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PAPR Reduction of OFDM Signal by Novel – PTS Using Recursive Phase Correlation Factor with Low Computational Complexity

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) uses as a high speed information transmission technology with excellent anti-interference capabilities. High Peak-to-Average Power Ratio (PAPR) of transmitted signal is one of the major drawbacks in Orthogonal Frequency Division Multiplexing (OFDM) systems. To overcome the drawback of high PAPR of transmitted signal we propose the novel based partial transmitted sequence scheme in OFDM. Partial Transmit Sequence (PTS) is one of the most attractive schemes to reduce PAPR in OFDM systems. In the conventional partial transmitted sequence the computational complexity increases with number of sub blocks. To reduce PAPR we propose Recursive Phase Correlation Factor (RPCF) with low complexity. Performance analysis shows that the proposed scheme offers a better PAPR reduction when compare with the conventional-PTS scheme.

Keywords:*Author Guide, Article, Camera-Ready Format, Paper Specifications, Paper Submission.*

1. Introduction

1.1 OFDM System

Orthogonal Frequency Division Multiplexing (OFDM) [1] is considered as a root technology for broadband mobile communications [2] due to its high spectral efficiency. OFDM can be easily implemented by the Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) process in digital domain and has the property of high-speed broadband transmission [3]. The channel bandwidth is divided into many channels so that in a multi-user environment each channel is allocated to a single user. However the difference lies in the fact that the carriers chosen in OFDM are much more closely spaced than in FDMA. The orthogonality principle [5] [10] [20] essentially implies that each carrier has a null at the centre frequency of each of the other carriers in the system while also maintaining an integer number of cycles over a symbol period. OFDM signal has high Peak to Average Power Ratio(PAPR) [5] because of the overlapping of multi-carrier signals with large number of sub- carriers. PAPR reduction is one of the most important research interests for the OFDM systems.

To transmit high PAPR signal without distortion requires more expensive power amplifier with high linear characteristics. OFDM has been adopted for various wireless communication systems [6][7][12] such as wireless local area networks (WLANs) wireless metropolitan area networks (WMANs) digital audio broadcasting (DAB) and digital video broadcasting (DVB).OFDM is a very attractive technique for achieving high data rate in the wireless communication systems.

1.2 PAPR formulation in OFDM Systems

In the discrete time domain, an OFDM signal x_n of N subcarriers can be expressed as in (1)

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}, 0 \le n \le N-1 \qquad (1)$$

where x_k; $k = 0, 1, \ldots, N-1$, are input symbols modulated by QAM and is the discrete time index [13]. The PAPR of an OFDM signal is defined as the ratio of the maximum to the average power of the signal, as given in (2)

$$\mathrm{PAPR}\,(x) = 10\log_{10}\frac{\max\limits_{0\le n\le N-1}\{|x_n|^2\}}{E\{|x|^2\}}\,(\mathrm{dB}) \qquad (2)$$

where E {.} denotes the expected value operation and $X = [X_0, X_1, \ldots, X_{N-1}]^T$.

It should be noted that the PAPR of a continuous-time OFDM [1] [20] signal cannot be precisely described by the use of N samples per signal period. Therefore, some of signal peaks may be missed and PAPR reduction performance estimates are unduly optimistic. To avoid this problem, the oversampling is usually employed, which can be obtained by LN – point IFFT of data sequence with $(L - 1)\,N$ zero-padding. It is shown in [10] [18] that an oversampling factor $L = 4$ is sufficient to approximate the real PAPR results.

Moreover, the distribution of PAPR bears stochastic characteristics in a practical OFDM system, usually being expressed in terms of Complementary Cumulative Distribution Function (CCDF) [3]. The CCDF can be also used to evaluate and compare the performance of any PAPR reduction schemes, and the CCDF of discrete-time PAPR is given in (3)

$$\begin{aligned}\mathrm{CCDF}\,(N, \mathrm{PAPR}_0) &= \Pr\{\mathrm{PAPR} > \mathrm{PAPR}_0\}\\ &= 1 - (1 - e^{-\mathrm{PAPR}0})^N \qquad (3)\end{aligned}$$

where N is the number of subcarriers in an OFDM system and PAPR_0 is a certain value of PAPR.

