A NOVEL APPROACH TO PAPR REDUCTION WITH REDUCED COMPLEXITY BASED ON OICF ALGORITHM

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ABSTRACT

In this project aims to reduce the complexity by employing the reduction of PAPR (Peak to Average Power Ratio) by combining reduction autocorrelation of the input sequence with optimized iterative clipping and filtering scheme. Here the research focus in this is changed from clipped signal to clipping noise. We transform the optimization problem in the original OICF (Optimized Iterative Clipping and Filtering) algorithm into an equivalent form, where a PAPR reduction vector added to the subcarriers becomes the optimization parameter. The solution to the transformed problem can be approximately obtained by using simple algebraic operations with O (N) complexity rather than by executing special software. Based on this, a simplified OICF (Optimized Iterative Clipping and Filtering) algorithm itself leads to no out of band radiation. So OICF (Optimized Iterative Clipping and Filtering) is an optimal algorithm, and another attractive advantage of this algorithm is that it only needs about three iterations to converge to the desired. However, the optimal filter design needs to solve a convex optimization problem by using some special software, which has O (N^3) complexity for OFDM (Orthogonal Frequency Division Multiplexing) systems with 256 subcarriers

General Terms-- OFDM, peak-to-average power ratio, clipping and filtering, convex optimization.

I.INTRODUCTION

Multi-Carrier Modulation is a data transmission technique which divides a high-bit rate data stream into several parallel low bit-rate data streams modulating several carriers. Orthogonal Frequency division Multiplexing is one such scheme for high speed wide band communication systems. It is well known for its less susceptibility to multipath fading and narrow band interference, high spectral efficiency and robustness. It supports parallel data transmission and overcomes the problems faced by single carrier modulation. This has been adopted in many wireless and wired applications such as Digital Video Broadcasting,

Digital Audio Broadcasting, Wireless Local Area Networks, WiMax, Metropolitan Area Networks and Digital subscriber Lines. However the non constant envelope property of OFDM signals is a well-known limitation that leads to nonlinear distortion in practical implementations. Hence many PAPR-reduction techniques have been proposed in the literature, including probabilistic techniques[1]- [], coding[7], [8], clipping/filtering techniques[11]-[15]. These various techniques provide different sets of tradeoffs that may include computational complexity, data rate, and bit error rate (BER) performance. Among these techniques, clipping and filtering is possibly the simplest PAPR-reduction scheme. This scheme directly clips OFDM signals to a predefined threshold and then uses a filter to eliminate the out-of-band radiation. Nevertheless, the filtering operation results in peak regrowth. Hence, iterative clipping and filtering (ICF) is usually needed to suppress the peak regrowth[11]. However, the convergence rate of ICF becomes very slow after the first several iterations, and the in-band distortion cannot be eliminated at all when using ICF. Therefore, some modified algorithms have been developed [13][14]. In [13] it is found that the clipping noise obtained after several clipping and filtering iterations is approximately proportional to that generated in the first iteration.

Based on this, a simplified ICF (SICF) algorithm is proposed, where the computational complexity can be significantly reduced by scaling the clipping noise generated in the first iteration. Another algorithm called iterative constrained clipping (ICC) is introduced in [14], which can achieve sufficient PAPR reduction while satisfying spectral mask and error vector magnitude (EVM) constraints which are specified by most modern communications standards.

In this paper, we change the research focus from the clipped signal to the clipping noise. Our analysis shows that the optimization problem in the original OICF algorithm can be transformed into an equivalent form, where a PAPR-reduction vector added to the subcarriers becomes the optimization parameter. Further analysis shows that the solution of the transformed problem can be approximately obtained by using simple algebraic operations with $O(N)$ complexity rather than by executing special software. Based on this,OICF algorithm is proposed. Like the OICF algorithm, the simplified algorithm itself leads to no out of band radiation. In the meantime, simulation results show that, for an OFDM system with N = 256 subcarriers and quadrature phase shift keying (QPSK) modulation, after one iterations the OICF algorithm achieves desired PAPR.

II.CHARACTERIZATION OF THE OFDM SIGNAL

In this section, we first review the PAPR problem of OFDM signals.

