PAPR REDUCTION OF OFDM SIGNALS USING SELECTIVE MAPPING AND CLIPPING HYBRID SCHEME

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ABSTRACT

The Orthogonal Frequency Division Multiplexing is one of the modulation techniques widely used in the broadband wireless technology. One of the main problems of this technology is the high peak-to-average power ratio of transmission signal due to the superposition of many subcarriers. This paper presents a new hybrid peak-to-average power ratio reduction technique, which combines a selective mapping method with the clipping method. The paper presents the performance and advantages of the new technique and compares it with other existing methods.

Index Terms— OFDM, PAPR, SLM, Clipping

1. INTRODUCTION

The Orthogonal Frequency Division Multiplexing (OFDM) is one of the very efficient and often used modulation techniques used in broadband wireless communication systems like WiMAX, DVB-T, or wireline systems like ADSL. One of the main issues of the OFDM based systems is the Peak-to-Average Power Ratio (PAPR) of the transmitted signal. Due to the time-domain superposition of the many data subcarriers which composes the OFDM signal, the PAPR may reach high values. Due to the large number of subcarriers, the resulting time-domain signal exhibits Rayleigh-like characteristics and large time-domain amplitude variations. These large signal peaks requires the high power amplifiers (HPA) to support wide linear dynamic range. The increased signal level causes non-linear distortions leading to an inefficient operation of HPA 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. These methods can be characterized by various parameters like non-linearity, amount of processing and size of side information needed to be sent to receiver.

Some of the well known linear methods are selective mapping (SLM) [1], partial transmit sequence (PTS) [2], and tone reservation (TR) [3].

The SLM method performs several vector rotations of the original frequency-domain OFDM signal, based on a set of predefined vector arrays. For each signal variant obtained, its corresponding PAPR is evaluated. The one with the lowest PAPR is chosen for the transmission.

The PTS method have a similar approach with the difference that same rotation angle is applied to more than one vector. The method considers the N complex values representing OFDM signal vectors as being grouped into K sub-blocks of N/K elements each. After calculation of the corresponding PAPR of each signal variant, the one with minimal PAPR is being chosen for the transmission.

The efficiency of the SLM and PTS methods increases with the number of phases from the considered set. The efficiency of the PTS method also increases when a higher number of blocks are used. The drawback is that a better efficiency requires an increased amount of computation at the transmitter's and receiver's sides.

For the regeneration of the original signal, the receiver must know those phases' sets and block sizes and displacements. When these arrays have a well defined limited amount of elements, they can be predefined within the receiver. When these arrays have a variable amount of elements, then additional information is required to be sent to receiver. Therefore another disadvantage of these methods may rise when this amount of additional information is comparable to the amount of effective data information within the transmitted frames. Optimizations of these methods has been proposed in several papers [4,5].

The TR method is another linear PAPR reduction technique which instead of altering the data subcarriers, it uses a set of reserved set of subcarriers (tones) to generate signals with lower PAPR level. [3]

Since the original variant, several derivate techniques have been proposed: selective mapping of partial tones (SMOPT) [6], One-Tone One-Peak (OTOP) [7] and one-by-one iteration [8].

The class of non-linear methods is represented by approaches like active constellation extension (ACE), clipping, partial clipping, and signal compression.

The ACE method operates on tones whose base band modulation symbol is an outer point of the constellation.

It moves the complex values of those tones toward outside of the original constellation in order to reduce the PAPR level of the transmitted signal. [9]

The clipping method is another well known non-linear PAPR reduction technique, where the amplitude of the signal is limited to a given threshold. Taking in consideration 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 after interpolation.. Other methods perform 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 [10].

The partial clipping method is another nonlinear technique which supposes that only subcarriers having the highest phase difference between the original signal and its clipped variant will be changed. [11]

For additional PAPR reduction, some papers proposed μ-law/A-law companding functions [12], exponential companding function [13], piecewise-scales [14] or polynomial ratio functions [15] after the clipping.

The rest of the paper is organized as follows. The second paragraph describes the OFDM signal and some of its properties. The third section describes the proposed hybrid PAPR reduction scheme. Next, the numerical results highlighted by the computer simulation are presented and discussed. Based on the results obtained, some conclusions are presented.