The rest of the paper is organized as follows. In section II, we discuss the existing techniques for PAPR reduction. In section III, the proposed system is discussed and section IV shows the simulation results supporting the ideas presented. Finally, the results are summarized in section V.

2. RELATED WORK

2.1 Partial Transmits Sequence (PTS)

In PTS, shown in Fig. 1, the input data sequence of an OFDM system with N subcarriers is firstly partitioned into V disjoint sub blocks X_i, i = 1,2, . . . , V, where all the subcarriers which are occupied by the other sub blocks are set to zero[9],[11]. The frequency domain input sequence is given as

$$X = \sum_{i=1}^{V} X_i \qquad (4)$$

By applying a phase weighting factor $b_i = \exp(j\varphi_i)$, $\varphi_i \in [0,2\pi]$ to the sub blocks $X_i = [X_{i,1}, X_{i,2}, \ldots, X_{i,N}]^T$, i = 1, 2, . . . , V, alternative frequency signal sequence is given as

$$X' = \sum_{i=1}^{V} b_i X_i \qquad (5)$$

After being transformed to time domain by IFFT, the time domain signal sequence becomes

$$x' = IFFT\left\{\sum_{i=1}^{V} b_i X_i\right\} = \sum_{i=1}^{V} b_i . IFFT\{X_i\} = \sum_{i=1}^{V} b_i x_i \quad (6)$$

where x' denotes the candidate sequence.

In the practical application of PTS, a set of phase weighting factors is usually selected for generating phase weighting sequences. Assume that there are W allowed phase weighting factors in this set. Without any loss of performance, we can set phase weighting factor for the first sub block to one and observe that there are $(V-1)$ sub blocks to be optimized.

For Optimal PTS (O-PTS), the optimum PAPR performance can be found after searching W^{V-1} alternative combinations if the number of sub blocks is V and the number of allowed phase weighting factors is W. In the process of phase weighting combination, large numbers of complex multiplications are needed, and the computational complexity is very large.

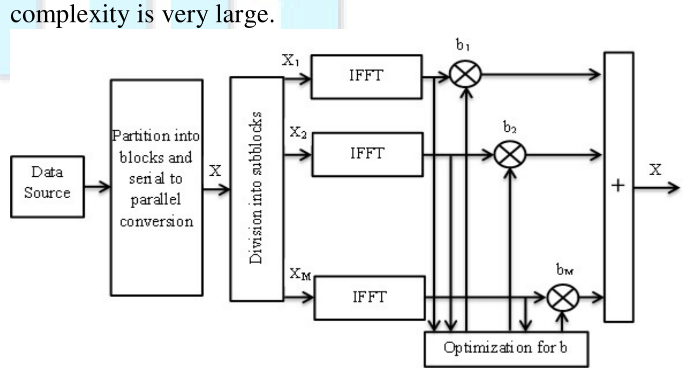

Fig. 1. Block diagram of PTS scheme.

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At the receiver, in order to recover the received signals successfully, the side information about phase weighting factors for PTS scheme is required. This information must be transmitted accompanying with the transmitted signal, and $[log_2 W^{V-1}]$ bits are required to represent this side information, where [.] rounds the elements to the nearest integers toward zero.

2.2 Selected Mapping (SLM)

In a Selected mapping (SLM) shown in Fig.2 [14] is a specific scheme for PAPR reduction. The SLM takes advantage of the fact that the PAPR of an OFDM signal is very sensitive to phase shifts in the frequency-domain data. PAPR reduction is achieved by multiplying independent phase sequences to the original data sequence and determining the PAPR of each phase sequence combination. The combination with the lowest PAPR is transmitted. In other words, the data sequence X is element-wise phased by *D N*-length phase sequences [15] [16].

