Adaptive Clipping for a Deterministic Peak-To-Average Power Ratio

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is the most commonly used multicarriers modulation in telecommunication systems due to the efficient use of frequency resources and its robustness to multipath fading channel. However, as multicarriers modulation in general, OFDM suffers from high Peak-to-Average Power Ratio (PAPR). Many works exist in literature for PAPR mitigation among which Clipping is one of the most efficient adding signal techniques in terms of numerical complexity. However, clipping techniques is a probabilistic technique for PAPR mitigation. In other words, the instantaneous PAPR of each clipped OFDM symbol depends on its content and then the PAPR at any value of the Complementary Cumulative Distribution Function (CCDF) increases when its corresponding CCDF values decreases. In this paper, we propose an adaptive clipping which offers a constant PAPR, so deterministic, at any value of the CCDF and so this approach outperforms the classical clipping in terms of signal degradation with the same performance in terms of PAPR reduction. Simulation results validate the interest of this approach.

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1 INTRODUCTION

Clipping is an efficient technique for PAPR mitigation which was firstly proposed by X. Li and J. Cimini (Li and Cimini, 1997). The clipping technique consists to clip the amplitudes of the signal which exceed a predefined threshold A. In practice, a normalized predefined threshold $\rho = \frac{A}{P_{x_n}}$ is used, where P_{x_n} represents the mean power of the discrete signal x_n which we want reduce the PAPR. It can be remarked that, ρ defines the PAPR below which the signal is not clipped. Due the strong amplitude variations of the OFDM symbol in the time domain, the instantaneous PAPR of each OFDM symbols highly depends on its content. Therefore, the instantaneous PAPR after Classical Clipping method (Li and Cimini, 1997) (CC) with a predefined ρ also depends on its content. Then, for each positive scalar value Φ if we denote by PAPR(Φ) the upper bounded PAPR at the value CCDF(Φ), it can be remarked that PAPR(Φ) increases when CCDF(Φ) decreases. In this paper, this upper bounded PAPR(Φ) will be called simply PAPR at the CCDF value CCDF(Φ).

Many clipping functions are proposed in the literature in order to avoid some drawbacks inherent in the classical clipping (CC) such as Out-of-Band emission, mean power Degradation and bit error rate (BER) degradation. Generally, clipping is associated with filtering in order to filter out-of-band emission (Li and Cimini, 1997). But this filter generates the peak-regrowth phenomena. In(Kimura et al., 2008) the authors propose Deep-Clipping to reduce the peak-regrowth phenomena and Out-of-Band emission. Mean-Power degradation can be reduced by using a clipping based on Gaussian function (Guel, 2009). However, all these approaches degrade the BER and the instantaneous output PAPR of this techniques also depends on the content of each OFDM symbol. Note that, BER degradation drawbacks is solved by means of tone reservation (TR) clipping (Guel and Palicot, 2009; Wang and Tellambura, 2008). Nevertheless, this approach degrades the performances in terms of PAPR reduction.

In practice, the desired PAPR(Φ) for the Input Back Off (IBO) definition on the High Power Amplifier (HPA) is defines at CCDF(Φ) close to zeros

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(10^{-4}). In this paper, this value will be denoted by $\text{PAPR}_{\text{CC}}^{(0)}$. So, due to the fact that PAPR(Φ) increases when CCDF(Φ) decreases, it can be remarked that, many OFDM symbol are more severely clipped than necessary or unnecessary clipped with respect to the desired output PAPR ($\text{PAPR}_{\text{CC}}^{(0)}$). That is the reason why we propose in this paper, an adaptive clipping (AC) in order to obtain a deterministic output PAPR i.e a same upper bounded PAPR at any value of the CCDF. The main goal of this approach is to make PAPR(Φ) constant at any value of the CCDF and so minimized the signal degradation with respect to classical clipping. For this purpose, the normalized threshold is adapted to the content of each OFDM symbol in order to get the desired PAPR after clipping. Therefore, in contrast the CC where the instantaneous PAPR depends on the content of the OFDM symbol, in the AC the instantaneous PAPR does not depends on the content of the OFDM symbol. Therefore, we qualify this approach as Adaptive Clipping with a constant output PAPR (PAPR(Φ)).

The paper is organized as follows: In Section 2, we briefly present the clipping technique and the problem formulation. In Section 3, we will present the Adaptive Clipping. A comparative study by simulation with the classical clipping will then be conducted in Section 4. The conclusion will be presented in Section 5.

2 CLASSICAL CLIPPING PRINCIPLE AND PROBLEM FORMULATION

In this paper, the scalars in the time domain and in the frequency domain will be denoted by lower case letters and capital letter respectively. The vectors containing the times domain samples and frequency domain samples will be represented by lower case letter in bold and upper case letter in bold respectively.

If $z(t)$ represents a signal in continuous time domain its PAPR in continuous time domain and discrete time domain will be denoted by PAPR_z and $\text{PAPR}_{[z]}$ respectively.