A. PAPR of OFDM Signals

The PAPR is a measure commonly used to quantify the envelope fluctuations of multicarrier signals. For a discrete time signal $x(n)$, the PAPR is defined as the ratio of the maximum power to the average power,

$$\mathrm{PAPR} = \frac{\max\limits_{n\in\mathcal{T}}[|x(n)|^2]}{E\{|x(n)|^2\}} \qquad (1)$$

Where $E\{|x(n)|^2\}$ is the average power of the signal$x(n)$ and $T$is the interval over which the PAPR is computed. In OFDM systems, a set oforthogonal subcarriers is used to transmit data symbols. For a system with Nsubcarriers, Data symbols form an OFDM block $\boldsymbol{X} = [X(0), . . .,X(N-1)]$. The discrete-time OFDM symbol $x(n)$ can be obtainedby

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

Where$X(k)$ represents the data symbol carried by the k-th Subcarrier, and L is the oversampling factor. In this paper, the oversampling operation is implemented by zero padding, i.e., appending $(L-1)N$zeros to the end of ***X*** to yield

$[X(0),X(1), . . . ,X(N-1), 0, 0,\dots\dots, 0(L-1)N]$. For this case, the interval T in (1) is $[0, LN-1]$.

B. CLIPPING RATIO

$x(n)$ is clipped to a predefined threshold by using a soft limiter. The clipped signal $\bar{x}(n)$ is given by

$$\bar{x}(n) = \begin{cases} Ae^{j\phi(n)}, & \text{if } |x(n)| > A \\ x(n), & \text{otherwise} \end{cases} \quad (3)$$

where$A>0$ represents the predefined threshold, and $\varphi(n)$ is the phase of $x(n)$. The clipping ratio γ is defined as

$$\gamma = \frac{A}{\sqrt{P_{av}}} \quad (4)$$

Where P_{av} is the average power of the signals before clipping.

Amplitude clipping leads to in-band distortion and out of band radiation. In order to satisfy the spectral constraint a filter is required to eliminate the out-of-band radiation. Filtering is applied to the baseband signals in the frequency domain , and the filter design is based on a rectangular window with frequency response defined by

$$H_r(k) = \begin{cases} 1, & 0 \le k \le N-1 \\ 0, & N \le k \le LN-1. \end{cases} \quad (5)$$

Unfortunately, a side effect of filtering is peak re-growth .Therefore, repeated clipping and filtering is required to suppress the peak regrowth. Nevertheless, the convergence rate of this method to the desired PAPR becomes very slow after several iterations. Another drawback of ICF is that this technique does not consider combating the in-band distortion.

C. ERROR VECTOR MAGNITUDE

The difference between the ideal constellation point and the deviated point is called the error vector. The EVM is equal to the square root of the ratio of the mean error vector power to the mean reference power. For a single OFDM symbol, its EVM is defined as

$$\text{EVM} = \sqrt{\frac{\frac{1}{N}\sum_{k=0}^{N-1}|X(k)-\hat{X}(k)|^2}{\frac{1}{N}\sum_{k=0}^{N-1}|X(k)|^2}} = \frac{\|\boldsymbol{X}-\hat{\boldsymbol{X}}\|_2}{\|\boldsymbol{X}\|_2} \quad (6)$$

Where$X(k)$ and X^ (k)denote the ideal and deviated data symbols, respectively; the mean power of $X(k)$ is used as the mean reference power; and $\|\cdot\|_2$denotes the 2-norm. Recently, a technique called OICF has been proposed in [15], which considers a comprehensive performance in terms of PAPR reduction, EVM and out-of-band radiation. As a result, it can effectively improve the performance of ICF.

$$\begin{aligned}
\min_{\boldsymbol{H}^{(m)}\in\mathbb{C}^N} \quad & \text{EVM} = \frac{\|\boldsymbol{X}^{(m)}-\hat{\boldsymbol{X}}_1^{(m)}\|_2}{\|\boldsymbol{X}\|_2} && (7a)\\
\text{subject to:} \quad & \hat{\boldsymbol{X}}_1^{(m)} = \bar{\boldsymbol{X}}_1^{(m)} \bullet \boldsymbol{H}^{(m)} && (7b)\\
& \bar{\boldsymbol{X}}_2^{(m)} = \boldsymbol{0} && (7c)\\
& \hat{\boldsymbol{x}}^{(m+1)} = \text{IDFT}(\hat{\boldsymbol{X}}_1^{(m)})_{LN} && (7d)\\
& \frac{\|\hat{\boldsymbol{x}}^{(m+1)}\|_\infty}{\|\hat{\boldsymbol{x}}^{(m+1)}\|_2/\sqrt{LN}} \le \sqrt{\text{PAPR}} = \gamma && (7e)
\end{aligned}$$

Where the operator '•' denotes element-by-element product,and IDFT($\boldsymbol{X}_1^{(m)}$)$_{LN}$ represents the LN-point inverse discreteFourier transform (IDFT) performed on $\boldsymbol{X}_1^{(m)}$ (since $\mathbf{x}_1^{(m)}$ contains only N components, zero padding is used prior to the LN-point IDFT). Note that $\boldsymbol{X}_1^{(m)}$ here is the deviated symbol in as well as the filtered OFDM symbol. The constraint functions (7c) and (7e) represent the desired out-of-band radiation and PAPR reduction requirements,respectively, and the purpose of this optimization problem is to find the optimal filter $\boldsymbol{H}_{(m)}$ to minimize the EVM.

