PAPR REDUCTION OF OFDM SIGNALS USING SEQUENTIAL TONE RESERVATION – CLIPPING HYBRID SCHEME

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ABSTRACT

This paper presents a new hybrid PAPR reduction technique for the OFDM signal, which combines a sequential tone reservation method with a signal clipping method. The simulation results highlight the advantages of the proposed PAPR reduction method.

Keywords: *OFDM, PAPR, tone reservation, clipping.*

1. INTRODUCTION

The Orthogonal Frequency Division-Multiplexing (OFDM) is one of the most popular technologies used in broadband wireless communication systems like WiMAX, DVB-T or ADSL. One of the main practical issues of the OFDM is the Peak-to-Average Power Ratio (PAPR) of the transmitted signal. Large signal peaks requires the power amplifiers (PA) to support wide linear dynamic range. Higher signal level causes non-linear distortions leading to an inefficient operation of PA causing intermodulation products resulting unwanted out-of-band power. In order to reduce the PAPR of OFDM signals, many solutions have been proposed and analyzed. The efficiency of these methods can be evaluated considering their characteristics of non-linearity, amount of processing and size of side information needed to be sent to receiver.

The clipping method is a nonlinear PAPR reduction scheme, where the amplitude of the signal is limited to a given threshold. Considering the fact that the signal must be interpolated before A/D conversion, a variety of clipping methods has been proposed.

Some methods suggest the clipping before interpolation, having the disadvantage of the peaks regrowth. Other methods suggest the clipping after interpolation, having the disadvantage of out-of-band power production. In order to overcome this problem different filtering techniques have been proposed. Filtering can also cause peak regrowth, but less than the clipping before interpolation [1].

Another clipping technique supposes that only subcarriers having the highest phase difference between the original signal and its clipped variant will be changed. This is the case of the partial clipping (PC) method [10].

To further reduce the PAPR, the dynamic of the clipped signal can be compressed. Some papers proposed μ-law/A-law companding functions [11], [8], exponential companding function [13] or piecewise-scales [2] after the clipping.

Linear methods like partial transmit sequence (PTS) or selective mapping (SLM) has been proposed for the reduction of PAPR as well. These methods generate different versions of the OFDM signal, by rotating each vector from the original signal with phases selected from a given set. Then the signal variant with the smaller PAPR is chosen for the transmission [3], [4].

Another PAPR reduction method is the tone reservation (TR). It uses tones on which no data is sent to reduce the transmitted signal peaks.

In order to reduce the computation complexity and to improve the performance of the tone allocation, several derivate techniques have been proposed: selective mapping of partial tones (SMOPT) [6], One-Tone One-Peak (OTOP) [12] and one by-one iteration [9].

An optimized method proposes to generate tones for the K largest peaks of the signal. The phases of these tones are chosen to be opposite to $\varphi_j+n\pi/2$, where φ_j is the phase of the identified peaks, j=1, 2, …, K and n=0, 1, 2, 3. The procedure is iterated until convergence reaches the expected threshold [9].

In the next paragraph we describe the OFDM signal structure. Next, we present the new hybrid PAPR reduction scheme where sequential tone reservation and signal clipping methods are described.

Finally, based on numerical results provided by the simulations, we analyse the performance of the new technique.

2. THE OFDM SIGNAL

In OFDM, the message bits are grouped in blocks { X_n, n=0,1,…,N-1}, and modulates in amplitude a set of N subcarriers, { f_n , n= 0,1,…,N-1}. These subcarriers are chosen to be orthogonal, that is $f_n=n\Delta f$, where $\Delta f=1/T$, and T is the OFDM symbol period. The resulting signal can be written as:

$$x(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}X_n e^{j2\pi f_n t} \quad . \qquad (1)$$

In order to avoid the intersymbol interference (ISI) generated by the multipath channels, a Cyclic Prefix (CP-corresponding to a guard interval) is added to the signal. After Digital-to-Analogue (D/A) conversion, the signal's spectrum is centred on a high frequency carrier and applied to a PA which drives the antenna load.

At the receiver, after the amplitude demodulation, the CP will be removed, the symbols being evaluated for a time interval of [0,T].

The expression of the PAPR for a given OFDM symbol is given by:

$$PAPR(x) = \frac{\max\left(|x(t)|^2\right)}{E\left[|x(t)|^2\right]}, \quad (2)$$

where $E[.]$ denotes the expectation operator.