2.1 Peak-To-Average Power Ratio Definition

One OFDM symbol at instant t in time interval $nT \leq t \leq (n+1)T$ can be expressed as follows:

$$x_n(t) = \sum_{k=0}^{N-1} X_{n,k} e^{2\pi jkFt} \tag{1}$$

Where F represents the inter-carrier frequency spacing, $T = 1/F$ is the OFDM symbol duration, $X_{n,k}$ is the n-th QAM symbols conveyed by the sub-carrier of index k.

The PAPR of this OFDM symbol in continuous time domain can be expressed as in (Louet and Palicot, 2005) by:

$$\text{PAPR}_{x_n(t)} = \frac{\underset{t\in[0,T]}{max} |x_n(t)|^2}{\mathbb{E}[|x_n(t)|^2]} \tag{2}$$

In practical, discrete OFDM symbol is used to evaluate the PAPR. In order to get a good approximation of the true analog PAPR it is necessary to oversampled the OFDM signal. Thus, as in (Ochiai and Imai, 2001) and (Louet and Hussain, 2008), many authors have shown that an oversampling factor of $L \geq 4$ is sufficient to obtain a good approximation of the analog signal PAPR. In OFDM system, an oversampled signal can be efficiently computed by an IFFT transformation and can be expressed as follows:

$$x_{n,m} = \sum_{m=0}^{NL-1} X_{n,m} e^{2j\pi n \frac{m}{NL}}, \tag{3}$$

where $\mathbf{X}_n = [X_{n,0}, \ldots, X_{n,NL-1}]$ is the L times oversampling equivalent QAM vector, generated by zeros padding $\mathbf{X}_n$ with $N(L-1)$ zeros. Therefore, from this NL OFDM samples, the discrete time PAPR can be expressed as in (Louet and Palicot, 2005) by following expression:

$$\text{PAPR}_{[x_n]} = \frac{\|\mathbf{x}_n\|_\infty^2}{\mathbf{E}(\|\mathbf{x}_n\|_2^2)}, \tag{4}$$

where $\mathbf{x}_n = [x_{n,0}, \ldots, x_{n,NL-1}]^T$ is the vector containing the NL samples of the OFDM signal $x_n(t)$.

2.2 Classical Clipping (CC) Principle

Classical clipping (CC) is a simple adding signal techniques for PAPR mitigation in that the output signal $\mathbf{y}_n = [y_{n,0}, \ldots, y_{n,NL-1}]$ after PAPR reduction is given as follows:

$$y_{n,m} = \begin{cases} x_{n,m} & \text{if } |x_{n,m}| > A \\ Ae^{j\arg(x_{n,m})} & \text{else} \end{cases} \tag{5}$$

In general, to evaluate the performances of the PAPR mitigation techniques the CCDF of the PAPR of signal $\mathbf{y}_n$ is computed or simulated. The CCDF function is defined as follows:

$$\text{CCDF}_{\mathbf{y}_n}(\Phi) = \mathbb{P}\left[\text{PAPR}_{[\mathbf{y}_n]} \geq \Phi\right] \tag{6}$$

This CCDF function for classical OFDM signal is presented in Figure1.

2.3 Problem Formulation

Let be the Figure 1 in which the CCDF of the CC technique and Ideal Clipping for PAPR reduction are shown. Ideal Clipping is a clipping with a **constant** upper bounded output PAPR. In other words, the Ideal Clipping output PAPR could not be greater than the desired output PAPR ($= \mathrm{PAPR}_0$), which is represented in the figure by the vertical solid line curve and would like to achieve by AC method.

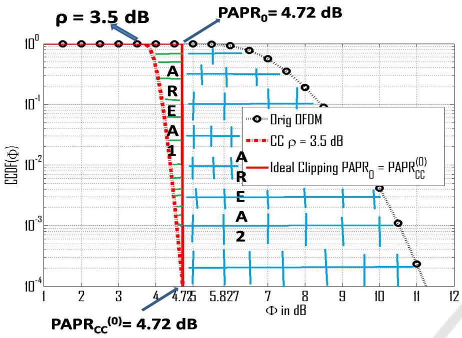

Figure 1: Scenario of CCDF curves of a classical clipping and Ideal Clipping

In this figure, $\mathrm{PAPR}_{\mathrm{CC}}^{(0)}$ represents the PAPR (upper bounded PAPR) of the clipped signal by CC $\mathbf{y}_n$ at the value of CCDF equal to 10^{-4} and PAPR_0 is the desired output PAPR of the ideal clipping at any value of the CCDF. In the AC method, the adapted threshold is computed for each symbol in function of PAPR_0.

Figure 1 shows that if the CCDF of the AC approaches the ideal clipping CCDF then AC will less degrade the signal than the CC with the same performance in terms of PAPR reduction.

