Achieving a Desired Deterministic Upper Bounded PAPR Value Using a Fast Adaptive Clipping Algorithm

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Abstract*—Orthogonal Frequency Division Multiplexing (OFDM) is the most commonly used multicarrier modulation in telecommunication systems due to the efficient use of the frequency resources and its robustness to multipath fading channels. However, as multicarrier signal in general, Peak-to-Average-Power Ratio (PAPR) is one of the major drawbacks of OFDM signals. Many works exist in the scientific literature on PAPR mitigation such as clipping methods, Tone Reservation based approaches, Partial Transmit Signals. However, in this paper we focus on clipping methods. This last is one of the most efficient adding signal techniques for PAPR reduction in terms of complexity. Nevertheless, clipping presents many drawbacks such as bit error rate degradation, out-of-band emission and mean power degradation. Adaptive clipping has been recently proposed in order to decrease these drawbacks. However, this approach is expensive in terms of numerical complexity, because an optimal threshold should be found for each OFDM symbol. This paper proposes a new approach to efficiently achieve the adaptive clipping, in terms of iterations number to find the optimal threshold. Theoretical analysis and simulation results validate the interest of this new clipping method.

Keywords–OFDM, PAPR, CCDF, Clipping

I. INTRODUCTION

The Peak-to-Average Power Ratio (PAPR) is one of the main issues of the Orthogonal Frequency Division Multiplex (OFDM) signal. Many works [1][2][3] exist in the literature for PAPR mitigation. Clipping [4][5][6] method is an efficient technique for PAPR mitigation where the peak-canceling signal is computed by clipping the amplitudes of the signal that exceed a predefined threshold A. In practice, a normalized threshold $\rho = \frac{A^2}{P_{x_n}}$ is used, where $P_{\mathbf{x}_n}$ represents the mean power of the discrete signal $\mathbf{x}_n$ whose PAPR has to be reduced. It can be noted that, the normalized threshold defines the PAPR below which the signal is not clipped.

Due the large amplitude variations of the OFDM signals in the time domain, the instantaneous PAPR of each OFDM symbol highly depends on its content. Therefore, the instantaneous PAPR after Classical Clipping(CC) method [4] with a predefined normalized threshold also depends on its content. Then, the upper bounded PAPR of the clipped signal, at each value of its Complementary Cumulative Distribution Function (CCDF), increases when the CCDF decreases. This is illustrated by the left curve in Figure 1. Note that this is also the case for the original OFDM CCDF curve. That means there is no deterministic upper bounded PAPR for CC method. It is exactly what we target in this work. This deterministic value corresponds to the vertical solid blue line depicted in Figure 1. In practice, the suitable upper bounded PAPR of the signal

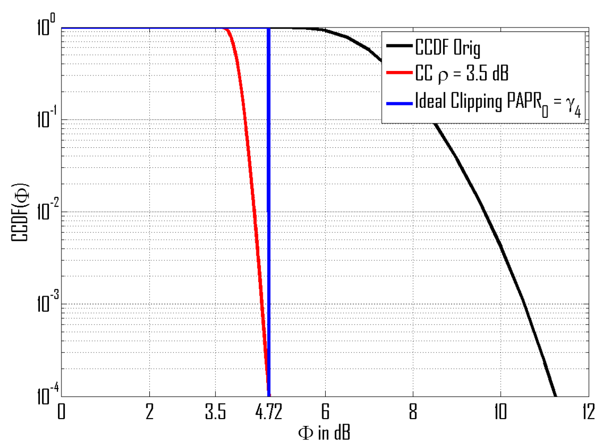

Figure 1. Scenario of CCDF curves of a classical clipping and Ideal Clipping.

for the Input Back Off (IBO) definition on the High Power Amplifier (HPA) is in general chosen at CCDF(Φ) close to zero (generally 10^{-4}). In this paper, this value is called the desired upper bounded PAPR and denoted as PAPR$_0$). Thus, in [7] the authors have shown that in CC techniques many OFDM symbols are either severely clipped or unnecessarily clipped with respect to this desired upper bounded PAPR. To illustrate this assertion, let us consider Figure 2 which is a zoom around 10^{-1} of the CCDF of the Figure 1. Note that our main objective is to have a PAPR clipping output about 4.72 dB (the vertical blue line). Therefore, all the symbols that have a PAPR value between 4.1 dB and 4.72 dB are clipped unnecessarily (see Δ_1 in figure 2). Besides this, all the symbols whose PAPR values are between 4.72 dB and 8.4 dB are severally clipped by the CC technique compared to ideal clipping (see indicated Δ_2 in figure 2). If we extend these considerations to all CCDF values, then we obtain the two areas of Figure 3:

