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ORIGINAL ARTICLES

A Novel Way to Enhance the PAPR of OFDM Systems

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ABSTRACT

Many authors addressed the problem of PAPR reduction of OFDM. These works were either increase the complexity of the system or reduce the bit rate or reduce the number of subcarriers to use the others for side information. In this paper, a suggested technique called Amplitude Phase Grouping has been introduced. This technique modifies the amplitude and or the phase of the signal. The simulation results showed that the PAPR can be reduced to an acceptable value with low complexity. The BER was the cost for this achievement at the same time, the side information were eliminated completely.

Key words: OFDM, PAPR, SLM

Introduction

The OFDM system has been applied in many wireless systems such as the IEEE 802.16d/e and others as in T. Hwang *et al*., 2009. The OFDM system suffers from the high Peak to Average Power ratio (PAPR). Without reducing this ratio, the system needs to be expensive with big size. To resolve this problem, many techniques have been introduced such as the Selected Mapping (SLM), Partial Transmit Sequences (PTS), Amplitude Clipping (AC), coding and others (S. H. Han and J. Lee, 2005). These techniques are either need high power, or increased complexity as in SLM method or increases the BER such as the AC-method.

In our previous work Taher *et al*., 2011 we succeeded to transmit the OFDM symbols without side information with low PAPR and less complexity compared to SLM- techniques. Two more developments will be executed to Taher *et al*., 2011. Different authors worked to make the system blind such as Kojima *et al*., 2010, it puts a method to send the side information blindly but still needs high complexity.

Background:

OFDM symbol can be described as T. Hwang *et al*., 2009

$$x(k)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}X(n)e^{j2\pi\frac{kn}{N}},\quad k=0,1,...,N-1 \qquad (1)$$

In Eq. (1); N represents the number of sub channels and the data samples are represented by X(n). The OFDM symbol generated in Eq. (1) suffers from the high PAPR which can be computed from,

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

Where E (•) the expectation operator. The events of PAPR occurrences can be carefully captured if the OFDM symbol in Eq. (1) oversampled by 4. Using this oversampled version of the OFDM signal we can find the PAPR distribution through the Cumulative Complementary Distribution Function (CCDF),

$$CCDF\left(PAPR_o\right)=\Pr\left(PAPR_o>PAPR\right) \qquad (3)$$

Where PAPRo is the clipping level.

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Suggested Algorithms:

The probability of constructive adding the samples after the IFFT process should be changed to reduce the events of high PAPR. To do so, we have suggested algorithms to modify either the phases, or the amplitudes, or both of the samples vector without reserve any subcarrier for side information because the Amplitude Phase Grouping (APG) algorithm didn't need side information to overcome this problem, besides the low complexity for whole the system. Here is the technique as follows: Given the samples vector, X', the first step to be accomplished to this vector is a cascade of two IFFT processes,

$$X' = \left[X'_1 \; X'_2 \; \ldots \; X'_N\right] \tag{4a}$$

From which,

$$X = IFFT\left(IFFT\left(X'\right)\right) \tag{4b}$$

Reshaping Eq. (4b) to X (k, R) where k × R = N,

$$X(k,R) = \begin{bmatrix} X_{1,1} & X_{1,2} & \ldots & X_{1,R} \\ X_{2,1} & X_{2,2} & \ldots & X_{2,R} \\ | & & & | \\ X_{k,1} & X_{k,2} & & X_{k,R} \end{bmatrix} \tag{5}$$

Eq. (5) can be written in polar and rectangular formats,

$$X_{Polar} = \left|X(k,R)\right| \angle X(k,R) \tag{6}$$

$$X_{Rctngl} = \mathrm{Re}\left[X(k,R)\right] + j\,\mathrm{Im}\left[X(k,R)\right] \tag{7}$$

The suggested technique is:

$$X_m = \begin{bmatrix} X_{1,1} & \left(X_{1,1} + X_{1,2}\right) & \ldots & \sum_{j=2}^{R} X_{1,j-2} \\ X_{2,1} & \left(X_{2,1} + X_{2,2}\right) & \ldots & \sum_{j=2}^{R} X_{2,j-2} \\ | & & & | \\ X_{k,1} & \left(X_{k,1} + X_{k,2}\right) & & \sum_{j=2}^{R} X_{k,j-2} \end{bmatrix} \tag{8}$$

Where, $X_{1,1}$, $X_{2,1}$, … $X_{k,1}$ are the unmodified elements. So, using the polar form in Eq. (6), there will be two sub-matrices, magnitude and phase matrices. According to Eq. (8), the first element in the magnitude matrix, $X_{1,1}$, will take the original value, the second element, $X_{1,2}$, is the sum of the first and second elements and so on. The same procedure will be done for the phase matrix. This is the APG1-algorithm.