In fact, let be AREA1 and AREA2 the domains represented in Figure 1. These domains illustrate the percentage of the number of OFDM symbols which PAPR is included in $\left[\rho, \mathrm{PAPR}_{\mathrm{CC}}^{(0)}\right]$ and exceed $\mathrm{PAPR}_{\mathrm{CC}}^{(0)}$ respectively. From Figure 1, it can be remarked that when $\mathrm{PAPR}_0 = \mathrm{PAPR}_{\mathrm{CC}}^{(0)}$:

- AREA2 represents the OFDM symbols which are both clipped by CC and ideal clipping. Therefore, with respect to $\mathrm{PAPR}_{\mathrm{CC}}^{(0)}$, these OFDM symbols are clipped more severely than necessary in CC.
- AREA1 represents the OFDM symbols which are not clipped by ideal clipped but clipped in CC. These OFDM symbols are clipped unnecessary in CC with respect to $\mathrm{PAPR}_{\mathrm{CC}}^{(0)}$.

Now, let be Ω_ρ the following probability:

$$\Omega_\rho = \mathbb{P}\mathrm{rob}\left[\mathrm{PAPR}_{[x_n]} \in \mathrm{AREA1}\right]. \quad (7)$$

When ρ decreases, $\mathrm{PAPR}_{\mathrm{CC}}^{(0)}$ decreases and then $\Omega_\rho \simeq 0$. Thus, to well characterize the probability that an OFDM symbol is unnecessary clipped, the following probability will be considered:

$$\Theta_\rho = \frac{\mathbb{P}\mathrm{rob}\left[\mathrm{PAPR}_{[x_n]} \in \mathrm{AREA1}\right]}{1-\mathbb{P}\mathrm{rob}\left[\mathrm{PAPR}_{[x_n]} \in \mathrm{AREA2}\right]}. \quad (8)$$

We remark that Θ_ρ represents the probability that an OFDM symbol is unnecessarily clipped knowing that their PAPR $\notin$ AREA2.
Ω_ρ^1 can be computed as follows:

$$\begin{aligned} \Omega_\rho &= \mathbb{P}\mathrm{rob}\left[\mathrm{PAPR}_{[x_n]} \in \mathrm{AREA1}\right] \\ &= \mathrm{CCDF}_{x_n}(\rho) - \mathrm{CCDF}_{x_n}(\mathrm{PAPR}_{\mathrm{CC}}^{(0)}) \end{aligned} \quad (9)$$

Many works exist in the literature on computing the CCDF of OFDM signal. In (Van Nee and de Wild, 1998), the authors give an approximation of the CCDF from a direct computation. However, other authors propose an approximation of the CCDF based on statistical studies (Louet and Hussain, 2008; Ochiai and Imai, 2001) when the oversampling factor $L \geq 4$. This approach gives a better approximation of the CCDF. In this paper we use this Y. Louet formula to compute Ω_ρ which is given by the following equation

$$\mathrm{CCDF}_{\mathbf{x}_n}(\Phi) = 1-\left(1-e^{-\Phi}\right)^{\tau_2 N^{\mu}}, \quad (10)$$

where $\tau_2 = \left(\frac{5.12}{\sqrt{e}}\right)^{\mu} e^{-0.5704}$ and $\mu = 1.07$. So, using (10), Θ_ρ can be expressed as follows:

$$\Theta_\rho = \frac{\left(1-e^{-\mathrm{PAPR}_{\mathrm{CC}}^{(0)}}\right)^{\tau_2 N^{\mu}} - \left(1-e^{-\rho}\right)^{\tau_2 N^{\mu}}}{\left(1-e^{-\mathrm{PAPR}_{\mathrm{CC}}^{(0)}}\right)^{\tau_2 N^{\mu}}} \quad (11)$$

Figures 2 and 3 represent the curves of Ω_ρ and Θ_ρ.

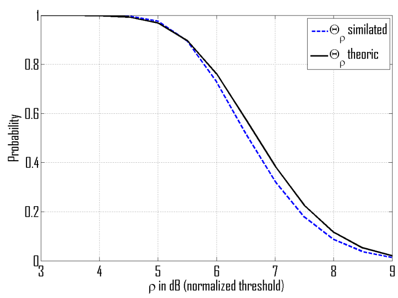

Figure 2: Probability that an OFDM symbol is unnecessarily clipped knowing that their PAPR $\notin$ AREA2.

From these figures, we remark that:

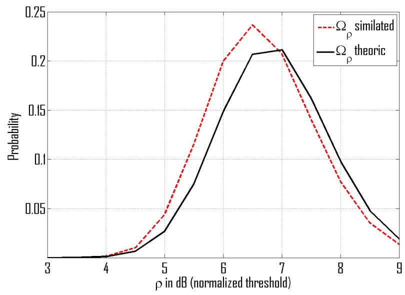

Figure 3: Probability that an OFDM symbol is unnecessarily clipped.

