommunications, vol. 5, Issue 1, **(2010)** October.

[5] S. H. Müller and J. B. Huber, "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences", Electron. Lett., vol. 33, no. 5, **(1997)**, pp. 368-369.

[6] S. H. Wong, A. S. Madhukumar and F. Chin, "Peak-to-average power reduction using partial transmit sequences: a suboptimal approach based on dual layered phase sequencing", IEEE Trans. Broadcast, vol. 49, no. 2, **(2003)**, pp. 225-231.

[7] N. V. Irukulapati, V. K. Chakka and A. Jain, "SLM based PAPR reduction of OFDM signal using new phase sequence", Electronics Letters, vol. 45, no. 2, **(2009)** November 19.\

[8] A. P. M. Zokogoyoro, I. J. Moumouni and S. Abouty, "SLM using Riemann Sequence combined with DCT transform for PAPR reduction in OFDM communication systems", Internationale conference on communication and Information Technology and Engineering , WASET, vol. 64, **(2012)** April, pp. 347-352.

[9] T. Yang, L. Chen and L. Lu, "An Improved Selected Mapping Scheme with Double Thresholds in OFDM Systems", JDCTA: International Journal of Digital Content Technology and its Applications, vol. 6, no. 9, **(2012)**, pp. 1-8.

[10] J. -C. Chen and C. -P. Li, "Tone reservation using near-optimal peak reduction tone set selection algorithm for PAPR reduction in OFDM systems", IEEE Signal Process. Lett., vol .17, no. 11, **(2010)** November, pp. 933–936.

[11] J. Tellado, "Peak to average power reduction for multicarrier modulation", Ph.D. dissertation, Stanford University, **(2000)**.

[12] H. Ochiai and H. Imai, "Performance analysis of deliberately clipped OFDM signals", IEEE Trans. Communication, vol. 50, no. 1, **(2002)** January.

[13] X. Li and L. J. Cimini Jr., "Effects of clipping and filtering on the performance of OFDM", IEEE Comm. Lett., vol. 2, **(1998)** May, pp. 131-133.

[14] X. Li and L. J. Cimini Jr., "Effects of Clipping and filtering on the Performance of OFDM", in Proc. Globecom, **(1997)**, pp. 1634-1638, http:// www.ieee.org/.

[15] R. O'Neill and L. N. Lopes, "Envelope Variations and Spectral Splatter in Clipped Multicarrier Signals", in Proc. PMRC'95, **(1995)** September, pp. 71-75.

[16] T. Jiang, W. Xiang, P. C. Richardson, D. Qu and G. Zhu, "On the nonlinear companding transform for reduction in PAPR of MCM signals", IEEE Trans. Wireless Comm., vol. 6, no. 6, **(2007)** June, pp. 2017-2021.

[17] R. W. Bauml, R. F. Fischer and J. B. Huber, "Reducing the peak-toaverage power ratio of multicarrier modulation by selective mapping", Electronic Letters, vol. 32, no. 22, **(1996)** October.

[18] H. Gacanin and F. Adachi, "Selective mapping with symbol re-mapping for OFDM/TDM using MMSE-FDE", Proc. IEEE 68th VTC, Calgary, Canada, **(2008)** September.

[19] B. S. Krongold and D. L. Jones, "PAR reduction in OFDM via active constellation extension", IEEE Trans. Broadcasting, vol. 49, no. 3, **(2003)** September, pp. 258-268.

[20] P. Boonsrimuang, K. Mori, T. Paungma and H. Kobayashi, "Proposal of simple PAPR reduction method for OFDM signal by using dummy subcarriers", IEICE Trans. Communication., vol. E91-B, **(2008)** March, pp. 784-794.