2. THE OFDM SIGNAL

In an OFDM based system, the signal contains a set of N baseband subcarriers, $\{f_n,\ n=0,1,\ldots,N-1\}$, which are modulated by the signal samples from a block of N symbols, $\{X_n,\ n=0,1,\ldots,N-1\}$. 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:

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

In order to avoid the intersymbol interference (ISI) generated by the multipath channels, a repeated signal sequence from the current period, corresponding to a guard interval, is added to the signal. After Digital-to-Analogue (D/A) conversion, the signal is amplitude modulated to a carrier frequency and applied to a high-power amplifier (HPA) which drives the antenna load. At the receiver, after demodulation, the guard interval will be removed, the symbols being evaluated for a time interval of $[0,T]$.

Time domain samples of the low-pass OFDM signals in the complex domain are appreciatively Gaussian distributed due to statistical independence of carriers. The weighted sums of random variables which forms peaks in the signal, causes the PAPR problem. The expression of the PAPR for a given OFDM signal block is given by:

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

where E[.] denotes the expectation operator.
This is usually evaluated using evaluates the complementary cumulative distribution function (CCDF) of the PAPR:

$$\begin{aligned} CCDF(Y) &= \Pr(PAPR > Y) = \\ &= 1-\Pr(PAPR < Y) \end{aligned} \qquad (3)$$

where Y is a given PAPR threshold.

3. THE HYBRID TECHNIQUE

In this paragraph we present the proposed hybrid PAPR reduction technique which has been obtained by serialization of selective mapping method and clipping method.
The main idea for combining the two methods is relaying on the observation that two different types of signal processing for PAPR reduction will increase the overall performance. One performs linear transformation by rotating the vectors from the frequency-domain signal, and the other one performs a non-linear transformation represented by signal limitation to a given threshold.
The SLM method consists in an iterative search algorithm, whose computation time depends by the amount of variants for phase changes. In case of the clipping method, which has a fixed number of operations, the computation time is constant. Therefore another advantage of the hybrid method is that total amount of computation time may be reduced, due to reduced size of search space used by the SLM block.

The performance of the proposed PAPR reduction technique is analyzed with a MATLAB simulator as presented in Figure 1.
Within this simulator, the uniformly random generated samples are mapped from binary representation to the M-QAM or M-PSK constellation points.
The obtained complex values are grouped in blocks of N elements each, forming the OFDM symbols. The obtained OFDM frames are applied sequentially to the SLM block and then to the clipping block. For the resulted signal, the PAPR level is evaluated using the CCDF characteristic. In order to evaluate the performance of a communication system when this PAPR reduction technique applied, the BER for the case of an AWGN channel is computed as well.

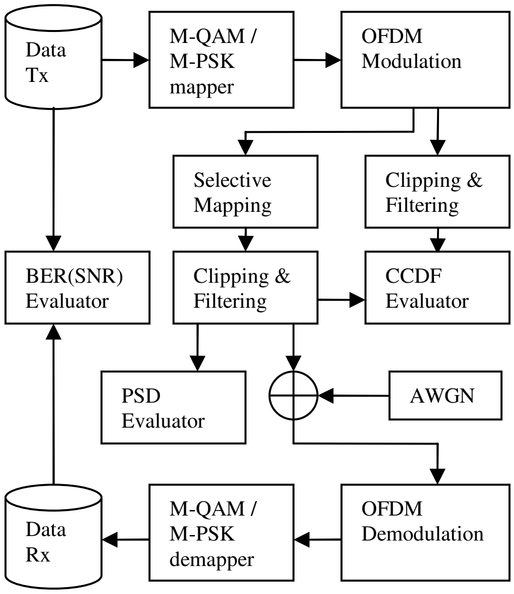

Figure 1. MATLAB model for the analysis of the hybrid PAPR reduction technique.

The applied SLM method is presented in the diagram from Figure 2. It generates a set of signal variants based on the algorithm consisting in the following steps.