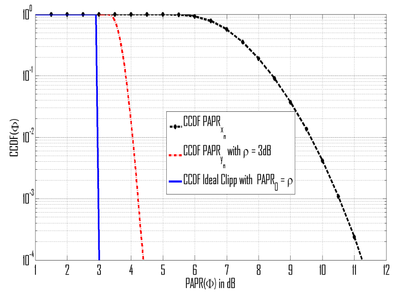

Figure 4: Illustration of Scenario 1 in terms of PAPR reduction

- If $0 \leq \rho \leq 5$dB.

Each OFDM symbol is clipped more severely than necessary with high probability and the probability to clip the symbol unnecessary is very low. Indeed, when $0 \leq \rho \leq 5$dB, $\Theta_\rho \simeq 1$ and $\Omega_\rho \simeq 0$ and then $\mathbb{P}\text{rob}\left[\text{PAPR}_{[x_n]} \in \text{AREA2}\right] \simeq 1$.

- If $5 \leq \rho \leq 6.5$dB.

Some signals are more severely clipped than necessary while others are clipped unnecessarily. Indeed, we remark that when ρ increases, the percentage of the signals clipped more severely than necessary i.e $\mathbb{P}\text{rob}\left[\text{PAPR}_{[x_n]} \in \text{AREA2}\right] = \text{CCDF}_{[x_n]}\left(\text{PAPR}^{(0)}_{\text{CC}}\right)$ decreases and at the same time Ω_ρ increases (see Figure 3) and then the advantages in terms of signal degradation (BER degradation, Out-of-Band emission and Mean Power degradation) of the AC with respect to the CC will not unchanged. Thus, we would expect that the AC gives better performances in terms of signal degradation than the CC when $\text{PAPR}_0 = \text{PAPR}^{(0)}_{\text{CC}}$ and $\rho \in [0, 6.5\text{db}]$.

- If $\rho \geq 6.5$dB.

Θ_ρ and Ω_ρ decrease both and then AC will have the same behavior than the CC.

The main goal of the AC is to minimize the domain designed by AREA1 (see Figure 1) by adapting the normalized threshold clipping to the content of each OFDM symbol in order to get a constant PAPR equal to PAPR_0 at any value of the CCDF.

In the following section, the AC is presented and compared to the CC in terms of PAPR reduction, adjacent channels pollution and data degradation. To achieve this comparison, two scenarios will be considered.

- Scenario 1:

This scenario compares the classical clipping at ρ and AC at $\text{PAPR}_0 = \rho$. Figure 4 illustrates this scenario in terms of PAPR reduction.

- Scenario 2:

In this scenario, CC at ρ is compared to AC at $\text{PAPR}_0 = \text{PAPR}^{(0)}_{\text{CC}}$. Figure 5 illustrates this scenario in terms of PAPR reduction.

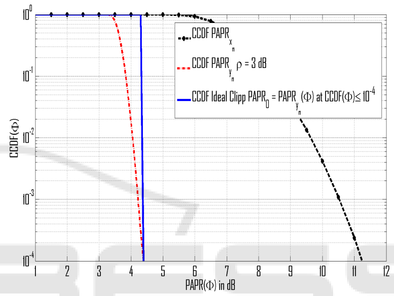

Figure 5: Illustration of Scenario 2 in terms of PAPR reduction

As we discussed on Figure 1, we expect that in scenario 1, AC will give worse performances in terms of BER degradation, adjacent channels pollution and mean power degradation than CC, at the opposite in scenario 2, AC should give better performances. Note that, in Figure 4 and 5, the solid line curve are drawn and represent the ideal clipping CCDF which we would like to obtain by AC.

3 ADAPTIVE CLIPPING

Let be $\mathbf{x}_n$ an OFDM signal which we would like to reduce its PAPR by classical clipping at threshold $\rho = 20\text{Log}_{10}\left(\frac{A}{\sqrt{P_{x_n}}}\right)$. Note that in CC ρ represents the ideal PAPR which we would like to obtain after clipping. But, due to the Mean Power degradation $\text{PAPR}_{[y_n]} \geq \rho$ for any $\mathbf{y}_n$ and then $\text{PAPR}^{(0)}_{\text{CC}} \geq \rho$.

Indeed, for each OFDM symbol $\mathbf{x}_n$ the instantaneous PAPR of $\mathbf{y}_n$ is given as follows:

$$\begin{aligned}\mathrm{PAPR}_{[y_n]} &= \frac{\max\limits_{m=0,\ldots,NL-1}\left\{|x_{n,m}|^2\right\}}{P_{y_n}}\\ &= \frac{A^2}{P_{y_n}}\end{aligned}$$

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

$$\begin{aligned}\mathrm{PAPR}_{[y_n]} &= \frac{\left(10^{\frac{\rho}{20}}\right)^2 P_{x_n}}{P_{y_n}}\\ &= \left(10^{\frac{\rho}{10}}\right)\left(\frac{P_{x_n}}{P_{y_n}}\right) \qquad (12)\end{aligned}$$