Another quality measure refers to the non-linearity of the transmitted signal which is produced by the PA. This is the Signal-to-Distortion Ratio (SDR) defined as:

$$SDR = \frac{\|x\|^2}{\|x - g(x)\|^2} \quad (3)$$

where $g(.)$ is the memoryless nonlinearity representing the effects of the PA.

The optimal solution for PAPR problem may not be the best solution for the SDR problem and vice versa. Because these two problems are correlated, in practice a suboptimal solution may be chosen [7].

3. HYBRID PAPR REDUCTION METHOD

In this paragraph we present the proposed hybrid PAPR reduction technique which has been obtained by serialization of sequential tone reservation method and the signal clipping method.

The performance of the proposed PAPR reduction technique is analyzed with a MATLAB simulator as presented in Fig.1. Within this simulator, the samples from the generated signal are grouped in blocks of same size like the OFDM symbols. Each sample, group of M bits, is transformed using the M-QAM or the M-PSK modulation, obtaining the frequency domain OFDM symbols. They are applied to the tone reservation block, where the amplitude and phase of the additional (no data) carriers (named pilots) are modified for the peak reduction.

The used tone reservation technique [5] is presented in the block diagram from Fig.2.

It selects T pilot tones positions from a complete set of Q no data carrier positions and a set of M complex values. There are M^T possible combinations.

This search space may lead to an increased amount of data computation. The chosen tone-reservation algorithm decreases the computation complexity by attempting a reduced search space by trying all M values on the first pilot $P[0]$, while the other pilots, $P[1],\ldots,P[T\text{-}1]$, have a "randomized" initial state. Once an optimal value $C[0]$ is found, a similar procedure is repeated on the other pilot positions. For further computation complexity reduction, the time-domain signals equivalent for all pilot tones are computed and stored initially into memory. Denoting by $c(n)$ the sum of the pilots selected, it can be written:

$$x'(n) = x(n) + c(n) = \\ = \sum_{k=0}^{N-1} \left(X_k + P(C[k])\right) \cdot e^{j2\pi \frac{kn}{N}} \quad (4)$$

and the computations could be performed in the time-domain. In this way, the computation complexity reduces from $O(M^T \cdot N \cdot \log_2 N)$ to $O(MT + N \cdot \log_2 N)$, where N represents the length of the transmitted block.

The tone reservation algorithm proposed considers both symmetrical and asymmetrical repartition of the pilots, as depicted in Fig.3 and Fig.4.

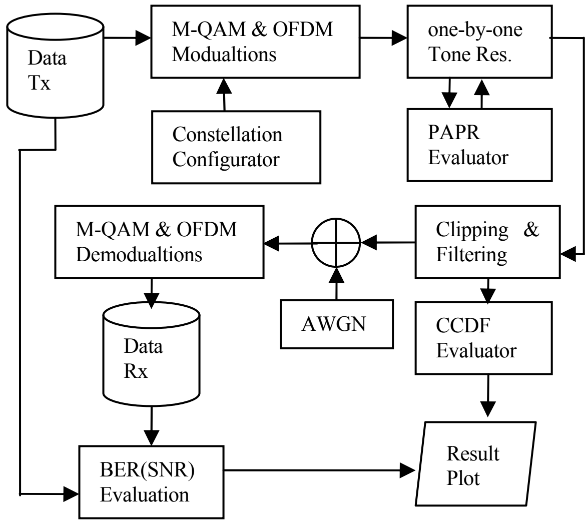

Figure 1. MATLAB model of the hybrid PAPR reduction technique.

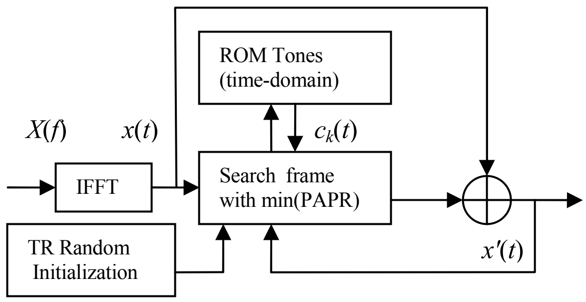

Figure 2. Tone reservation PAPR reduction method.

