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Analysis of a new Hybrid Clipping-SLM PAPR Reduction Technique

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Abstract – This paper presents new hybrid PAPR reduction technique for the OFDM signal, obtained as a combination between clipping and selective mapping methods. Based on the analysis of existing PAPR reduction methods, the advantages of the new technique are presented.
Keywords: OFDM, PAPR, Clipping, Selective Mapping.

I. INTRODUCTION

Orthogonal frequency division-multiplexing (OFDM) is one of the most popular technology used in broadband wireless communication systems like WiMAX, DVB-T and ADSL. One of the main practical issues of the OFDM is the peak-to-average power ratio (PAPR) of the time-domain signal. Large signal peaks requires the power amplifiers (PA) to support wide linear dynamic range. Higher signal level causes non-linear distortion leading to an inefficient operation of PA causing intermodulation products resulting unwanted out-of-band power.

Therefore, in order to reduce the PAPR of OFDM signals, many solutions has 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 time-domain signal is limited to a given threshold. Considering the fact that the signal must be interpolated before A/D conversion, variety of clipping methods has been proposed.

Some methods suggest the clip before interpolation, having the disadvantage of the peak regrowth. Other methods suggest the clip after interpolation, having the disadvantage of out-of-band power. In order to overcome this problem different filtering techniques has been proposed. Filtering may cause peak regrowth too, but less than for the case of clip before interpolation [1].

Derivates of clipping methods where the clipped signal is compressed has been proposed as well. Some papers proposed μ-law companding [2] or exponential law companding [3] after the clipping.

Another clipping technique supposes that only subcarriers having the highest difference between the phase of the original signal and the phase of the clipped symbol will be changed. This is the case of the partial clipping (PC) method [4].

Linear methods like partial transmit sequence (PTS) or selective mapping (SLM) were proposed too. In the PTS method the OFDM signal symbols are grouped into K sub-blocks of N/K symbols. In the simplest case, the blocks contain contiguous carriers, which is especially suitable for differential detection systems. Blocks may contain non-contiguous carriers for better peak factor (PF) reduction capability at the cost of extra complexity. The new signal is obtained by rotating the symbols from each block with one phase from a given set of K phases with values from a given finite set. The PTS performs several iterations to identify the best phase values for each block which minimize the PAPR [5]. Optimizations of this method has been proposed in several papers [6,7].

In a similar manner, the SLM method performs a vector rotation of the frequency domain OFDM signal, but in this case the set K of the phase vectors is predefined. Each OFDM block is multiplied carrier-wise with all vectors, resulting in a set of K different sequences. The one with the lowest PAPR is chosen for the transmission.

Another PAPR reduction method is tone reservation (TR). This is a promising method that uses tones on which no data is sent to reduce the time-domain signal peaks. In order to reduce the computation complexity and to improve the performance of the tone allocation, several derivate techniques have been proposed. Such methods are selective mapping of partial tones (SMOPT), One-Tone One-Peak (OTOP) and one-by-one iteration [8]. Another optimized TR method where the peaks phases are considered for computing pilot complex values is proposed in [9].

A similar approach, but without use of non-data subcarriers, is represented by the multiple signal representation method [10]. In this case, more possible complex values are assigned for each data symbol assigned according with a given set. The algorithm applies iteratively these alternative values

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on a subset of subcarriers, to generate a set of different signal representations. The one with lowest PAPR level is chosen for the transmission.

Alternative techniques like active constellation extension (ACE) [11], other constellation distortion method [12] or signal spectral masking [13] are proposed in literature as well.

The next paragraphs from this paper presents the basics of the OFDM signal, the new proposed hybrid PAPR reduction technique, and numerical results.

II. THE OFDM SIGNAL

In OFDM, the signal samples are grouped in blocks of N symbols, $\{X_n, n=0,1,\ldots,N-1\}$, which are modulating one of a set of N subcarriers, $\{f_n, n=0,1,\ldots,N-1\}$. 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:

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

In order to avoid the intersymbol interference (ISI) generated by the multipath channels, a guard interval is added to the signal. After digital-to-analog (D/A) conversion the signal is modulated to a carrier frequency and applied to a high-powered amplifier (HPA) which drives the antenna load.
At the receiver, after demodulation, the guard 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:

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

where $E[.]$ denotes the expected value.
Another measure of the non-linearity is determined by the relation between signal and the physical constraints of the HPA. 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 HPA.

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].

III. HYBRID PAPR REDUCTION METHOD

The present paper presents an analysis of a new PAPR reduction technique obtained as a combination of two well known already mentioned methods. This is the case of a new selective mapping - clipping hybrid technique, similar like in [14] but with new characteristics. For each of the components methods, some particular implementations are considered.

The evaluation of the performance of the proposed techniques is made with the Matlab model presented in block diagram from the Fig. 1.
Within this simulator, the uniformly distributed random generated samples are grouped in blocks of N elements. Each of these samples is modulated using baseband M-QAM or M-PSK method, forming the frequency domain OFDM frames.