Thus, since CC degrades the mean power of the clipped signal then $\frac{P_{x_n}}{P_{y_n}} \geq 1$. So the instantaneous PAPR of $\mathbf{y}_n$ satisfies the following inequality for each OFDM symbol:

$$\mathrm{PAPR}_{[y_n]} \geq 10^{\frac{\rho}{10}} (= \rho \text{ in dB}), \qquad (13)$$

therefore $\mathrm{PAPR}_{[y_n]} \geq \rho$ for any $\mathbf{y}_n$ i.e $\mathrm{PAPR}_{\mathrm{CC}}^{(0)} \geq \rho$. Furthermore, if we denote by $\mathrm{PAPR}_{[y_n]}(\Phi)$ the output PAPR at any value of the CCDF, then when $\mathrm{CCDF}_{y_n}(\Phi)$ increases $\mathrm{PAPR}_{[y_n]}(\Phi)$ decreases, so, some OFDM symbols are more severely clipped than necessary or unnecessary clipped with respect to $\mathrm{PAPR}_{\mathrm{CC}}^{(0)}$ (see Figure 1).

The main goal of the AC method, is to minimize the percentage of the OFDM symbols which are more severely clipped than necessary or unnecessary clipped with respect to the suitable output PAPR. Other adaptive clipping methods exist in the literature (Kim et al., 2003; Byuong Moo Lee, 2013). In (Kim et al., 2003), the authors proposed to adapt the normalized threshold ρ in function of the mapping constellation of the OFDM signal for a better compromise between PAPR reduction and BER degradation. In (Byuong Moo Lee, 2013), the authors proposed an iterative clipping and filtering scheme (Armstrong, 2002) in which the computation of the amplitude threshold A from the predefined normalized threshold, is processed at each iteration. This approach improves the performances on PAPR reduction but degrades more the signal. However, to the best of our knowledge this is the first work dealing with the threshold adaptation at each OFDM symbol in order to minimize the percentage of the OFDM symbols which are more severely clipped than necessary or unnecessary clipped with respect to the suitable output PAPR.

Let be PAPR_0 the constant desired output PAPR given by an ideal clipping at any value of the CCDF, so in AC approach, ρ is unknown and it is determined by the following equation for each OFDM symbol:

$$\mathrm{PAPR}_0 = \left(10^{\frac{\rho}{10}}\right)\left(\frac{P_{x_n}}{P_{y_n}}\right). \qquad (14)$$

From equation 14, we remark that in AC ρ depends on the content of each OFDM symbol.

3.1 Theoretical Analysis

From equation (14), we can easily deduce the following equation.

$$10^{\frac{\rho}{10}} = \mathrm{PAPR}_0\left(\frac{P_{y_n}}{P_{x_n}}\right)$$

So, if we replace this expression in equation (12) the instantaneous PAPR of the clipped signal by AC is expressed as follows:

$$\begin{aligned}\mathrm{PAPR}_{[y_n]} &= \left(\mathrm{PAPR}_0\frac{P_{y_n}}{P_{x_n}}\right)\left(\frac{P_{x_n}}{P_{y_n}}\right)\\ &= \mathrm{PAPR}_0, \qquad (15)\end{aligned}$$

therefore we can conclude that AC gives a constant output PAPR (upper bounded PAPR) i.e $\mathrm{PAPR}_{[y_n]}(\Phi) = \mathrm{PAPR}_0$ at any value of the CCDF.

3.2 Adapted ρ Computation

The computation of the adapted normalized threshold from equation 14 is a complex problem since P_{y_n} depends on the unknown ρ. Thus, we propose in this paper an exhaustive search to approximate the solution of the equation (14).

The following algorithm describes this approach.

Algorithm 1 Normalized threshold computation in AC

Require: $x_n, \varepsilon, \mathrm{PAPR}_0$
Ensure: y_n
  $\rho_0 \leftarrow \mathrm{PAPR}_0$
  Compute A such as $\rho_0 = \frac{A}{\sqrt{P_{x_n}}}$
  $y_n \leftarrow f(x_n, A)$
  while $|\mathrm{PAPR}_{[y_n]} - \mathrm{PAPR}_0| > \varepsilon$ **do**
    $\rho_0 \leftarrow \rho_0 - \varepsilon$
    Compute A such as $\rho_0 = \frac{A}{\sqrt{P_{x_n}}}$
    $y_n \leftarrow f(y_n, A)$
  end while

4 SIMULATION RESULTS

The simulations are performed for a 64 sub-carriers OFDM system with 16-QAM modulation on each carrier. For a good approximation of the true analog PAPR the signal is oversampled at a factor $L = 4$.

Figure 6 shows the performance in terms of PAPR reduction for two different case thresholds $\rho = 3.5$dB and $\rho = 5$dB.