- Area1: symbols are unnecessarily clipped

- Area2: Symbols are clipped more severely than necessary

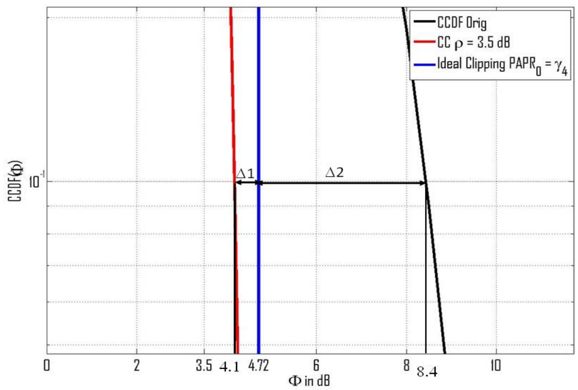

Figure 2. Zoom at CCDF=10^{-1} to illustrate symbols which are to much clipped by CC.

To avoid this drawbacks, the authors have proposed an Adaptive Clipping (AC) algorithm [7] in which the threshold is adapted to the content of each OFDM symbol and the desired upper bounded PAPR. Other adaptive clipping methods exist in the literature [8][9]. In [9], the authors proposed to adapt the normalized threshold ρ depending on the mapping constellation of the OFDM signal for a better compromise between PAPR reduction and BER degradation. In [8], the authors proposed an iterative clipping and filtering scheme [10] in which the computation of the amplitude threshold A from the predefined normalized threshold, is done at each iteration. This approach improves the performances on PAPR reduction but degrades more the signal. In contrast, in [7], the AC proposed approach and the classical clipping method [4] achieve same performance in terms of PAPR reduction. However, better bit error rate (BER), less out-of-band (OOB) emission and less mean power degradation are achieved. Nevertheless, the computational complexity of the proposed algorithm is high. In fact, from a predefined desired upper bounded PAPR (PAPR_0) and an initial normalized threshold $\rho_0 = \text{PAPR}_0$, an exhaustive search is performed to find the optimal threshold. For this purpose, having a predefined step $\epsilon > 0$, we check successively the values ρ_0, $\rho_0 - \epsilon$,. . . ,$\rho_0 - k\epsilon$. In this context, the number of iterations to find the optimal threshold $\rho^{(\text{opt})}$ depends on the content of each OFDM symbol and ϵ. In this paper, we propose an efficient approach to compute $\rho^{(\text{opt})}$, which consists to adapt the step ϵ at each iteration. This technique is equivalent to clipping the signal iteratively by adapting A in function of PAPR_0 and the content of the clipped signal at the previous iteration. Therefore, we named this approach as Iterative Adaptive Clipping (IAC).

The paper is organized as follows. In Section II, the problem formulation and AC principle will be briefly presented. In Section III, we will present IAC approach and show that IAC method performs fewer iterations than AC approach to reach $\rho^{(\text{opt})}$. A comparative study in terms of signal degradation with the classical clipping will then be conducted in Section IV. The conclusions will be presented in Section V.

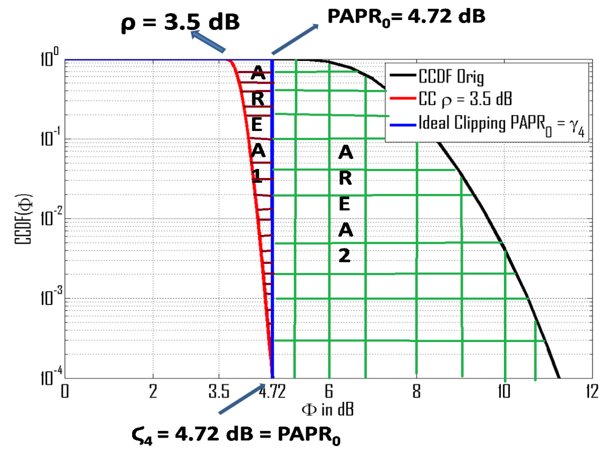

Figure 3. Scenario of CCDF curves of a classical clipping and Ideal Clipping.