1) Starting with a set of N data symbols X_{in}, representing an OFDM frame:

$$x_{in}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_{in}(n) e^{j2\pi f_n t}, \qquad (5)$$

2) Rotate all constellation vectors from X_{in} using the phase table $\varphi_{n,h}$, where n=1…N is the index of a vector, and h=1..R is the index of the signal variant from a set of R possibilities. The signal becomes:

$$X_{slm}(n,h) = X_{in}(\varphi(n,h)). \qquad (6)$$

3) Apply IFFT to get the corresponding time-domain signal representation $x_{slm}(t,h)$.

$$x_{slm}(t,h) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_{in}(\varphi(n,h)) e^{j2\pi f_n t}. \qquad (7)$$

4) Compute the PAPR for all R variants, and choose the one with lowest PAPR level for the transmission.

The signal X_{slm} is derived from X_{in} which has modified values for phase of all vectors. Because the receiver must reconstruct the original signal by applying the inverse vector rotations, it has to know the rotation angle table. For this purpose, it is necessary either to consider a predefined table or to transmit additional information to the receiver.

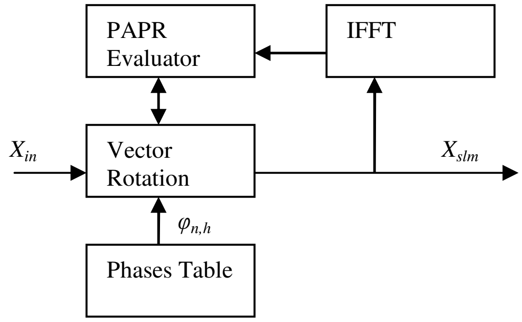

Figure 2. The SLM derivate method for PAPR reduction.

This side-information may contain only some label bits or the phase vector itself, depending on the availability of the phase set at the receiver.

The data bits are usually coded using a recursive convolutional code which may affect almost all bits from the respective frame if it is non-systematic. For this case, the literature provides the following CCDF approximation [16]:

$$\Pr(PAPR_{SLM} > Y) \approx \left(1 - e^{-\sqrt{\frac{\pi}{3}} \cdot K \sqrt{Y} \cdot e^{-Y}}\right)^{U} \qquad (8)$$

where K is the number of the symbols within a block, and U is the oversampling factor.

The applied clipping technique [10] is presented in the block diagram from Figure 3.

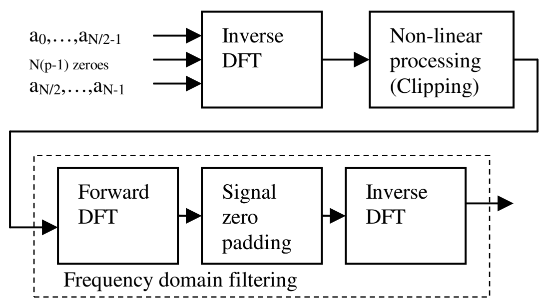

Figure 3. Clipping based PAPR reduction model .

In this method, additionally to the effective clipping, the signal is adapted and applied to a frequency domain filter. Such filtering techniques are used and detailed presented in some works [10,17].

Considering an oversampling factor p, the input array of complex values $[a_0,\ldots,a_{N-1}]$ is padded with a sequence of $N(p$-1) zeroes placed in the middle. Then, the obtained signal is converted from frequency to time domain using an oversized IFFT. This results in a trigonometric interpolation of the time domain signal, which fits well for the signals with integral frequencies over original FFT window, like is the case of OFDM. The interpolated signal is then clipped by limiting its amplitude. The clipping ratio applied in this method is defined as ratio of the clipping level A to the root-mean-square power σ of the unclipped baseband signal.

$$CR = 20 \cdot \log_{10}\left(\frac{A}{\sigma}\right). \qquad (9)$$

Additional research on the various clipping techniques has been made in several paper [18,19].

The proposed hybrid PAPR reduction technique contains both linear and non-linear signal processing blocks. This fact represents a high flexibility from the signal processing point of view. When SLM block uses a reduced set of phase arrays, its smaller PAPR reduction can be compensated by the clipping block. This case has the advantage of a reduced amount of computation, but also has the disadvantage of a higher signal distortion. When the SLM block uses an extended set of signal variants, the increased PAPR reduction allows a decreased signal distortion. This case presents a better BER performance but with the drawback of an increased amount of computation.