4.1 Scenario 1: Comparison Between AC and CC with $PAPR_0 = \rho$

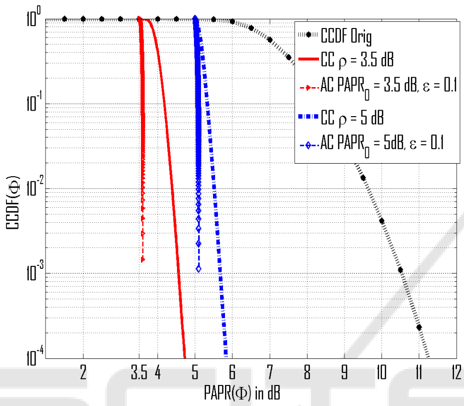

Figure 6: Comparison between CC and AC in terms of PAPR reduction for different thresholds $\rho = 3.5$dB and $\rho = 5$dB

The simulation results show that AC outperforms CC when $PAPR_0 = \rho$. We can remark also that AC converges to the ideal clipping and gives a deterministic PAPR equal to $PAPR_0 + \varepsilon$ at any value of the CCDF. This results confirm our theoretical analysis equation (15)

4.1.1 Comparison in Terms of BER Degradation

In this subsection, BER degradation are evaluated in the context of scenario 1.

The Figures 7 and 8 show the performances of AC compared to classical clipping.

The simulation results (Figure 7,8) confirm that the CC less degrades the In-Band data than the AC. Indeed, in order to get a PAPR equal to ρ (normalized threshold of the CC) the OFDM symbol with high PAPR are clipped by an adapted threshold smaller than ρ.

4.1.2 Comparison in Terms of Mean Power Degradation and Out-of-Band Emission

In this section, the performances in terms of mean power degradation and adjacent channels pollution

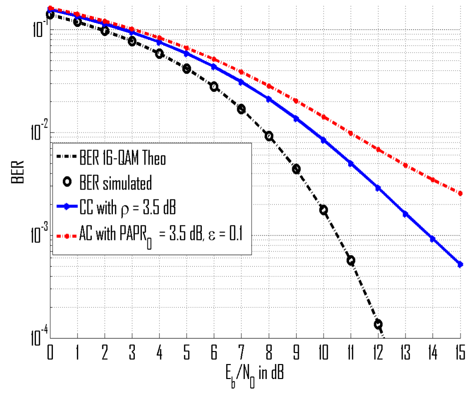

Figure 7: Comparison of CC and AC in terms of BER degradation for $\rho = 3.5$ dB

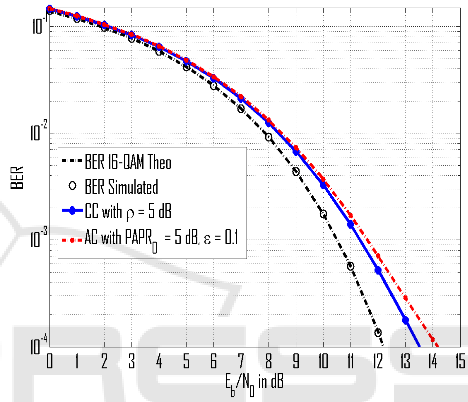

Figure 8: Comparison of CC and AC in terms of BER degradation for $\rho = 5$ dB.

which are achieved.

The Figure 9 compares AC and CC in terms of mean power variations.

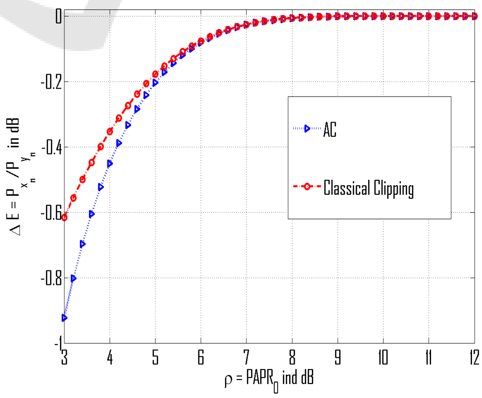

Figure 9: Comparison of CC and AC in terms of mean power degradation

Figure 9 shows that the Mean Power degradation created by AC is more severe than the CC one. These simulation results are consistent with our expectations.

The Figures 10 and 11 represent the DSP of OFDM signal before and after PAPR reduction by AC and CC.

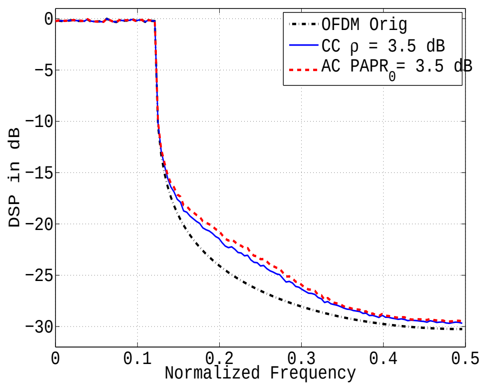

Figure 10: Comparison of DSP of the AC and CC methods for $\rho = 3.5$dB.

