Select Mapping Technique with Random Rotational Phase Sequence for PAPR Reduction in OFDM Communication Systems

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Abstract - This paper discusses the reduction of the peak-to-average-power ratio (PAPR) of an Orthogonal Frequency Division Multiplexing (OFDM) wireless communication transmission system implementing a select mapping method (SLM) that uses a random rotational phase sequence (SLM-RRPS). In this project, different random rotational phase sub-blocks U were used, as well as different numbers of sub-carriers, 64 and 128, as a parameter for the randomly generated OFDM signal. The source signal PAPR reduction was analyzed and compared with and without the implementation of the SLM-RRPS method. In addition, the behavior of this method was analyzed by increasing the U sub-blocks, the size of the sub-carriers and the inverse fast Fourier transform (IFFT). Simulations showed that this method is very efficient in reducing PAPR. By increasing the number of U sub-blocks (U = 4,8,16,32) and sub-carrier 64, a reduction of up to 4.43 dB is obtained. On the other hand, another OFDM signal was generated, this time increasing the number of sub-carriers to 128, which obtained a good result with PAPR reduction of the original signal up to 2.35 dB.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a digital communication technology that implements orthogonal multi-carrier modulation technique. This orthogonality is associated with multiple sub-carriers and overlapping frequencies. One of the most important characteristics of OFDM is high spectral efficiency, however a disadvantage of this technology is a high peak-to-average power ratio (PAPR). The high value of PAPR is due to the fact that each sub-carrier is statistically independent, so when the number of sub-carriers reaches a certain point, PAPR is larger than a single-carrier system [1]. The OFDM is widely used in mobile communication, digital video broadcasting-terrestrial (DVB-T), digital audio broadcasting (DAB) and is also used in wireless communication standards such as IEEE 802.11a, IEEE 802.16 and IEEE 802.20 [2].

Although OFDM is a widely accepted technology in modern communications, it can lead to certain drawbacks such as inter-symbolic interferences (ISI). High values of PAPR prevent the power amplifier (PA) operating in the maximum performance regions, as a result, PAs operate in regions with higher energy consumption, where PA will consume more energy and would be less efficient [3].

To achieve a better PA efficiency, there are several techniques for reducing the PAPR of the OFDM signals [4]. Distortion techniques are often used, as they are simple and practical to implement. The crest factor reduction (CFR) consists in the combination of a limiting and filtering block for the RF signals. Although this technique is efficient in reducing PAPR, clipping of time-domain signals generates important out of band spectral regrowth and in band distortion [3]. Another efficient method in PAPR reduction is the coding technique implemented for signals with small number of sub-carriers, but presents an inefficient transmission rate for a larger number of sub-carriers. [1]. Probabilistic methods are used in techniques such as partial transmit sequences (PTS), select mapping (SLM), among others for PAPR reduction [5]. PTS separates the source data blocks into disjoint subgroups, optimizes the phase of each cluster to obtain the lowest PAPR of the combining signal. SLM disposes the original data blocks in parallel and multiplies them by a phase sequence, before applying IFFT, then the symbol with the lowest PAPR is selected [6]. These last two techniques allow an effective reduction of PAPR, however they implement many iterative sequences in fast Fourier transform (FFT) which causes high computational complexity.

In this work, we reduce the PAPR from the original OFDM signal using SLM technique with rotational phase sequence as a random complex phase vector being implemented with a different number of sub-carriers.

This article is organized as follows. Section II describes the system model. Section III describes the SLM-RRPS technique. Section IV addresses the simulations and results. Conclusions are given in Section V.

II. SYSTEM MODEL

An OFDM system consists of a block of N symbols, $\{\ X_n, n = 0,1,\ldots,N-1\ \}$ formed with each symbol modulation, each belonging to a different set of N sub-carriers and each of them represents a data bit $\{ f_n$, n=0,1…,N-1}. These data are transmitted through bandwidth of N orthogonal sub-carriers, this is, $f_n = n\Delta f$, where $\Delta f = \frac{1}{NT}$ and T is the period of the original symbol [7]. Here the signal is modulated and demodulated with N FFT and IFFT operation points corresponding to the number of sub-carriers. Mathematically The OFDM symbol can be expressed as shown below [7]

$$x(t) = \sum_{n=0}^{N-1} X_n \, e^{j2\pi f_n t}, \qquad 0 \le t \le NT \qquad (1)$$

One important benefit in OFDM is that a reliable transmission over spectrally shaped channel is presented without any equalization, this is due to introducing a guard-period and application of a differential encoding [5]. However, because of the statistical independence of the sub-carriers, corresponding time-domain samples in the equivalent complex valued low pass domain are approximately Gaussian distributed. This causes a high PAPR, which is given by

$$\text{PAPR} = 10\log 10 \, \frac{\max[|x(t)|^2]}{\text{E}\,[|x(t)|^2]} \qquad (2)$$