4. NUMERICAL RESULTS

The MATLAB simulations have been performed for base-band signals with N=128 and N=256 subcarriers using M-QAM and M-PSK modulations.

The results presented in this paper are obtained using a phase rotation array containing 3 sets of phase values given by $\varphi_k^N = 2k\pi / M$, where M={4,5,6} and k=0…M-1. The table contains phase sequences with the repetitive patterns of the forms $\{\varphi_0,\varphi_1,\ldots,\varphi_{M-1}\}$, $\{\varphi_0,\varphi_0,\varphi_1,\varphi_1,\ldots,\varphi_{M-1},\varphi_{M-1}\}$ and $\{\varphi_0,\varphi_1,\ldots,\varphi_{M-1},\varphi_{M-1},\varphi_{M-2},\ldots,\varphi_0\}$, for each value of M.

The numerical results have shown that the proposed scheme improves the PAPR reduction in comparison with the use of only one of the component methods.

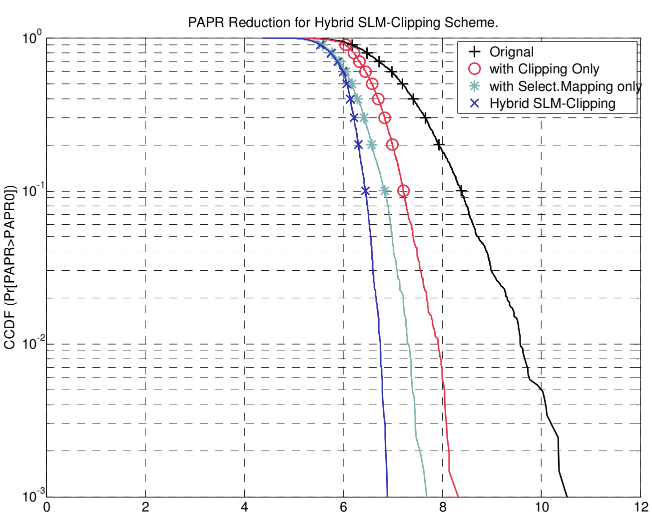

Figure 4. PAPR reduction using hybrid SLM-Clipping method.

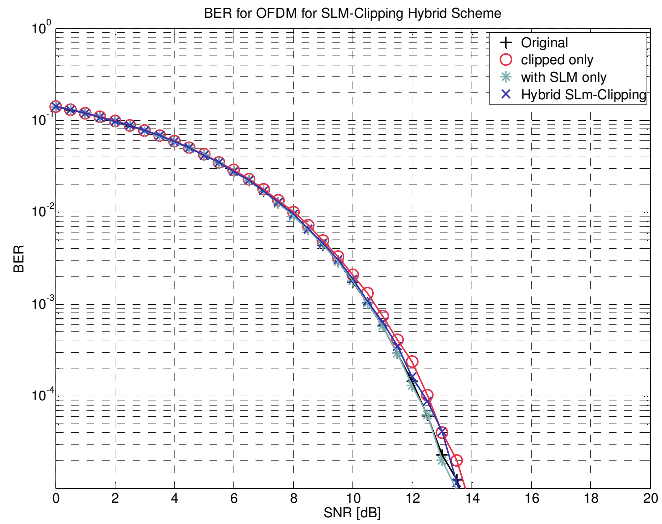

Figure 5. BER of OFDM signal before and after PAPR reduction.