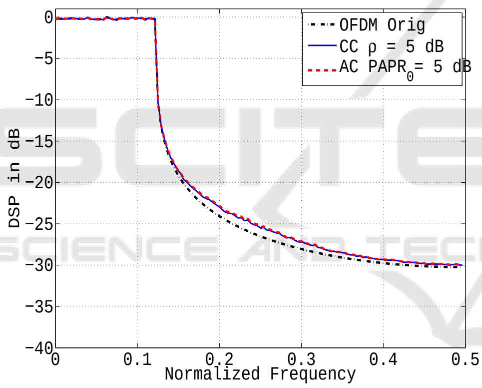

Figure 11: Comparison of DSP of the AC and CC methods for $\rho = 5$dB.

As in terms of mean power variations, the Out-Of-Band Emission (Figure 10,11) created by the AC will be more polluting than those due to the classical clipping. In addition, we remark that, when ρ increases the Out-of-Band emission due to the AC is the same as in classical clipping (Figure 11). Nevertheless, when ρ increases $\text{PAPR}_{\text{CC}}^{(0)} - \rho$ decreases and therefore AC and classical clipping give same performances in terms of PAPR reduction.

In conclusion, these simulation results (Figure 7,8, 9, 10,11) are consistent with our theoretical analysis. Indeed, from equation (14), we can show that for each OFDM symbol, the corresponding adapted threshold is smaller than ρ. This remark can be directly deduced from the algorithm used for the adapted threshold computation.

4.2 Scenario 2: Comparison Between AC and CC with $\text{PAPR}_0 = \text{PAPR}_{\text{CC}}^{(0)}$

In this section, comparison between AC and CC at same performance in terms of PAPR reduction i.e: $\text{PAPR}_0 = \text{PAPR}_{\text{CC}}^{(0)}$ is achieved.

Figure 12 shows the performances in terms of PAPR reduction for two different case thresholds $\rho = 3.5$dB and $\rho = 5$dB.

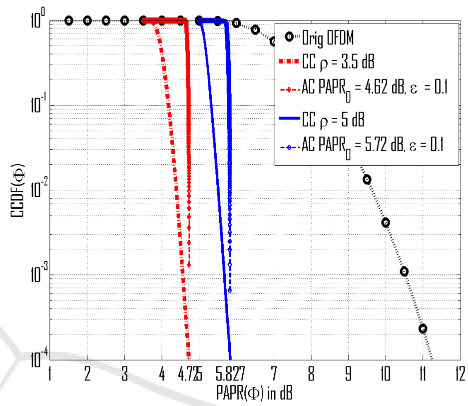

Figure 12: Comparison of CC and AC in terms of PAPR reduction for different thresholds $\rho = 3.5$dB and $\rho = 5$dB.

The simulation results confirm that when $\text{PAPR}_0 = \text{PAPR}_{\text{CC}}^{(0)}$ AC gives a same performances in terms of PAPR reduction than classical clipping. As in the previous scenario (Section 4), We remark that the AC converges to the ideal clipping and gives a deterministic PAPR equal to $\text{PAPR}_0 + \varepsilon$ at any $\text{CCDF}(\Phi)$. This results confirm our theoretical analysis equation (15).

In the following subsection, AC and CC will be compared in terms of signal degradation.

4.2.1 Performance in Terms of BER Degradation

In this subsection, the AC are compared to clipping in terms of BER degradation.

The Figures 13 and 14 compare the BER degradation due to AC and CC after PAPR reduction.

As in the theoretical analysis section, the simulation results (Figure 14 and 13) show that AC outperforms CC in terms of BER degradation. This results confirm the theoretical analysis (see Figure 2,3) in that we have shown that many OFDM symbols are clipped more severely than necessary ($\rho = 3, \ldots, 5$dB) or unnecessarily (5 dB $\leq \rho \leq$ 6.5 dB) with respect to $\text{PAPR}_{\text{CC}}^{(0)}$.

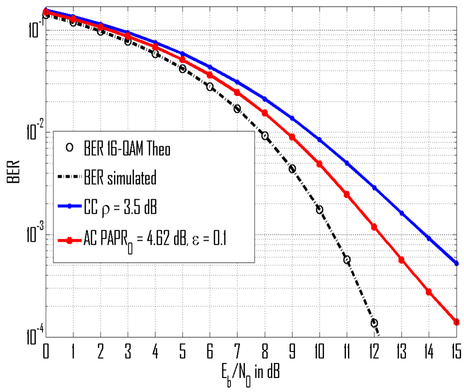

Figure 13: Comparison of CC and AC in terms of BER degradation for $\rho = 3.5$ dB.