The magnitudes of the real and imaginary parts of the output signal have a Gaussian distribution and the amplitude of the OFDM signal has a Rayleigh distribution behavior. The peak power distribution of OFDM signals is N times the average power considering phase values as being the same [7]. The probability density function (PDF) of power is show in equation (3).

$$F(z) = 1 - e^{-z} \, , \qquad (3)$$

where z is a threshold of PAPR and maximum z value is comparable to PAPR. The probability of a PAPR below the maximum threshold point z_{max} is expressed with cumulative distribution function (CDF) considering N number of sub-carriers by

$$P(PAPR \le z) = F_{z_{max}}(z)^{\text{N}} = (1 - e^{-z})^{\text{N}} \qquad (4)$$

The complementary cumulative distribution function (CCDF) is used if PAPR is considered to exceed the threshold value. CCDF expresses the probability that PAPR of an OFDM signal exceeds that threshold z point, it is mathematically calculated as follows [8]

$$P(PAPR \ge z) = 1 - P(PAPR \le z) \qquad (5)$$

High linear PAs operate in a large back-off region to avoid nonlinear distortion and spectral interference in the communication signal. Hence, PA must operate in a higher gain power region, but without being affected by non-linearity distortions [3].

III. SLM TECHNIQUE

SLM is an efficient distortionless PAPR reduction technique, based on the frequency domain with little overhead, which enables high output gains and RF system transmission improvements. [9]. The basic principle of SLM consists in symbol scrambling. At this point, a set of candidate signals is generated. These candidate signals represent the same information, then the signal with the lowest PAPR of all is selected. The recovery of the information in the receiver presents some difficulties if there is any error in the received data coming from the transmitted selected signal [1].

Figure 1 shows the basic structure of SLM. The input data blocks are multiplied by random sequential series, as a result of this multiplication, candidates $\text{X}^{(1)}, \text{X}^{(2)}, \dots, \text{X}^{(\text{U})}$ are IFFT converted and the one with the lowest PAPR is selected. The multiplying series can be referred as a side information to allow the receiver to recover the source data [10].

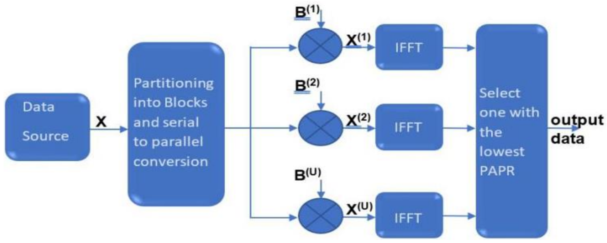

Fig.1. Block diagram of SML technique

A. SLM random rotational phase sequence

In SLM with random rotational phase, random data of complex value are considered to be source data, which are converted into symbols using signal modulation techniques. These symbols are converted in a series to parallel (S/P) arrangement in such a way that they are divided into several data blocks. Data blocks have N data symbols that correspond to the N sub-carriers of the modulated OFDM signal from transmitter. They represent N symbols of complex values after being mapped by different digital modulation schemes and converted into that (S/P) arrangement [11].

The complex vector of OFDM source data block $\text{X}_n = [x_0, x_1, x_2, \dots\dots, x_{\text{N}-1}]^{\text{T}}$ is multiplied element by element with U random phase sequences vector $\text{B}^{(\text{U})} = [\text{B}^{(\text{u})}{}_0, \text{B}^{(\text{u})}{}_1, \text{B}^{(\text{u})}{}_2, \dots\dots, \text{B}^{(\text{u})}{}_{\text{N}-1}]^{\text{T}}$, where u = 1,2,3.........U. Phase sequences are vectors generated and chosen randomly from a set of values $[\pm 1, \pm \text{j}]$ [5]. In this approach U is considered as being a random phase rotation of OFDM source data blocks as it follows:

$$\text{X}^1{}_n = [x_0 * \text{B}^{(\text{u})}{}_0, x_1 * \text{B}^{(\text{u})}{}_1, \dots\dots, x_{\text{N}-1} * \text{B}^{(\text{u})}{}_{\text{N}-1}]^{\text{T}} \qquad (6)$$

After obtaining the output signals, IFFT is applied, and then the candidate with the lowest PAPR is selected and then transmitted on the receiver. This method helps to reduce PAPR efficiently without having to insert distortions in the signals, but increases the computational complexity of the system. SLM becomes more efficient in reducing PAPR as we increase the number of U rotating sub-blocks sequences. One way to improve the computational complexity and system overhead is to implement fewer IFFT conversions.