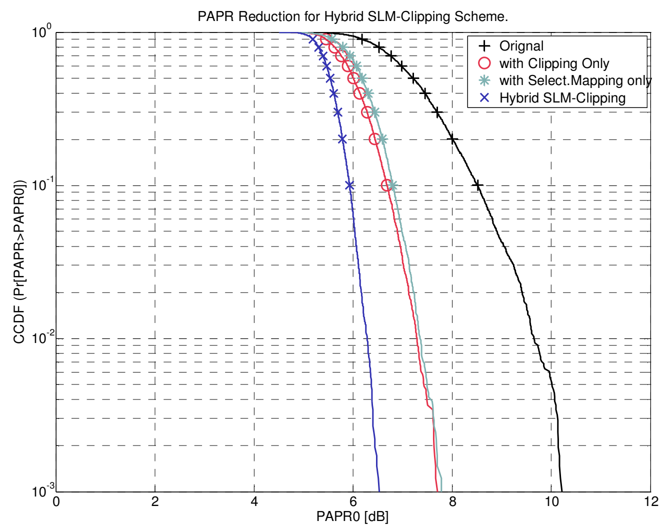

Figure 6. PAPR reduction using hybrid SLM-Clipping method.

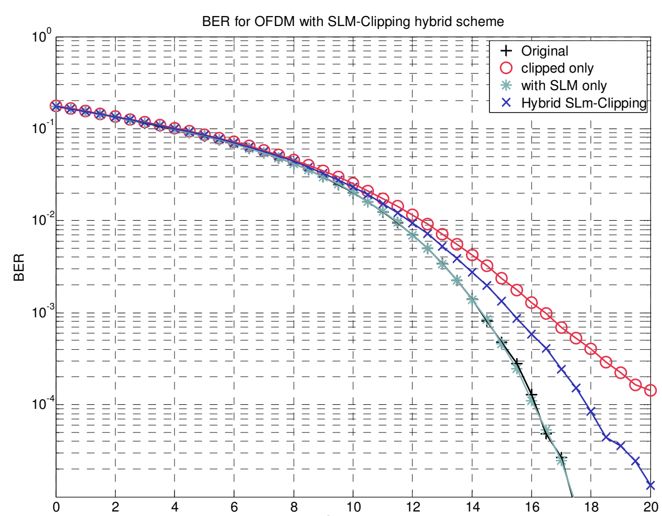

Figure 7. BER of OFDM signal before and after PAPR reduction.

For the evaluation of the performance of the proposed technique, two cases are considered and presented.

The first case considers an OFDM signal with N=128 subcarriers with a 16-QAM modulation and a clipping rate of *CR*=12. The Figure 4 and Figure 5 indicate the corresponding PAPR reduction and BER performance respectively. The second case considers an OFDM signal with N=256 subcarriers with a 16-PSK modulation using a clipping rate of *CR*=9.5. The corresponding results are indicated in the Figure 6 and Figure 7.

The two cases show also that a lower clipping threshold has an increased influence in the BER performance degradation. Therefore in order to avoid this degradation, an extended SLM vector rotation table can be used.

The computation complexity of the hybrid technique is given by the sum of operations done by SLM and clipping methods. Considering the block structure and parameters of these component methods, presented in the previous section, the computation complexity of the SLM bock is $O(R\cdot(1+N\cdot\log_2(N)))$.

Considering the block diagram of the clipping method which with contains frequency domain filtering block, which performs Fourier transformations on the zero padded signal, its computation complexity is given by the sum of operations required by the effective clipping and filter related blocks.

This which is sum of $O(N\cdot p\cdot(1+\log_2(N\cdot p)))$ and respectively $O(N\cdot(p-1)+2\cdot N\cdot p\cdot\log_2(N\cdot p))$.

Therefore, for a given OFDM signal of N subcarriers, the total amount of operations depends by the parameters R and p, which can be adjusted in order to limit the total delay within the PAPR reduction blocks.

5. CONCLUSIONS

In this paper we proposed an alternative PAPR reduction technique based on combination of a partial transmit sequence method with the clipping method.

The paper presented the SLM and clipping algorithms used within the hybrid technique.

The numerical results show that the hybrid scheme brings higher PAPR reduction than the component methods. By comparison with clipping only, we showed that the combination of the two methods decreases the signal distortion level and requires less iterative computation effort for generation of transmitting signal and recovering the original signal at the receiver side.

The considered two methods have few variants with different efficiency and performance. The SLM method may consider different set of phases and rotation tables.

In future work, we will consider different set of values for the phases and various tables for vector rotation.

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