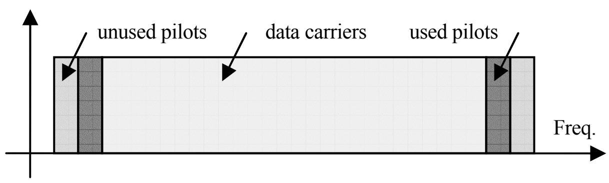

Figure 3. Allocation of reserved tones within an OFDM symbol. (symmetrical)

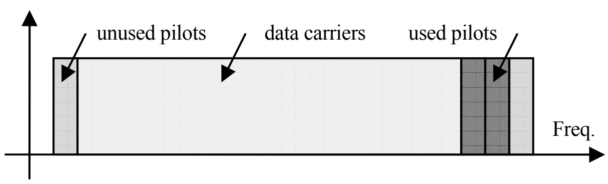

Figure 4. Allocation of reserved tones within an OFDM symbol (lateral).

To further reduce the PAPR a clipping technique [1] is applied next. It is presented in the block diagram from Fig.5 as well. Here the input vector $[a_0,\ldots,a_{N-1}]$ is first converted from frequency to time domain using an oversize IFFT. For the oversampling factor *p*, the input vector is padded with *N*(*p*-1) zeros placed in the middle of the vector. This results in a trigonometric interpolation of the time domain signal, which fits well for the signals with integral frequencies over the original FFT window, like is the case of OFDM.

The interpolated signal is then clipped by limiting its amplitude. The clipping ratio is defined as the clipping level *A* divided by the root-mean-square power σ of the unclipped baseband signal.

$$CR = 20 \cdot \log_{10}\left(\frac{A}{\sigma}\right). \tag{5}$$

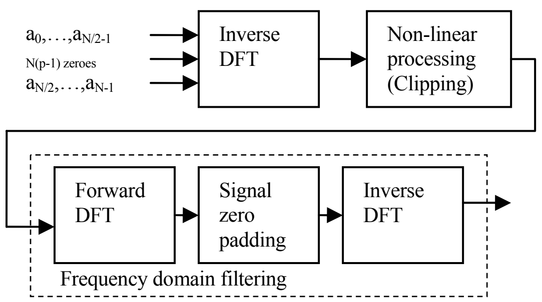

Figure 5. MATLAB model of the clipping based peak reduction technique.

In order to evaluate the performance of the proposed PAPR reduction scheme, the MATLAB simulator evaluates the complementary cumulative distribution function (CCDF) of the PAPR of the given OFDM signal. This is expressed as:

$$CCDF(Y) = \Pr(PAPR > Y) = \\ = 1 - \Pr(PAPR < Y) \tag{6}$$

where *Y* is a PAPR threshold.

The literature provides a reference expression for CCDF of PAPR higher than the threshold r_0 of OFDM with *N* subcarriers [14]:

$$CCDF(r_0) \approx 1 - \left(1 - e^{-r_0}\right)^N. \tag{7}$$

4. NUMERICAL RESULTS

The MATLAB simulations have been performed for base-band OFDM symbols with different length and configurations, using M-QAM and M-PSK modulations with M=16 and M=64 constellation points.

The results presented in this paper are obtained for OFDM frames with the repartition of pilots as previously indicated in Fig.3, with constellations of the pilot search space points identical with the constellations of the modulations used.

The clipping rate defined in (5) has been set to a value of CR=12, and the filtering over-sampling factor was set to *p*=2.

The numerical results have shown that the new proposed scheme improves the PAPR reduction factor and the bit error rate (BER) in comparison with the simple signal clipping method used in its second step.

Fig.6 presents the CCDF of PAPR for a 16-PSK based OFDM signal with *N*=128 data carriers, *Q*=24 pilot carriers from which *T*=8 are used for peak reduction. The corresponding BER(SNR) characteristics, for a communication channel is the Additive White Gaussian Noise (AWGN) in complex space, are presented in Fig.7.

Similar results for 64-QAM OFDM signal with *N*=128, *Q*=24, and *T*=12 are presented in Fig. 8 and Fig. 9 respectively. By comparing the curves from Fig.6 and Fig.8, it can be observed that the PAPR reduction factor increases with the increasing of the number of used reserved tones. The better BER, presented in Fig.7 and Fig.9, is obtained due to less clipped peaks within the time-domain signal.