These OFDM frames are applied to the SLM block, where the angle of each frequency domain vector is changed, according with a given phase pattern from a given set.
Next, the obtained signal is applied to the clipping block, where the signal is converted to time-domain, and then clipped and filtered.
For the resulted signal the complementary cumulative distribution function (CCDF) is calculated. This is:

$$\begin{aligned}CCDF &= \Pr(PAPR>Y)=\\ &=1-\Pr(PAPR<Y)\end{aligned} \quad (4)$$

Due to use of non-linear processing, for a better evaluation of the proposed method, the BER characteristic for a channel with additive white gaussian noise is computed as well.

The selective-mapping block uses a phase pattern obtained according with the following procedure.
The algorithm generates a set of uniformly distributed angle values, of the form $\varphi_k^N=2k\pi/M$, where $M=\{4,8\}$ and $k=0\ldots M-1$. These values are grouped in repetitive patterns of the following forms: $\{\varphi_0,\varphi_1,\ldots,\varphi_{M-2},\varphi_{M-1}\}$, $\{\varphi_{M-1},\varphi_{M-2},\ldots,\varphi_1,\varphi_0\}$, $\{\varphi_0,\varphi_{M-2},\ldots,\varphi_1,\varphi_{M-1}\}$, $\{\varphi_0,\varphi_{M-1},\ldots,\varphi_1,\varphi_{M-2}\}$, $\{\varphi_{M-1},\varphi_1,\ldots,\varphi_{M-2},\varphi_0\}$, $\{\varphi_{M-2},\varphi_{M-1},\ldots,\varphi_0,\varphi_1\}$.
Next, the subcarriers of the frequency-domain signal are split in four contiguous blocks of different size.

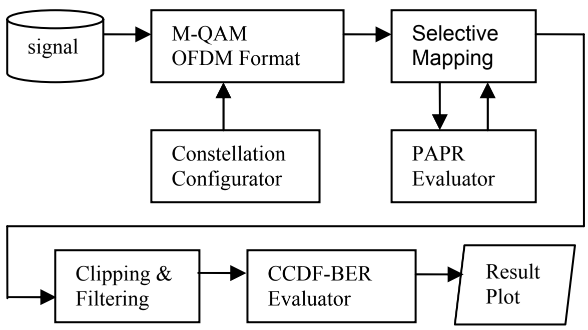

Fig. 1. MATLAB model of the hybrid PAPR reduction technique.

The present work considers two such grouping, one considers that blocks sizes increase with a factor of 1.5 and the other one with a factor of 2.0 respectively. The previously presented angle patterns are applied to each of these blocks. Additionally, the present work considers a different set of possible M angles for different blocks, $\{M_{B0}, M_{B1}, M_{B2}, M_{B3}\}$, according with following set of predefined patterns: {4,4,4,4}, {4,4,8,8}, {4,8,4,8} and {8,8,8,8}.

Once the complete angle patterns for entire OFDM frequency-domain signal are generated, the SLM block applies them to the original signal, to generate signal derivates with various PAPR. The one with the smallest PAPR is then chosen for the transmission.

The block diagram for this version of SLM is presented in the Fig. 2.

This method presents the advantage of linearity, but with the drawback of iterative computation depending on the size of the phase set.

Another aspect of this method is that the receiver must know which was the phase vector used by the transmitter for PAPR reduction. This can be solved by sending some additional bits to receiver. 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 from the OFDM signal is usually coded using a recursive convolutional code which may affect almost all bits from the frame if it is non-systematic. This provides a good randomization of the OFDM signal.

If the label bits are set at the beginning of the payload within the block, no side information needs to be transmitted to the receiver. In the literature, assuming the above aspects, the CCDF for the SLM have the following approximation [15]:

$$\Pr\left(PAPR_{SLM} > Y\right) \approx \left(1 - e^{-\sqrt{\frac{\pi}{3}} \cdot K \sqrt{Y} \cdot e^{-Y}}\right)^{U} \qquad (5)$$

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

Next, the obtained OFDM signal is applied to the clipping block. The used clipping technique is presented in the diagram from Fig. 3.

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 $N(p-1)$ zeroes placed between data vectors according with the schemes from Fig. 4.

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 the case of OFDM.

The interpolated signal is then clipped by limiting its amplitude to a given level. Next, the signal is applied to the filtering block where all padding elements are enforced back to zero.

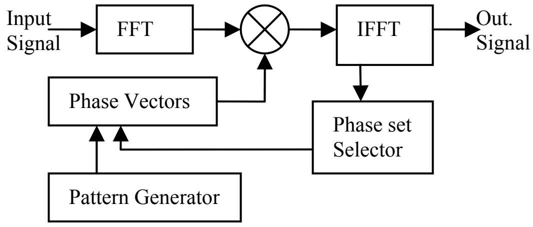

Fig. 2. MATLAB model of the SLM based peak reduction technique.

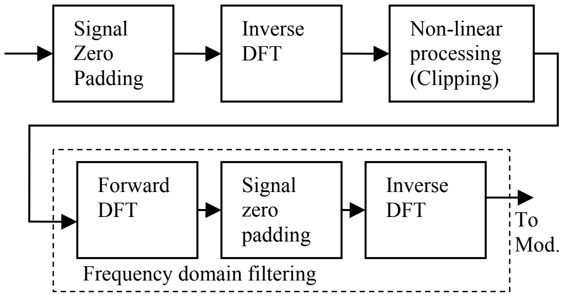

Fig. 3. MATLAB model of the clipping based peak reduction technique.