For the APG2-algorithm, the previous procedure will be done using Eq. (7); hence, there are two matrices, the first is the real and the other is the imaginary matrices. The APG3-method, is the modified version of APG1 where only the phase matrix will be modified (cumulatively adding the elements). It can be other matrices to be modified but we did not get better results. After reshaping the produced matrices, it will go to the other parts of the OFDM system's parts. At the receiver, the reverse of the above procedure will be implemented. The complexity has been reduced dramatically without side information as will be presented in the next section.

Complexity Analysis:

Consider an OFDM system of N-subcarriers using SLM method of U phase rotation vectors. This system needs high number of multiplication operations as,

$$Mul_{SLM} = U \times N\left(1 + \frac{1}{2}\log_2 N\right) \tag{9a}$$

And addition operations are,

$$Add_{SLM} = U \times N \log_2 N \tag{9b}$$

While bits for side information are,

$$N_{si} = \log_2 U \tag{9c}$$

In contrast to APG algorithms, N_{si} are eliminated completely. For APG1-method there are 3–IFFT blocks, so that, the number of multiplications has been reduced to,

$$Mul_{APG1} = \frac{3N}{2}\log_2 N \tag{10a}$$

In APG1, the number of additions can be calculated using Eq. (10b). In this equation, there are $2R\ (k - 1)$ operations of addition. Still there are other addition operations, it is the three blocks of the IFFT operation, so that, the overall number of addition operations will be,

$$Add_{APG1} = 2R(k-1) + 3N\log_2 N \tag{10b}$$

Regarding the APG2-method, equations (10a–10b) still used, while for the APG3, they are not, because of the modification achieved only for one matrix of APG1- matrices, so that, the addition processes reduced to,

$$Add_{APG3} = R(k-1) + 3N\log_2 N \tag{24c}$$

From the above analysis, it is seen that our algorithm reduces the whole complexity of the system compared to SLM-method as well as the side information has been eliminated also.

Simulations and Results:

The simulation environment was 16–QAM, 256 subcarriers, U =4 phase rotation vectors (for SLM), and 10^5 OFDM symbols. Fig. (1) presents the CCDF values for each of APG(1-3), SLM, and original OFDM based systems. The original system gives around 12.8 dB. The SLM reduced the value to 9.8 dB, for the APG1 and APG2; it has been reduced to 7.8 dB and 8.5 dB respectively, while for APG3 it was reduced down to 5.8 dB. It is seen that APG1 is better than APG2 but at the expense of BER as will be seen later. APG3 as shown is better than all others with lower complexity where total number of multiplications for SLM and APG's methods are 5120, and 3072 respectively and the number of addition operations were 8192, 6528, and 6336 for the SLM, APG1, 2, and APG3 respectively as depicted in Table I. so, there are 66.7% reduction in the number of multiplication operations for APG's methods, while 25.5% and 29.3% reduction in numbers of addition operations for APG1,2, and APG3 respectively. Table II gives the maximum and minimum values of the PAPR for all cases. It is shown that the maximum values for all APG's methods are lower than the minimum value of the SLM-technique. Regarding APG3, it gives max PAPR = 3.8 dB while its min PAPR = 1.9 dB.

The BER performance of the OFDM based SLM method is distortion less, so that, the BER did not affected in our simulations. The APG-algorithm has some effects on the BER performance. It needs a little bit more power to overcome the problem. This extra power can be considered as the cost of the achieved gain in the PAPR reduction performance. Fig. (2) presents the BER performance of APG1, APG2, and APG3 based algorithms compared to the original system. From Fig. (2), it can be seen that APG1, and 3 need more power, while APG2 needs less power. So, there are some dB's were paid as a penalty for the gain of the PAPR reduction.