IV. SIMULATION AND RESULTS

For this project, we analyzed the SLM method through several random phase sequences and different number of sub-carriers. In the simulation, the parameters were established as shown below:

-number of Sub-carriers: N = 64;
-mapping method: QAM-16;
-number of U phase sequence blocks:2,4,8,16;
-IFFT size: 64;
-PAPR value form original signal: 6.9 dB;
-minimum PAPR value with SLM:4.8 dB.

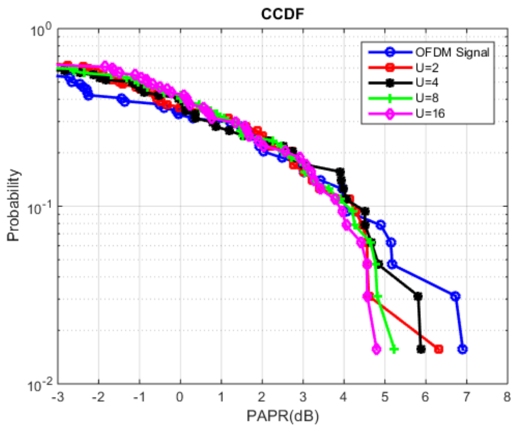

Fig. 2. CCDF's of PAPR in original signal, SLM technique with U = 2,4,8,16 sub-blocks (N = 64, Mapping method QAM-16 modulation)

Matlab simulation results reported in table 1 that the transmission system achieved an efficient PAPR reduction from the original communication signal. In table 1, the comparison between the PAPR of the OFDM original signal and the PAPR of the signal implementing the SLM-RRPS technique is shown.

TABLE 1. SIMULATION RESULTS FOR THE INVESTIGATED METHOD WITH SUB-BLOCKS 2,4,8,16 AND N = 64

PAPR (dB)				
OFDM signal without SLM	SLM U Phase rotation			
6.9	6.31	5.87	5.23	4.8
	U=2	U=4	U=8	U=16

In figure 2 we can compare PAPR value from the source signal with the PAPRs of the different rotation phase sequences of the SLM technique. Reduction in PAPR system is better as the rotation phase sequences blocks increase. Consequently, the CCDF of U = 16 shows the best result. Comparing the source OFDM signal with the product of that processed signal with the U = 16 phase sequence block, PAPR can be reduced up to 2.1 dB in the probability of $10^{-1.9}$.

A second simulation was performed. In figure 3, an increase of 2 times the values of the U sub-blocks of the phase sequence rotation from the first simulation was considered. In this case, U = 4, 8, 16, 32, in addition, a new random digital data signal was generated using the same modulation format. The Parameters in the second simulation were established as follows:

-number of Sub-carriers: N = 64;
-mapping method: QAM-16;
-number of U phase sequence blocks:4,8,16,32;
-IFFT size: 64;
-PAPR value form original signal: 8.88 dB;
-minimum PAPR value with SLM:4.45 dB.

In table 2 we can see that once again the simulation shows the efficiency in PAPR reduction from the source OFDM signal, in comparison with the same signal when the SLM method with rotation phase sequence is applied.

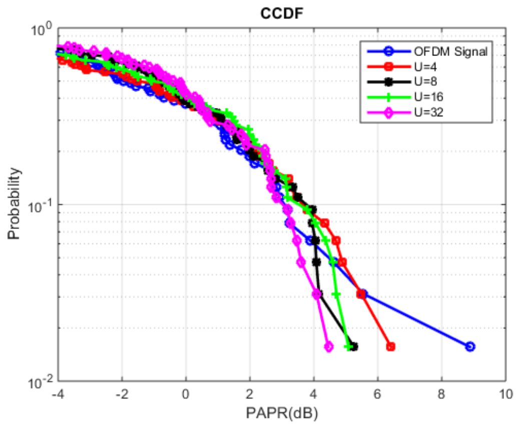

Fig. 3. CCDF's of PAPR in original signal, SLM technique with U = 4,8,16,32 sub-blocks (N = 64, Mapping method QAM-16 modulation)

TABLE 2. SIMULATION RESULTS FOR THE INVESTIGATED METHOD WITH SUB-BLOCKS 4, 8, 16, 32 AND N = 64

PAPR (dB)				
OFDM signal without SLM	SLM U Phase rotation			
8.88	6.42	5.25	5.09	4.45
	U=4	U=8	U=16	U=32

From figure 3 we can notice that as we increase the values of U sub-blocks, system PAPR values are better. The CCDF of the U larger block sequence CCDF shows the best result. Comparing source signal with the signal having already been treated with a higher value of phase sequence SLM, PAPR was reduced to 4.43 dB in the probability of $10^{-1.9}$.