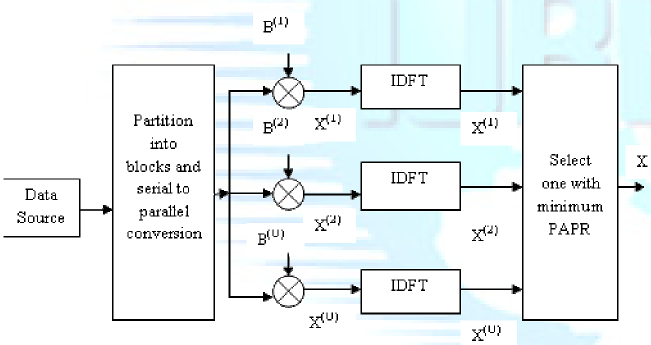

Fig. 2. Block diagram of SLM Scheme

PAPR reduction is achieved by multiplying independent phase sequences to the original data and determining the PAPR of each phase sequence combination. The combination with the lowest PAPR is transmitted.

3. PROPOSED SYSTEM

The block diagram of the proposed OFDM system with Recursive Phase Correlation Factor(RPCF) technique for PAPR reduction is shown in Fig 3. RPCF is designed with help of Correlation Phase Weighting Factor (CPWF) and Recursive Phase Weighting. The input data stream is generated from random source. Data is mapped on to Quadrature Amplitude Modulation (QAM) [3]-[8] constellation. These serially mapped symbols are converted into parallel, and then symbols are partitioned into sub blocks based on PTS [14]. Each sub-block is multiplied with phase sequence generated using RPCF technique.

After phase sequence multiplication the sequence which yields minimum PAPR will be selected and transmitted. In this model, Channel noise is assumed to be Gaussian. At the Receiver phase sequence recovery is done and signals are passed through FFT. Demapping of symbols is carried out to recover the original data. It is seen that this method greatly reduces the phase search complexity with comparable computational complexity [4].

3.1 Recursive Phase Correlation Factor

In this section, a novel PTS scheme is presented based on listing the phase factors into multiple subset stable and utilizing the correlation among phase factors in each subset, inorder to reduce the computational complexity [9]. There are W^{V-1} phase weighting sequences generated for obtaining candidate sequences. Consider all the phase weighting sequences, we can find the relationship between phase weighting sequences if the following conditions are satisfied:

i) The number of phase weighting factors *W* is even;
ii) The set of allowed phase weighting factors is
$$\{e^{j(2\pi k/W)}, k = 0,1,\ldots,W-1\}.$$
iii)Find the basis vectors of all phase weighting vectors and put them in the first row, note that only one element in the adjacent basis vectors is different.
iv) In each column, the phase weighting vectors have the same basis vector.
v) For the adjacent phase weighting vectors in the same column, only the sign of one element is different.
vi) The sign of the last phase weighting vectors in one column is the same as the first phase weighting vectors in the next column.[6]

For V>2, $x^{(0)}=x$, list the corresponding Table according to the Rules and let $B_1=\{1,1,\ldots,1\}$. Thereby, $x_{B1,1}$ is given by

$$x_{B1,1}=x^1+x^2+\ldots\ldots+x^V \qquad (4.1)$$

$$x_{B1,1}=b_{B1,1,1}\,x^1+ b_{B1,1,2}x^2+ b_{B1,1,3}\,x^3$$
$$=\mathrm{sgn}(b_{B1,1,1})\,x^1+\mathrm{sgn}(b_{B1,1,2})x^2+\mathrm{sgn}(b_{B1,1,3})x^3$$
(4.2)

In order to reduce the computational complexity, we make use of the rule 3 to calculate $x_{B1,2}$ from $x_{B1,1}$.