II. ADAPTIVE CLIPPING ANALYSIS PRINCIPLE

Throughout this paper an OFDM signal $x_n(t)$ is given by the following equation

$$x(t) = \sum_{n=-\infty}^{+\infty} \sum_{m=0}^{M-1} X_{m,n} g(t - nT_u)\, e^{j2\pi mFt} \tag{1}$$

where M means the total carriers, g is the window function of duration T_u, $F = \frac{1}{T_u}$ is the intercarrier space, mF the m^{th} frequency, and $X_{m,n}$ the symbol carried out by the m^{th} carrier at time nT_u.

In this paper, if $\mathbf{z}$ denotes a vector containing the time domain samples of the signal $z(t)$ in continuous time domain, its PAPR will be denoted by $\text{PAPR}_{\mathbf{z}}$. The positive scalar γ_e will represent in this paper the upper bounded PAPR of the signal at the CCDF value equal to 10^{-e} (e constant), i.e.,

$$\gamma_e = \max_{\Phi} \left\{ \text{CCDF}_{\mathbf{y}_n}(\Phi) \geq 10^{-e} \right\} \tag{2}$$

where $\text{CCDF}_{\mathbf{y}_n}(\Phi) = \mathbb{P}rob[\text{PAPR}_{\mathbf{y}_n} \geq \Phi]$ and $\mathbf{y}_n$ is the signal after clipping. Let $\mathbf{x}_n = [x_{n,0}, \ldots, x_{n,NL-1}]^T$ be the vector containing the samples of the OFDM signal $x_n(t)$ oversampled by a factor L. The PAPR of $x_n(t)$ can be approximated from $\mathbf{x}_n$, as follows:

$$\text{PAPR}_{\mathbf{x}_n} = \frac{\max\limits_{m=0,\ldots,NL-1} \left\{ |x_{n,m}|^2 \right\}}{P_{\mathbf{x}_n}} \tag{3}$$

where $P_{\mathbf{x}_n}$ is the mean power of the $\mathbf{x}_n$ signal before clipping.

The Classical Clipping (CC) proposed in [4] is one of the most popular clipping technique for PAPR reduction known in the literature. It is sometimes called hard clipping or soft clipping. To avoid any confusion, the (CC) name will be used in this paper. In [4], its effects on the performance of OFDM, including the power spectral density, the PAPR and BER are evaluated. The function-based clipping used for CC technique is defined as;

$$f(r, \text{A}) = \begin{cases} r, & r \leq \text{A} \\ A, & r > \text{A} \end{cases} . \tag{4}$$

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where A is the clipping threshold. From this equation, the PAPR of the output signal $\mathbf{y}_n$ after CC, if some samples of $\mathbf{x}_n$ are greater than the clipping threshold A, is given as follows:

$$\mathrm{PAPR}_{\mathbf{y}_n} = \frac{A^2}{P_{\mathbf{y}_n}} \tag{5}$$

Given, $A = \left(10^{\frac{\rho}{20}}\right)\sqrt{P_{\mathbf{x}_n}}$, the PAPR of $\mathbf{y}_n$ can be rewritten as follows:

$$\begin{aligned} \mathrm{PAPR}_{\mathbf{y}_n} &= \left(10^{\frac{\rho}{10}}\right)\left(\frac{P_{\mathbf{x}_n}}{P_{\mathbf{y}_n}}\right) \\ \text{then } \mathrm{PAPR}_{\mathbf{y}_n}(\text{ in dB }) &\geq \rho(\text{ in dB}) \end{aligned} \tag{6}$$

Therefore, it can be noticed that $\gamma_e \geq \rho$ for any $e \geq 0$. So γ_e increases when e increases. In practice, the desired γ_e for IBO parameterization of the HPA is generally chosen at CCDF value equal to 10^{-4}, i.e., γ_4. Then, we may remark that by using CC method many OFDM symbols are clipped more severely than necessary or unnecessarily clipped with respect to γ_4 [7]. Figure 3 shows the domains representing the set of OFDM symbols which are clipped more severely than necessary (AREA2) or unnecessarily clipped (AREA1) for a CC with $\rho = 3.5$ dB, in respect to Ideal Clipping (see vertical blue line of Figure 3), for the same upper bounded PAPR at CCDF value equal to 10^{-4} (γ_4). The vertical blue line represents the ideal clipping CCDF for $\mathrm{PAPR}_0 = \gamma_4$, which corresponds to the deterministic desired upper bounded PAPR. It is obvious that the output upper bounded PAPR of such ideal clipping is constant at any value of the CCDF. In [7], this ideal clipping has been approached by AC. The theoretical analysis and simulation results achieved by the authors have demonstrated that AC method outperforms CC in terms of signal degradation having the same performance on PAPR reduction.