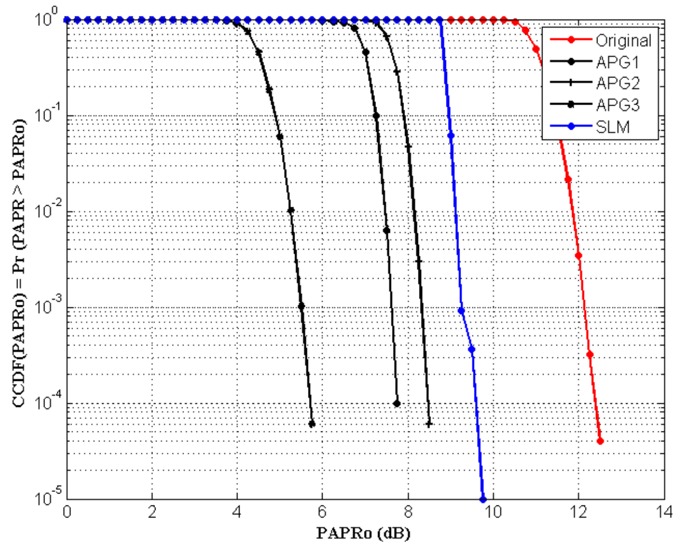

Fig. 1: PAPR comparison of Original OFDM and APG (1, 2, and 3) & SLM methods.

Table I: Computational complexity and side information comparison.

Method	# Mul.	Reduction %	# Add.	Reduction %	SI
SLM	5120	N/A	8192	N/A	2
APG1	3072	66.7	6528	25.5	0
APG2	3072	66.7	6528	25.5	0
APG3	3072	66.7	6336	29.3	0

Where,
Mul. : is the number of multiplication operations,
Add. : is the number of addition operations,
SI: number of bits for side information.

Table II: Max and Min captured values.

Method	Max (PAPR) dB	Min(PAPR) dB	# OFDM Symbols
Original OFDM	19.8	9.4	10^5
SLM-OFDM	13.9	7.7	10^5
APG1-OFDM	6.2	3.3	10^5
APG2-OFDM	7	3.2	10^5
APG3-OFDM	3.8	1.9	10^5

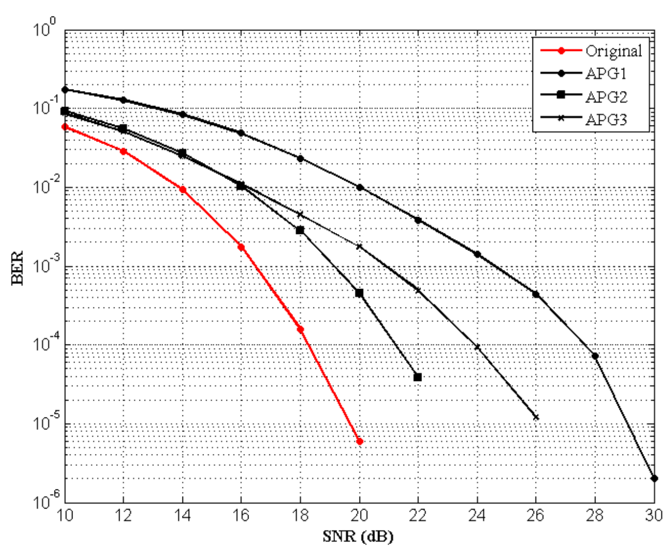

Fig. 2: BER comparison of Original OFDM and APG (1, 2, and 3) & SLM methods.

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Conclusion:

A novel algorithm has been introduced that doesn't need side information and reduces the PAPR significantly with out complexity as compared to the SLM-method. This technique divided to three sub-methods called APG1, APG2, and APG3. As stated in the previous section, the PAPR reduced very good but at the cost of BER, hence, our suggested technique (s) are not distortion less unlike the SLM which is distortion less. So that, some dB's of SNR has been paid as a cost for this gain in the PAPR and the computational complexity. It can be concluded that the best APG method is the APG2, because it needs little more power while the others needs more and although its computational complexity is more than APG3 but still less complexity than the SLM method.

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