According to the Rule 3 $x_{B1,2}$ can be expressed as

$x_{B1,2}= b_{B1,2,1} x^1+ b_{B1,2,2}x^2+b_{B1,2,3}x^3$
$=sgn(b_{B1,2,1)} x^1+sgn(b_{B1,2,2})x^2+sgn(b_{B1,2,3})x^3$
$=x_{B1,1} -sgn(b_{B1,1,2}).2x^2$(4.3)

The $x_{B1,3}$ can be expressed as,

$x_{B1,3}=b_{B1,3,1} x^1+b_{B1,3,2}x^2+ b_{B1,3,3}x^3$
$=sgn(b_{B1,3,1)} x^1+sgn(b_{B1,3,2})x^2+sgn(b_{B1,3,3})x^3$
$=x_{B1,2} -sgn(b_{B1,2,3}).2x^3$(4.4)

The $x_{B1,4}$ can be expressed as,

$x_{B1,4}= b_{B1,4,1} x^1+b_{B1,4,2}x^2+ b_{B1,4,3}x^3$
$=sgn(b_{B1,4,1)} x^1+sgn(b_{B1,4,2})x^2+sgn(b_{B1,4,3})x^3$
$= x_{B1,3} -sgn(b_{B1,3,4}).2x^4$(4.5)

Similarly $x_{B1,i+1}$ is calculated as,

$x_{B1,i+1}= b_{B1, i+1 ,1} x^1+ b_{B1, i+1,2}x^2+ b_{B1, i+1,3}x^3$
$=sgn(b_{B1, i+1,1)} x^1+sgn(b_{B1, i+1,2})x^2+ sgn(b_{B1, i+1,3})x^3$
$= x_{B1, i} -sgn(b_{B1,i.m}).2x^m$(4.6)

The $x_{B2,i+1}$ is calculated as

$x_{B2,i+1}= b_{B2, i+1 ,1} x^1+ b_{B2, i+1,2}x^2+b_{B2, i+1,3}x^3$
$=sgn(b_{B2, i+1,1)} x^1+sgn(b_{B2, i+1,2})x^2+ sgn(b_{B2, i+1,3})x^3$
$= x_{B2, i} -sgn(b_{B2,i.m}).2x^m$(4.7)

The $x_{B3,i+1}$ is calculated as

$x_{B3,i+1}= b_{B3, i+1 ,1} x^1+ b_{B3, i+1,2}x^2+ b_{B3, i+1,3}x^3$
$=sgn(b_{B3, i+1,1)} x^1+sgn(b_{B3, i+1,2})x^2+ sgn(b_{B3, i+1,3})x^3$
$= x_{B3, i} -sgn(b_{B3,i.m}).2x^m$(4.8)

The $x_{B4,i+1}$ is calculated as

$x_{B4,i+1}= b_{B4, i+1 ,1} x^1+ b_{B4, i+1,2}x^2+ b_{B4, i+1,3}x^3$
$=sgn(b_{B4, i+1,1)} x^1+sgn(b_{B4, i+1,2})x^2+ sgn(b_{B4, i+1,3})x^3$
$= x_{B4, i} -sgn(b_{B4,i.m}).2x^m$(4.9)

From rule 6 we have,

$x_{B2,1}= b_{B2,1,1} x^1+ b_{B2,1,2}x^2+ b_{B2,1,3}x^3$
$=sgn(b_{B2,1,1)} x^1+sgn(b_{B2,1,2})x^2+sgn(b_{B2,1,3})x^3$
(4.10)

$x_{B2,2}= b_{B2,2,1} x^1+ b_{B2,2,2}x^2+ b_{B2,2,3}x^3$
$=sgn(b_{B2,2,1)} x^1+sgn(b_{B2,2,2})x^2+sgn(b_{B2,2,3})x^3$
$= x_{B2,1} -sgn(b_{B2,1,2}).2x^2$(4.11)