The AC method consist to adapt the normalized threshold ρ_n for each OFDM symbol $\mathbf{x}_n$ which we want to clip with respect to the desired upper bounded PAPR value PAPR_0 by solving the following equation

$$\mathrm{PAPR}_0 = \gamma_4 = \left(10^{\frac{\rho_n}{10}}\right)\left(\frac{P_{\mathbf{x}_n}}{P_{\mathbf{y}_n}}\right), \tag{7}$$

where $P_{\mathbf{y}_n}$ is the mean power of the clipped signal $\mathbf{y}_n$ with ρ_n.

From (7), it can be noticed that $P_{\mathbf{y}_n}$ depends on the unknown parameter ρ_n. In [7], an exhaustive research in $[0, \gamma_4]$ is proposed to solve (7). Having $\epsilon > 0$, the authors proposed to check successively $\rho_0 = \gamma_4$, $\rho_1 = \rho_0 - \epsilon$, ... , $\rho_m = \rho_{m-1} - \epsilon$,..., to reach $\rho^{(\mathrm{opt})}$ which satisfies

$$(\mathrm{PAPR}_{\mathbf{y}_n} - \gamma_4) \leq \delta, \tag{8}$$

where $\delta > 0$ is a satisfactory residual error. In other words, if the algorithm has performed m iterations, then $\rho^{(\mathrm{opt})} = \gamma_4 - m\epsilon$. Note that, in AC, the step (ϵ) is constant at each iteration. Therefore, the number of necessary iterations to find $\rho^{(\mathrm{opt})}$ depends on the content of each OFDM symbol,γ_4, and ϵ. A less complex approach is proposed in this paper. The main idea is to find $\rho^{(\mathrm{opt})}$ in the interval $[0, \gamma_4]$ with few iterations. For this purpose, we propose, for each OFDM symbol, to adapt the step ϵ at each iteration in order to increase the convergence rate towards $\rho^{(\mathrm{opt})}$. The following section presents the description of the IAC proposed approach.

III. ITERATIVE ADAPTIVE CLIPPING APPROACH

In this section, we present the IAC proposed method and theoretical analysis of its performances in terms of PAPR reduction. Theoretical comparison with AC in terms of convergence speed will be also presented.

We denote by $f(., A)$ the CC function, see (4), used in [4]. Having $\delta > 0$, IAC approach consists of searching the normalized threshold $\rho^{(\mathrm{opt})}$ which satisfies (8). To find this threshold we check successively $\rho_0 = \mathrm{PAPR}_0$, $\rho_1 = \rho_0 - \epsilon_1$,...,$\rho_m = \rho_{m-1} - \epsilon_m$. ϵ_m is the step between ρ_{m-1} and ρ_m. In others words it is the step which will give the ρ_m threshold, which will be used to clipp $\mathbf{y}_n^{(m-1)}$. $\mathbf{y}_n^{(m-1)}$ being the ouput signal after the $(m-1)^{\mathrm{th}}$ clipping iteration. Note that ϵ_m is not constant and should depend on the content of each OFDM symbol and its clipped version at the previous iterations. Therefore, we defined the step ϵ_m at the m^{th} iteration as

$$\epsilon_m = 10\mathrm{Log}_{10}\left(\frac{P_{\mathbf{y}_n^{(m-2)}}}{P_{\mathbf{y}_n^{(m-1)}}}\right), \tag{9}$$

with the notation $P_{\mathbf{y}_n^{(-1)}} = P_{\mathbf{x}_n}$ at the first iteration. The flow chart of the IAC approach is given in Figure 4.

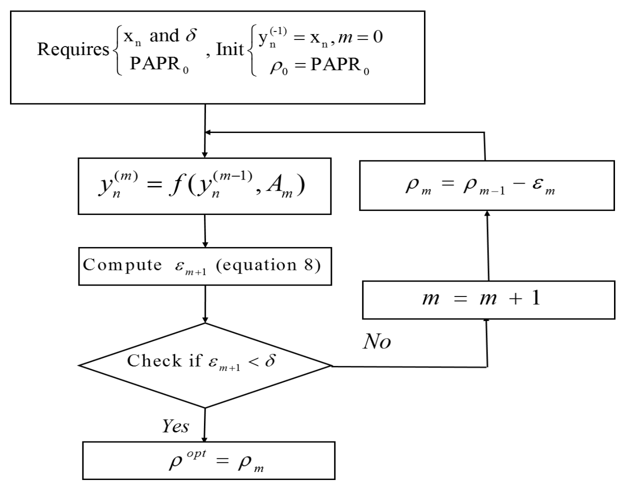

Figure 4. Flow chart of the IAC approach.