III.PROPOSED ALGORITHM

A. SIMPLIFIED OICF ALGORITHM DESCRIPTION

Step 1: Initialization conditions: give the clipping ratio γ and the maximum number of iterations M. Let m = 0 and p = 1.

Step 2 : Construct the basic vector D_b =[1, 1,.. . , 1 (N ones) , 0, 0,.. . , 0 (N(L−1) zeros)] in the frequency domain.

Step 3: Convert D_b to the time domain by using an LN point IDFT.

Step 4 : Calculate the clipping threshold.

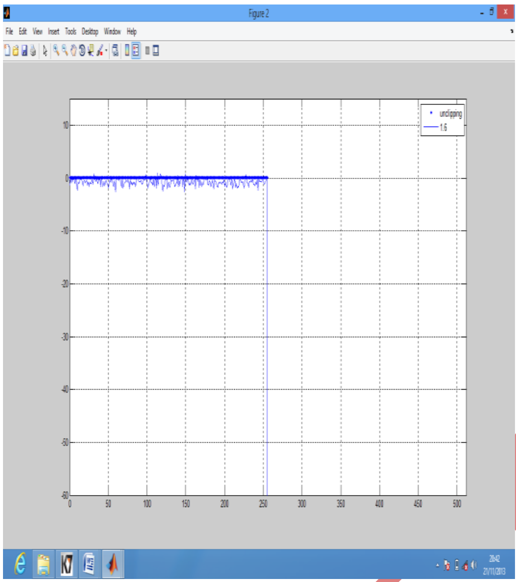
Step 5 : For the p-th pulse exceeding the threshold calculate the scaling factor.

Step 6 : Apply a right circular shift of n_p components to d_n such that its maximum peak is also located at n = n_p.

Step 7 : Scale the shifted vector d_s to obtain the PAPR-reduction vector d_r. Then, dis used to suppress the p-th peak above the threshold .

Step 8 : Let p = p + 1 and repeat Steps 5-7 until all the P peaks above the threshold are suppressed.

Step 9 : If m + 1 < M, increase the iteration counter as m = m+1 and repeat Steps 4 otherwise, transmit.



In Algorithm 1, the basic vector ***Db.*** is first converted to thetime domain. Subsequently, it is scaled and circularly shiftedto yield the PAPR-reduction vector to suppress each signalpeak above the threshold. Alternatively, these operations can be performed equivalently in the frequency domain by usingthe properties of the DFT. From the linearity and shift property domain as

$$\begin{aligned}\mathrm{DFT}\left(d_r(n)\right)_{NL} &= \mu^{(m)}(n_p)\mathrm{DFT}\left(d_s(n)\right)_{NL} \\ &= \mu^{(m)}(n_p)\mathrm{DFT}\left(d_n(n-n_p)_{NL}\right)_{NL} \quad (8) \\ &= \mu^{(m)}(n_p)e^{-j\frac{2\pi n_p k}{NL}}D_n(k).\end{aligned}$$

Based on this analysis, a second algorithm, namely Algorithm2, is proposed and its detailed steps are stated as follows:

Step 1 : Initialization conditions: give the clipping ratio γ and the maximum number of iterations M. Let $m = 0$.

Step 2 : Construct the basic vector ***Db***in the frequency domain.

Step 3 : Calculate***Dn***= ***Db***/*db*.(0).

Step 4 : Calculate the clipping threshold $A(m)$ according to (4).

Step 5 : For the P peaks exceeding the threshold $A(m)$, compute the scaling factors as respectively.

Step 6 : Calculate the PAPR-reduction vector in the frequency domain as

$$D_f(k)=\sum_{n_p=n_1}^{n_P}\mu^{(m)}(n_p)e^{-j\frac{2\pi n_p k}{NL}}D_n(k),\ k=0,1,\ldots,LN-1. \quad (9)$$

Step 7: Convert Df to the time domain by using an $2\pi npk,NLDn(k)$, $k = 0, 1, \ldots, LN-1$..