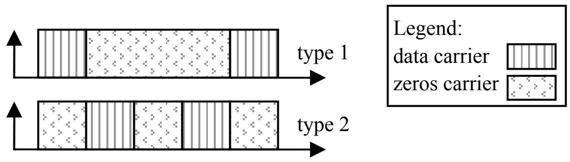

Fig. 4. Displacement of zero padding elements.

The clipping ratio applied in this method is defined as ratio of the clipping level to the root-mean-square power of the unclipped baseband signal.

$$CR = 20 \cdot \log_{10}\left(\frac{A}{\sigma}\right) \qquad (6)$$

For further PAPR reduction the clipping with filtering procedure can be iteratively repeated. The number of cycles is limited by a given PAPR reduction gradient additionally obtained in the previous cycle.

IV. NUMERICAL RESULTS

The performed simulations has been made for OFDM frames of N=128 and 256 subcarriers using M-QAM and M-PSK modulations with M=16. For a relevant accuracy, the simulations where made using 4096 OFDM frames. The clipping block considers the clipping rate set to CR=3, an oversampling of type 2 with a factor of p=4, and 2 cycles.

The CCDF(PAPR) for the case of 16-QAM is presented in the Fig. 5. The numerical results showed that the hybrid method provides better PAPR reduction. The PAPR reduction slightly increases when the clipping uses 2 cycles.

The corresponding BER(SNR) characteristic is presented in Fig. 6.

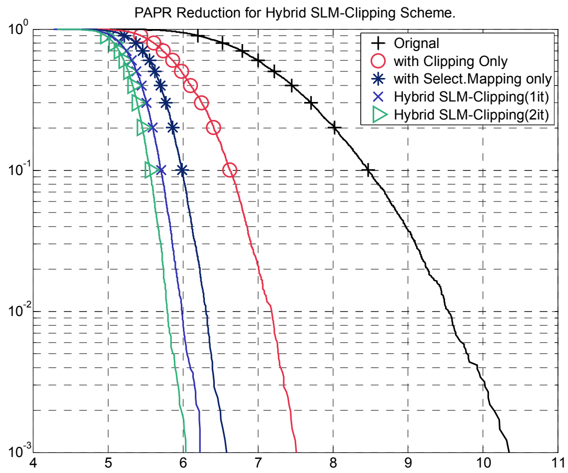

Fig. 5. CCDF for PAPR in case of hybrid method with 2 clipping iterations.

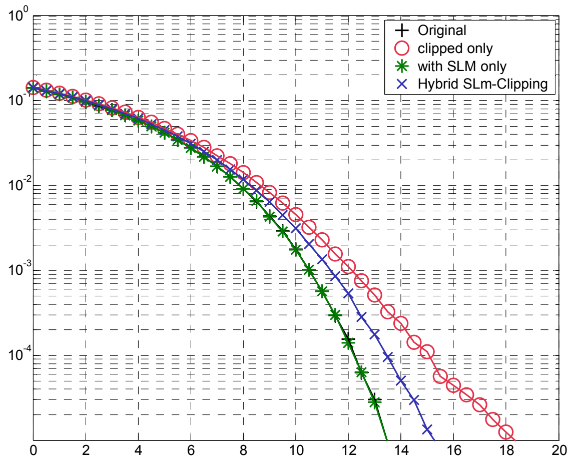

Fig. 6. BER for OFDM signal when SLM-clipping methods applied.

Compared to the case when only clipping method is applied to the signal, the hybrid technique presents a smaller BER. This is because of fewer peaks which have to be reduced by the clipping method.

Another important aspect of the proposed technique is the computation complexity. The SLM method requires a number of IFFT operations equal with the size of pattern table. The clipping method requires 3 oversized FFT operations per cycle. Due to these facts, the balance between PAPR reduction, BER performance and amount of computation can be adapted according to the requirements of particular application.

IV.CONCLUSIONS

We proposed a simple but novel PAPR reduction scheme based on a combination of two conventional methods. In the proposed scheme a serialization of a SLM derivate method with a clipping method is considered.

The proposed method showed an additional PAPR reduction when clipping after SLM method is applied. An important aspect of the proposed method is that the PAPR and BER can be adjusted according to the number of angle patterns used by the SLM block and clipping rate used by the clipping block. Therefore, an increased number of patterns within SLM block provide better PAPR and BER characteristics. The drawback of this case is an increased number of operations. A smaller clipping ratio provides a better PAPR reduction, having the disadvantage of an increased BER.

By using the SLM method, in some cases side-information must be transmitted to the receiver. If the phase set is defined at receiver the side information can significantly reduced. More, when the phase set is limited to smaller number of vectors, no additional side-information may be required. In this case the receiver may detect the used vector by iterative search, with less computational effort.

Due to the diversity of PAPR reduction techniques, the subject remains open for further research.

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