The amplitude threshold A_m at the m^{th} iteration can be expressed from the corresponding normalized threshold ρ_m as follows:

$$\begin{aligned} A_m &= 10^{\frac{\rho_m}{20}}\sqrt{P_{\mathbf{x}_n}} \\ &= \left(10^{\frac{\rho_0 - \epsilon_1 - \ldots - \epsilon_m}{20}}\right)\sqrt{P_{\mathbf{x}_n}} \\ &= \left(10^{\frac{\mathrm{PAPR}_0}{20}}\right)\left(10^{\frac{-\sum_{l=1}^{m}\epsilon_l}{20}}\right)\sqrt{P_{\mathbf{x}_n}} \\ &= \left(10^{\frac{\mathrm{PAPR}_0}{20}}\right)\left(\prod_{l=1}^{m} 10^{\frac{-\epsilon_l}{20}}\right)\sqrt{P_{\mathbf{x}_n}} \end{aligned} \tag{10}$$

Then, from (9) we obtain the following expression after some derivation

$$\begin{aligned} A_m &= \left(10^{\dfrac{\text{PAPR}_0}{20}}\right)\left(\prod_{l=1}^{m}\sqrt{\frac{P_{\mathbf{y}_n^{(l-1)}}}{P_{\mathbf{y}_n^{(l-2)}}}}\right)\sqrt{P_{\mathbf{y}_n}} \\ &= \left(10^{\dfrac{\text{PAPR}_0}{20}}\right)\sqrt{P_{\mathbf{y}_n^{(m-1)}}} \end{aligned} \tag{11}$$

Then, by substituting (11) in (5) the PAPR of the clipped signal at the m^{th} iteration satisfies the following expression:

$$\text{PAPR}_{[\mathbf{y}_n^{(m)}]} - \text{PAPR}_0 = \epsilon_{m+1}. \tag{12}$$

Therefore, if we define $\epsilon_{m+1} \leq \delta$ as the criteria for stopping IAC at the m^{th} iteration, then, for each OFDM symbol the PAPR of the output signal after PAPR reduction by IAC is less than $\text{PAPR}_0 + \delta$. So, the CCDF curve of the IAC will approach the ideal clipping and give the desired deterministic upper bounded PAPR. The following Algorithm 1 describes the IAC proposed technique.

Algorithm 1 IAC algorithm

Require: $\mathbf{x}_n$ input OFDM signal , $\delta > 0$ and PAPR_0
Ensure: $\mathbf{y_n}$ output signal
  $m \leftarrow 0$
  $\epsilon_m \leftarrow 1$
  $\mathbf{y}_n^{(-1)} \leftarrow \mathbf{x}_n$
  while $\left(\text{PAPR}_{\mathbf{y}_n^{(m)}} - \text{PAPR}_0\right) = \epsilon_m \geq \delta$ **do**
    $m \leftarrow m + 1$
    Compute A_m from equation 11
    $\mathbf{y}_n^{(m)} \leftarrow f(\mathbf{y}_n^{(m-1)}, A_m)$
  end while

For convergence speed comparison with AC, we can remark that, at each iteration, AC and IAC algorithms have almost the same numerical complexity. Therefore, convergence speed comparison will be achieved by comparing the number of iterations performed by these algorithms for each OFDM symbol.

For each OFDM symbol $\mathbf{x}_n$ and $\delta > 0$, let $N_{\mathbf{x}_n,1}, N_{\mathbf{x}_n,2}$ be the number of iterations performed by AC and IAC to converge towards $\rho^{(\text{opt})}$, respectively. So, $\rho^{(\text{opt})}$ is approximated by $\rho_{N_{\mathbf{x}_n,1}} = \text{PAPR}_0 - N_{\mathbf{x}_n,1}\epsilon$ and $\rho_{N_{x_n,2}} = \text{PAPR}_0 - \sum_{l=1}^{N_{\mathbf{x}_n,2}} \epsilon_l$ in AC and IAC, respectively. Let's define the average step for the IAC as,

$$\epsilon_{\mathbf{x}_n} = \frac{1}{N_{\mathbf{x}_n,2}} \sum_{l=1}^{N_{\mathbf{x}_n,2}} \epsilon_l. \tag{13}$$