Step 8: If$m + 1 < M$, increase the iteration counters as $m = m+1$ and repeat Steps 4-7. Otherwise, transmit $\boldsymbol{x}_{(m+1)}$.

Evidently, Algorithms 1 and 2 have exactly identical performance in terms of PAPR reduction, BER and out-of-band radiation. However, we show in the next subsection that Algorithm 2 has lower complexity because the PAPR-reduction vector in this algorithm can be calculated by efficiently using the Discrete Fourier transform (DFT) technique.

B. COMPLEXITY ANALYSIS

In the original OICF algorithm, solving the optimizationproblem leads to $O(N^3)$ complexity. Additionally, an extra FFT/inverse FFT (IFFT) pair with $O(N\log_2 N)$ complexityrequires to be performed in each iteration. Hence, thecomplexity of the whole algorithm is $O(N^3)$.Instead of solving the optimization problem, Algorithm1 consists of only some simple operations such as circularshift, multiplication/division, and addition/subtraction.Since the basic vector $\boldsymbol{D}_b$is a constant vector and $\boldsymbol{d}_n$=IDFT$(\boldsymbol{D}_b)_{LN}d_b(0)$ can be computed offline, the cost ofSteps 2 and 3 can be ignored. The complexity of Step 4is $O(N)$. Assume P peaks exceed the threshold $A_{(m)}$, andin order to reduce all these peaks, Steps 5-7 require to berepeated P times. In total, Step 5 requires P real subtractionsand P complex multiplications to calculate the scaling factors; Step 6 requires PLN circular shifts; Step 7 requires PLNcomplex multiplications to scale the vector $\boldsymbol{d}_s$ and PLNcomplex subtractions to suppress the peaks. Note that here$P$ is a random variable related to N and its expectation iscalculated as Equation

$$\mathrm{E}(P) = N\sqrt{\frac{\pi}{3}}\gamma e^{-\gamma^2}. \qquad (10)$$

The expectation of PLN is then given by $\mathrm{E}(P)LN = \pi/3\gamma e-\gamma 2$Therefore, the complexity of the wholealgorithm is determined by Steps 6 and 7, i.e., $O(N^2)$.

$$\mu^{(m)}(n) = \begin{cases} \mu^{(m)}(n_p), & n = n_1, n_2, \ldots, n_P \\ 0, & \text{otherwise.} \end{cases} \qquad (11)$$

Now it is easy to find that above equation has the same form as the DFT. Therefore, it can be efficiently solved by using the FFT algorithm. From the value of P is generally small. For example, we have $\mathrm{E}(P) \approx 3$ for γ = 1.40and N =256. So the inputs of the FFT used to compute (10) are sparse. For this case, the complexity of the FFT can be further reduced to $O(N)$ by using a wavelet transform [9]. (Hence, in Algorithm 2, calculating the PAPR-reduction vector only has $O(N)$ complexity.) Step 7 contains an IFFT with $O(N\log_2 N)$ complexity and LN complex subtractions.

Based on the analysis above, the overall complexity of Algorithm 2 is determined by Step 7, i.e., $O(N\log_2 N)$.
In summary, the original algorithm and two simplified algorithms have $O(N^3)$, $O(N^2)$, and $O(N\log_2 N)$ complexity, respectively. Especially, the original algorithm needs to solve an optimization problem with $O(N^3)$ complexity, where the optimization parameter is the filter coefficient vector $\boldsymbol{H}_{(m)}$;

IV. SIMULATION RESULTS

In attempt to compare the performance of the original and proposed algorithms, we consider an OFDM system with 256 subcarriers and QPSK modulation. Previous studies have suggested that the oversampling factor $L = 4$ can provide sufficiently accurate PAPR results, and thus L is set to 4 in our simulations.

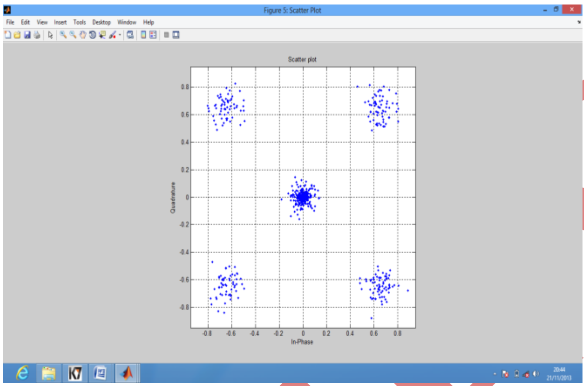


Fig2. subcarrier positions

We now turn to a more general case where multiple peaks exceeding the threshold are suppressed. In this case, the original and simplified algorithms both need to perform several Iterations before converging to the signal with minimal EVM subject to a PAPR threshold. However, our simulation results show that only single iteration is sufficient to obtain such a signal. The clipping ratio γ is still set to 1.40 in the simulation.