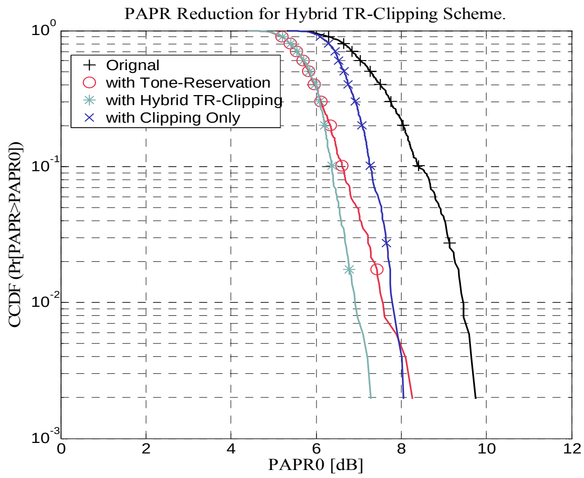

Figure 6. PAPR reduction of an OFDM signal when TR and signal clipping methods are used.

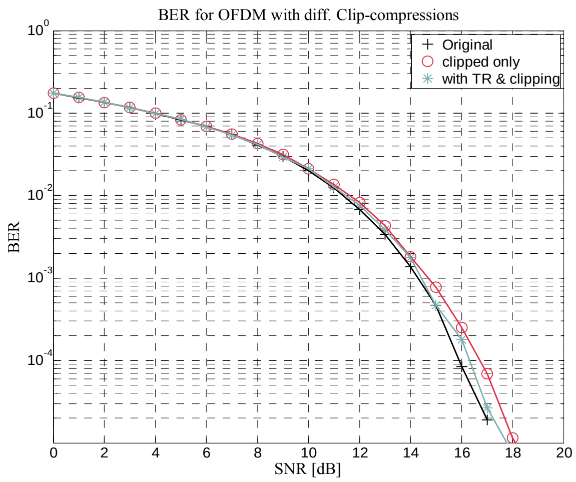

Figure 7. BER(SNR) for the OFDM signal when PAPR reduction methods are applied.

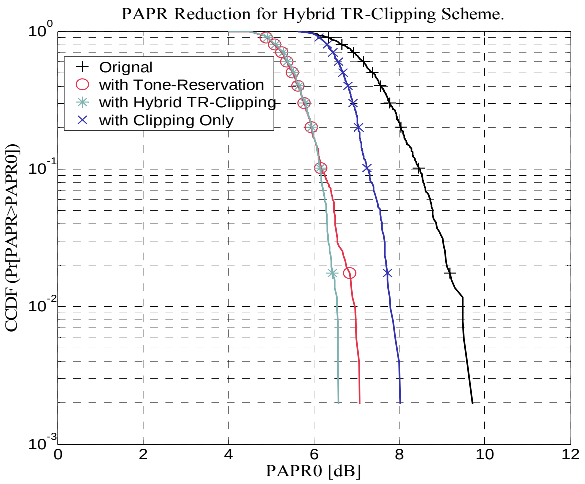

Figure 8. PAPR reduction of an OFDM signal when TR and signal clipping methods are used.

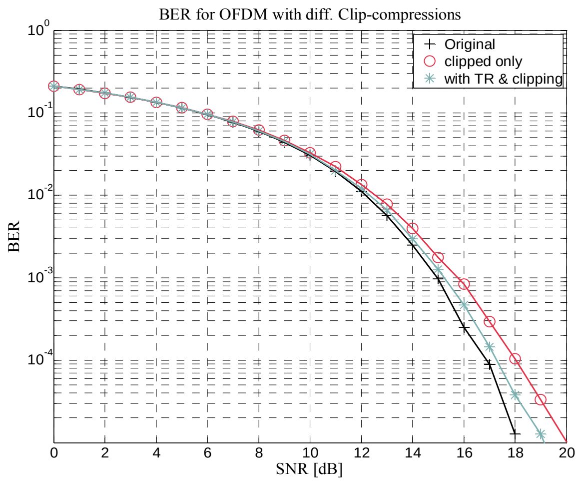

Figure 9. BER(SNR) for the OFDM signal when PAPR reduction methods are applied.

5. CONCLUSIONS

We presented a new hybrid PAPR reduction scheme. This technique is composed by a tone-reservation step followed by a signal clipping operation. This new PAPR reduction method combines the advantages of linearity from the first step with the reduced computation complexity of the second step, providing a better PAPR reduction without any bit error rate (BER) degradation.

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