Then, for each OFDM symbol $\mathbf{x}_n$, the number of iterations performed by IAC to find $\rho^{(\text{opt})}$ is equal to the number of iterations performed by AC when the step is equal to $\epsilon_{\mathbf{x}_n}$. In fact, from (6) the PAPR of the output signal at the m^{th} in AC with the step $\epsilon_{\mathbf{x}_n}$ can be expressed as follows

$$\text{PAPR}_{[\mathbf{y}_n^{(m)}]} = \text{PAPR}_0 - m\epsilon_{\mathbf{x}_n} + 10\text{Log}_{10}(\frac{P_{\mathbf{x}_n}}{P_{\mathbf{y}_n^m}}). \tag{14}$$

After few derivations and by using (13), we obtain

$$\text{PAPR}_{[\mathbf{y}_n^{(m)}]} - \text{PAPR}_0 = 10\text{Log}_{10}\left[\left(\frac{P_{\mathbf{y}_n^{(m-1)}}}{P_{\mathbf{x}_n}}\right)^{\frac{m}{N_{\mathbf{x}_n,2}}} \frac{P_{\mathbf{x}_n}}{P_{\mathbf{y}_n^{(m)}}}\right]$$

Therefore, since the number of iterations performed by IAC to compute the normalized threshold for the OFDM symbol $\mathbf{x}_n$ is $N_{\mathbf{x}_n,2}$ we remark that

$$\begin{cases} \left(\text{PAPR}_{[\mathbf{y}_n^{(m)}]} - \text{PAPR}_0\right) & \geq \quad 10\text{Log}_{10}\left[\frac{P_{\mathbf{y}_n^{(m-1)}}}{P_{\mathbf{y}_n^{(m)}}}\right] \\ & \geq \quad \epsilon_m > \epsilon \text{ If } m < N_{\mathbf{x}_n,2} \\ \left(\text{PAPR}_{[\mathbf{y}_n^{(m)}]} - \text{PAPR}_0\right) & = \quad \text{Log}_{10}\left[\frac{P_{\mathbf{y}_n^{(N_{\mathbf{x}_n,2}-1)}}}{P_{\mathbf{y}_n^{(N_{\mathbf{x}_n,2})}}}\right] \\ & = \quad \epsilon_{N_{\mathbf{x}_n,2}+1} < \epsilon \text{ If } m = N_{\mathbf{x}_n,2} \end{cases}$$

which proves that, for each $\mathbf{x}_n$ the number of iterations performed by IAC is equal to the number of iterations performed by AC in which the step is equal to $\epsilon_{\mathbf{x}_n}$. Thus, for each OFDM symbol, the comparison between $N_{\mathbf{x}_n,1}$ and $N_{\mathbf{x}_n,2}$ can be achieved by comparing $\epsilon_{\mathbf{x}_n}$ and ϵ. However, since $\mathbf{x}_n$ is a random signal we will compare IAC and AC by comparing the mean of number of iterations required for each algorithms. This is equivalent to compare $\mathbb{E}\left[\epsilon_{\mathbf{x}_n}\right]$ defined in (15) and ϵ (the constant step in AC) as,

$$\mathbb{E}\left[\epsilon_{\mathbf{x}_n}\right] \simeq \frac{1}{P_{\mathbf{x}_n}} \sum_{m=0}^{N_2} \int_0^{+\infty} f(r, A_m) p(r) \text{d}r \tag{15}$$

where $p(r)$ is the probability density function of the amplitudes of the signal OFDM signal and $N_2(respN_1)$ represent the mean of the number of iterations performed by IAC (resp AC) over a great number of K OFDM symbols.

$$N_i = \frac{1}{K} \sum_{n=0}^{K} N_{\mathbf{x}_n,i}, i = 1,2 \tag{16}$$

After some computations [6] we obtain,

$$\mathbb{E}\left[\epsilon_{\mathbf{x}_n}\right] = \frac{1}{P_{\mathbf{x}_n}} \sum_{m=0}^{N_2} \left(1 - e^{\frac{-A_m^2}{P_{\mathbf{x}_n}}}\right) \tag{17}$$

In [7], in order to obtain the desired upper bounded PAPR equal to $\text{PAPR}_0 + \delta$, the step ϵ must be chosen less or equal to δ. It is clear that the number of iterations increases when ϵ decreases. Thus, the optimal step in AC is $\epsilon = \delta$. From (17) and the fact that in IAC $\epsilon_m > \epsilon$ if $m < N_{\mathbf{x}_n,2}$, IAC converges more quickly than AC if $\epsilon_1 \geq \epsilon$. Therefore, from (9) we can deduce that, for each PAPR_0 $N_1 \geq N_2$ if and only if

$$\epsilon_1 = 10\text{Log}_{10}\left(\frac{1}{1 - e^{-\text{PAPR}_0}}\right) \quad \geq \quad \epsilon.$$