A third simulation was performed, in which an increase in the number of N sub-carriers was considered:

-number of Sub-carriers: N = 128;
-mapping method: QAM-16;
-number of U phase sequence blocks:2,4,8,16;
-IFFT size: 128;
-PAPR value form original signal: 7.85 dB;
-minimum PAPR value with SLM: 5.72 dB.

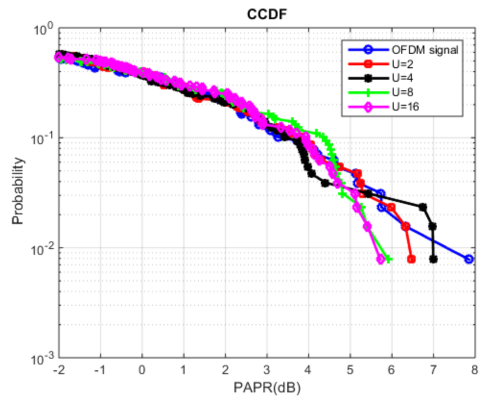

Fig. 4. CCDF's of PAPR in original signal, SLM technique with U = 2,4,8,16 sub-blocks (N = 128, Mapping method QAM-16 modulation)

In this third simulation we can see that we have increased the number of sub-carriers. This was possibly the cause of the slight PAPR increase in the second U sub-block of rotational random phases. However, from table 3, we can see that in the third and fourth U blocks, the system was stabilized, reducing the PAPR by 2.13 dB with respect to the original OFDM signal.

We can also see in figure 4 that in the last two sub-blocks, the CCDF showed an improvement. Nevertheless, this improvement is not very significant between the third and fourth blocks, which can cause greater system complexity as IFFT between U sub-blocks increases.

TABLE 3. SIMULATION RESULTS FOR THE INVESTIGATED METHOD WITH SUB-BLOCKS 2, 4, 8, 16 AND N = 128

PAPR (dB)				
OFDM signal without SLM	SLM U Phase rotation			
7.85	6.48	6.99	5.91	5.72
	U=2	U=4	U=8	U=16

A fourth simulation was implemented in which the number of sub-carriers remained fixed, but the U sub-blocks of random phase sequences were increased twice. We can see in table 4 that increasing the number of U sub-blocks of phase sequences generated a greater PAPR reduction of the source signal, however this increase is not so significant when compared to the third simulation.

We can notice from figure 5 that effectively by increasing the number of rotational phase sequences, CCDF in the probability of $10^{-2.1}$ provides a better PAPR than that from source OFDM signal.

-number of Sub-carriers: N=128;
-mapping method: QAM-16;
-number of U phase sequence blocks:4,8,16,32;
-IFFT size: 128;
-PAPR value form original signal: 7.85 dB;
-minimum PAPR value with SLM:5.52 dB.

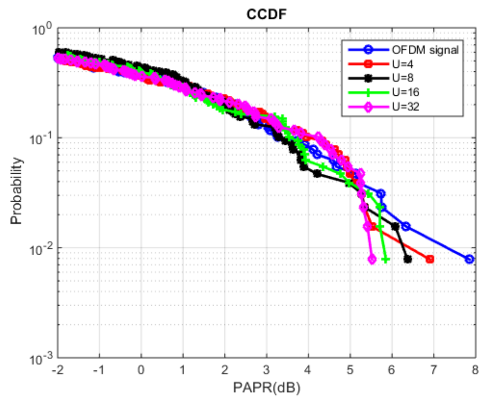

Fig. 5. CCDF's of PAPR in original signal, SML technique with U = 4,8,16,32 sub-blocks (N = 128, Mapping method QAM-16 modulation)

Comparing simulations three and four, we can see that increasing the number of U sub-blocks of rotational phase sequences twice, when increasing the number of sub-carriers, does not necessarily lead to significant reductions from the original signal PAPR, but it can lead to increases in the complexity and overload of the system.

TABLE 4. SIMULATION RESULTS FOR THE INVESTIGATED METHOD WITH SUB-BLOCKS 4, 8, 16, 32 AND N = 128

PAPR (dB)				
OFDM signal without SLM	SLM U Phase rotation			
7.85	6.92	6.37	5.85	5.52
	U=4	U=8	U=16	U=32

V. CONCLUSIONS

We studied the behavior and effects of SLM with random rotational phase sequences to reduce PAPR from an OFDM signal. Through a series of computer simulations, we showed that SLM is an efficient technique in reducing the PAPR of an OFDM communication system. Yet, there should be a trade-off between the number of sequences of random rotational phases and the complexity of OFDM that allows the optimal improvement in the PAPR reduction.

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