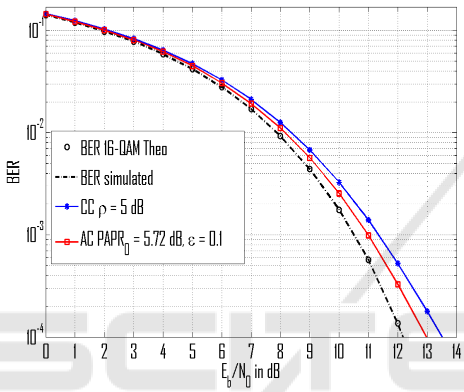

Figure 14: Comparison of CC and AC in terms of BER degradation for $\rho = 5$ dB.

4.2.2 Performance in Terms of Mean Power Degradation and Out-of-Band Emission

As in subsection 4.1.2, the performances in terms of mean power degradation and adjacent channels pollution which is caused by the OOB components, are studied.

The Figure 15 shows the mean power variation of the signal due to the CC and AC method.

The simulation results (see Figure 15) show that AC less degrades the Mean Power of the clipped signal than the CC for the same output PAPR at the CCDF value less or equal to 10^{-4}. For example, for an output PAPR equal to 4.5dB, $\Delta E = -0.4$dB in CC method and $\Delta E = -0.2$dB in AC approach.

The Figures 16 and 17 represent the DSP of OFDM signal before and after PAPR reduction by AC and CC.

The simulation results (Figure 16,17) show that the AC less pollutes the adjacent channels than the CC with the same performances in terms of PAPR reduction.

These simulation results in terms of BER degra-

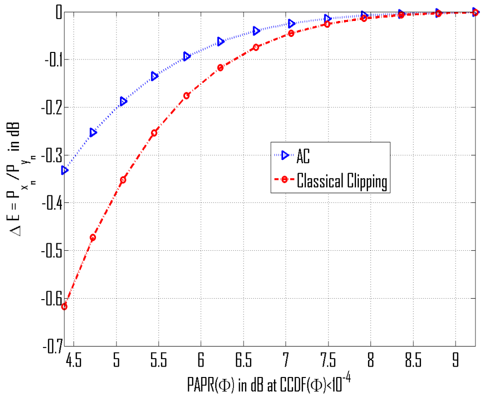

Figure 15: Comparison of CC and AC in terms of mean power degradation

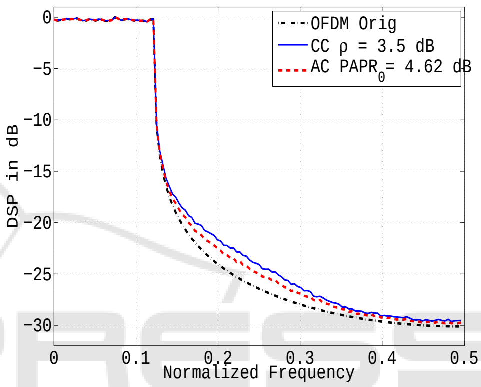

Figure 16: Comparison of DSP of the AC and CC methods for $\rho = 3.5$dB.

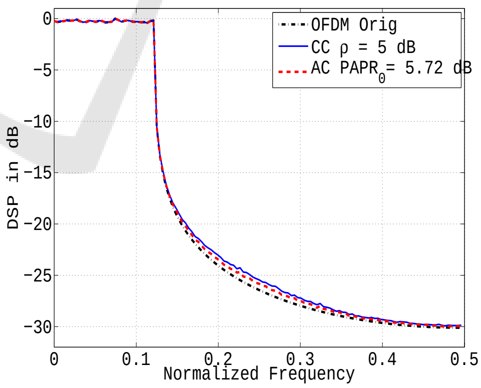

Figure 17: Comparison of DSP of the AC and CC methods for $\rho = 5$dB.

dation, mean power variations and adjacent channels pollution are consistent with our theoretical analysis of the ideal clipping. Indeed, we have shown that (Figures 1A, B) when $0 \leq \rho \leq 6.5$dB and $PAPR_0 = PAPR_{CC}^{(0)}$ many OFDM symbol are clipped more severely than necessary or unnecessarily in CC with respect to $PAPR_{CC}^{(0)}$.

In conclusion, these simulation results (Figure 13, 14,15,16 and 17) are consistent with our theoretical analysis.

Indeed, as in section 4.1, we can show from equation (14) that for each OFDM symbol, the corresponding adapted threshold is greater than ρ when $\mathrm{PAPR}_0 = \mathrm{PAPR}_{\mathrm{CC}}^{(0)}$. This remark can be directly deduced from the algorithm used for the adapted threshold computation.

5 CONCLUSION AND FUTURE WORK

In this paper an adaptive clipping is presented and compared to classical clipping in terms of PAPR reduction and signal degradation. This comparison has been achieved by a theoretical study and validated by simulation. We have shown that AC approaches the ideal clipping and then have same performance in terms of PAPR reduction but outperforms classical clipping in terms of signal degradation. Furthermore, AC gives a deterministic PAPR which is very important for IBO definition on high power amplification (HPA). However, the computation of the adapted threshold in AC is complex. A more simple iterative approach is being studied.

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