After some derivations, we can conclude that:

$$N_1 \geq N_2 \text{ If and only if } \quad \text{PAPR}_0 \leq \ln\left(\frac{10^{\frac{\epsilon}{10}}}{10^{\frac{\epsilon}{10}} - 1}\right) \tag{18}$$

IV. SIMULATION RESULTS

The performance of the proposed IAC and the CC method are analyzed under same PAPR reduction, i.e., $\text{PAPR}_0 = \gamma_4 - \delta$, and compared in terms of signal degradation and convergence speed. The simulations are performed for an OFDM signal

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with 16-QAM modulation in which $M = 64$, an oversampling factor $L = 4$.

Figure 5 confirms that the CCDF curves of the IAC approximate the ideal clipping CCDF curve. Beisdes, the IAC and CC method achieve the same upper bounded PAPR value at CCDF equal to 10^{-4}. It can be also noticed from depicted results, that IAC method reach a deterministic upper bounded PAPR.

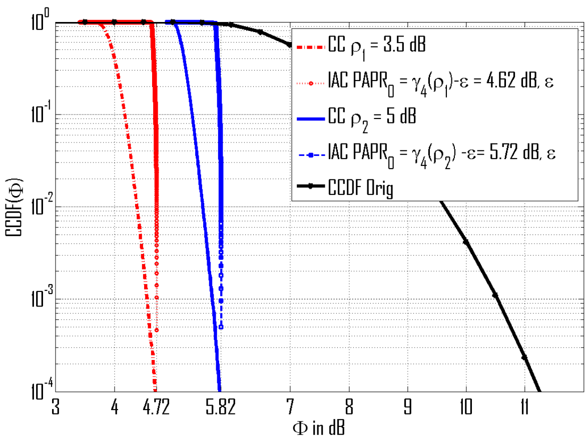

Figure 5. Performance of IAC in terms of PAPR reduction for different thresholds $\rho_1 = 3.5$dB and $\rho_2 = 5$dB

In the following, the IAC is compared with CC in terms of BER degradation.

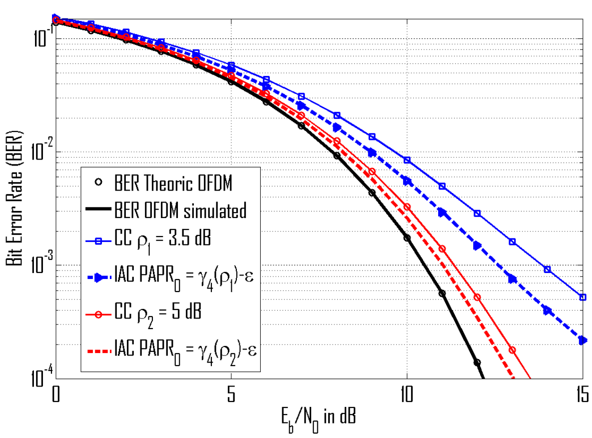

Figure 6. Comparison of CC and IAC in terms of BER degradation for $\rho = 3.5$dB.

Results depicted in Figure 6 show that IAC outperforms CC in terms of BER degradation. The obtained gain at 10^{-4} of BER, is greater than 1 dB. This result confirms the theoretical analysis undertaken in [7] where the authors have shown that in CC many OFDM symbols are clipped more severely (see AREA 2 in Figure 3) than necessary or unnecessarily (see AREA 1 in Figure 3) with respect to γ_4.

The performances in terms of Mean Power degradation and adjacent channels pollution which is due to the effect of the OOB components, are depicted in Figure 7.

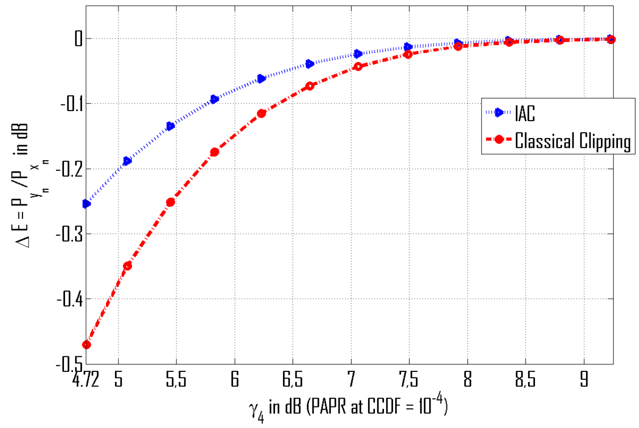

Figure 7. Comparison of CC and IAC in terms of Mean Power degradation for $\rho = 3.5$dB and a PAPR at CCDF 10^{-4}

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From the simulation results depicted in Figure (7), it can be noticed that IAC degrades less the Mean Power of the clipped signal than the CC for the same PAPR performance reduction at a CCDF $\leq 10^{-4}$. For example, for $\gamma_4 = 4.72$dB, $\Delta E = -0.47$dB in CC method and $\Delta E = -0.25$dB in proposed IAC approach.