We can see the EVMdifference between them is very small. After one iterationthe difference is only 0.05%, and then it reduces to zeroafter two iterations. With one iteration, the original OICFalgorithm can obtain 0.02dB larger PAPR reduction than the simplified algorithm. However, after one iterations theirPAPRs simultaneously converge to 8dB.

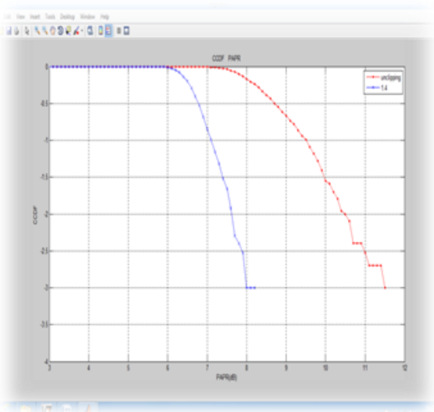


Fig 3 CCDF plot for the proposed method after clipping level optimization. N = 256

PAPR CCDF curves for the signals processed by using the OICF algorithmThe curve for the unclipped signal (i.e., the original signal) is also plotted. The unclipped signal of PAPR from 12db to 11db. Clearly, our algorithm can significantly reduce the PAPR of OFDM signals. With one iteration, the PAPR-reduction performance of our algorithm isreduce from 12db to 8db.

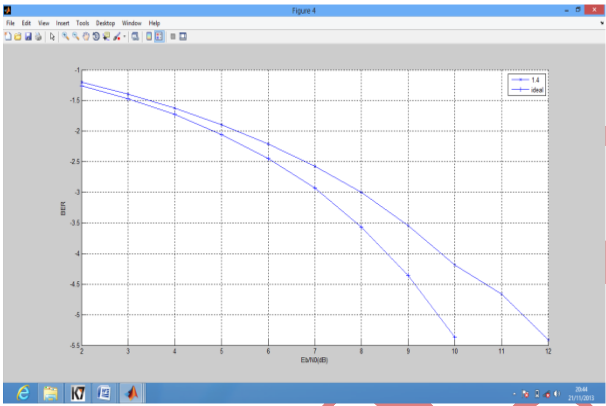


Fig. 4. BER performance of OICF algorithms in an AWGN channel (256 subcarriers, QPSK, L = 4, γ = 1.40).

BER performance of the algorithms in an additive white Gaussian noise (AWGN) channel. As a reference, the solid curve shows the uuencoded BER of the unclipped OFDM signal without any PAPR reduction method. As shown in fig the BER performance after one iteration the optimizedalgorithm reduced from 12db to 10db.
Finally, we consider passing the PAPR-reduced signals through a solid-state power amplifier (SSPA), which is modulated

$$s_o(t) = \frac{|s_i(t)|}{[1 + (\frac{|s_i(t)|}{q})^{2v}]^{\frac{1}{2v}}} e^{j\phi(t)} \qquad (12)$$

There $i(t) = |si(t)|ej\varphi(t)$ and $so(t)$ are the input and output signals, respectively. The parameters v = 3 and q = 2.4 are chosen in our simulations. Table I lists adjacent channel power ratios (ACPRs) for the two algorithms, where ACPR is defined as the ratio of the power in the adjacent channel to the power in the main channel . We can see the ACPRs for two algorithms are -32.03dB and -32.02dB after one iteration, respectively, and finally converge to -32.04dB after two iterations. From the simulation results above, we know that with three iterations, the original OICF algorithm (which is an optimal algorithm) achieves the convergence to the desired PAPR, and our simplified algorithm exhibits almost the same performance as the original one. Owing to much lower complexity, the proposed algorithm is more attractive than the original OICF.

V CONCLUSION

Thus the existing Optimized iterative Clipping and filtering method by analyzing the clipped noise is discussed elaborately. In this theseis a simplified algorithm is described to employ OICF. By using this approach the performance of OFDM system with much reduced PAPR is shown in this phase. Whereas the combination of reducing the autocorrelation of the input sequence with the existing method would further improve performance and reduce complexity which will be shown in the next phase.

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