Figure (8) represents the Power Spectrum Density (PSD) of both OFDM signal before PAPR reduction and after PAPR reduction by IAC and CC respectively.

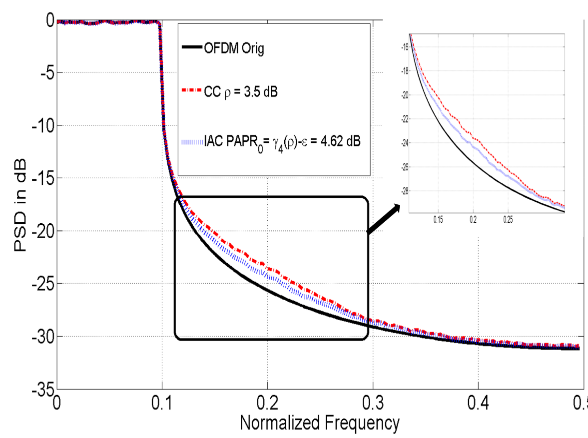

Figure 8. Comparison of the OFDM PSD using IAC and CC for threshold $\rho = 3.5$dB

Similar as in Figure 7, for BER degradation and mean power variation, Figure 8 shows that IAC pollutes less the adjacent channels than CC when $\text{PAPR}_0 = \gamma_4 - \epsilon$.

As a general conclusion, obtained results in terms of signal degradation confirm that when $\text{PAPR}_0 = \gamma_4 - \epsilon$, IAC

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degrades less the signal than CC method (see Figure 6, 7, 8).

In the following, we compare N_1 and N_2 defined by

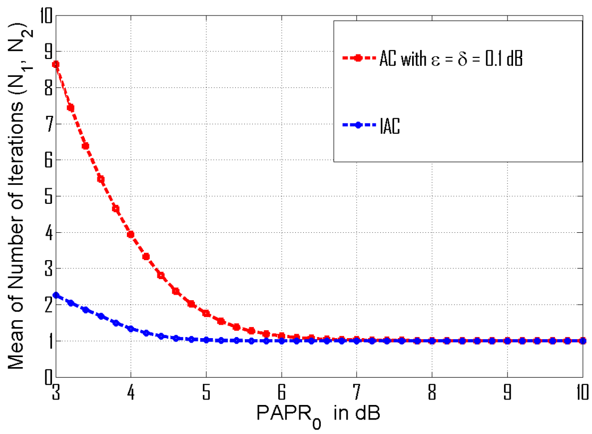

Figure 9. Mean of number of iterations performed by IAC and AC for each OFDM symbol in function of PAPR_0

equation (16) by simulation with $K = 10^4$. Figure 9 shows that IAC method converges more quickly than AC method, for instance, when $\gamma_4 = 3$dB, and $N_1 \simeq 4N_2$.
Obtained results confirms our theoretical analysis undertaken in Section III (see equation (18)). In fact, from Figure (9), it can be remarked that $N_1 \geq N_2$ when $\gamma_4 \leq 6$ which is coherent with equation (18) (with $\epsilon = 0.1\mathrm{dB} \Rightarrow 10\mathrm{Log}_{10}\left[\mathrm{Log}\left(\frac{10^{\frac{0.1}{10}}}{10^{\frac{0.1}{10}}-1}\right)\right] = 5.77\mathrm{dB} \simeq 6\mathrm{dB}$).

V. CONCLUSION

In this paper, a new method for approximating the normalized adapted threshold for the adaptive clipping is presented. The theoretical analysis and simulation results achieved in this paper show that this approach converges more quickly than the one based on exhaustive research with a constant step. This approach outperforms also CC in terms of signal degradation, with the same performances in terms PAPR reduction. Furthermore, IAC gives a deterministic desired upper bounded PAPR which is very important for IBO definition on high power amplifiers (HPA). Our future work will focus on the extension of proposed work to other clipping functions as deep clipping and smooth clipping combined with Out Of Band noise suppression approcahes.

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