$x_{B2,3}= b_{B2,3,1} x^1+ b_{B2,3,2}x^2+ b_{B2,3,3}x^3$
$=sgn(b_{B2,3,1)} x^1+sgn(b_{B2,3,2})x^2+sgn(b_{B2,3,3})x^3$
$= x_{B2,2} -sgn(b_{B2,2,2}).2x^3$(4.12)

$x_{B2,4}= b_{B2,4,1} x^1+ b_{B2,4,2}x^2+ b_{B2,4,3}x^3$
$=sgn(b_{B2,4,1)} x^1+sgn(b_{B2,4,2})x^2+sgn(b_{B2,4,3})x^3$
$= x_{B2,3} -sgn(b_{B2,3,2}).2x^4$(4.13)

Similarly $x_{B3,1}$ is calculated as,

$x_{B3,1}= b_{B3,1,1} x^1+ b_{B3,1,2}x^2+ b_{B3,1,3}x^3$
$=sgn(b_{B3,1,1)} x^1+sgn(b_{B3,1,2})x^2+sgn(b_{B3,1,3})x^3$
(4.14)

$x_{B3,2}= b_{B3,2,1} x^1+ b_{B3,2,2}x^2+ b_{B3,2,3}x^3$
$=sgn(b_{B3,2,1)} x^1+sgn(b_{B3,2,2})x^2+sgn(b_{B3,2,3})x^3$
$= x_{B3,1} -sgn(b_{B3,1,2}).2x^2$ (4.15)

$x_{B3,3}= b_{B3,3,1} x^1+ b_{B3,3,2}x^2+ b_{B3,3,3}x^3$
$=sgn(b_{B3,3,1)} x^1+sgn(b_{B3,3,2})x^2+sgn(b_{B3,3,3})x^3$
$= x_{B3,2} -sgn(b_{B3,2,2}).2x^3$ (4.16)

$x_{B3,4}= b_{B3,4,1} x^1+ b_{B3,4,2}x^2+ b_{B3,4,3}x^3$
$=sgn(b_{B3,4,1)} x^1+sgn(b_{B3,4,2})x^2+sgn(b_{B3,4,3})x^3$
$= x_{B3,3} -sgn(b_{B3,3,2}).2x^4$ (4.17)

Table 1: Phase Weighting Sequences

	Phase weighting sequence		Phase weighting sequence
B_1	[1, 1, 1, 1]	B_5	[1, -1, -1, -1]
B_2	[1, 1, 1, -1]	B_6	[1, -1, -1, 1]
B_3	[1, 1, -1, 1]	B_7	[1, -1, 1, -1]
B_4	[1, 1, -1, -1]	B_8	[1, -1, 1, 1]

All the phase weighting factor sequences, identified by B_1, B_2,…… ,B_8, are shown in Table1[9].

4. SIMULATION RESULTS

To compare and evaluate the PAPR reduction performance, extensive simulations have been performed based on Recursive Phase Correlation Factor (RPCF) technique using MATLAB. In simulations, an OFDM system has been considered with N=8 and 16, oversampling factor L=4 and Quadrature Amplitude Modulation (QAM) is implemented. The simulation parameters used are given in Table 2. It is seen from the conventional schemes, highest PAPR results when all the bits in a data block are same and orthogonal [19]. It is proved from the results that PTS with RPCF works effectively gives reduced PAPR for all types of data blocks.

In the simulation we used 16-QAM baseband modulation scheme. Each modulated symbol is transmitted through N=16 sub carriers by 64-point IFFT and L=4 oversampling is employed to estimate PAPR precisely. To analyze PAPR reduction and power amplifier efficiency, we consider class A power amplifier which is the mostlinear with power efficiency.

Table 2: Simulation Parameters

Parameter	Specifications
Modulation	QAM
Number of data subcarriers M	8, 16
Number of FFT/IFFT points(N)	64
Number of data symbols	16
Over sampling factor	L=4
Bandwidth, BW	1 MHz
Sampling Frequency, (BW x L)	4 MHz
Number of Guard Interval Samples	32
Channel Model	Gaussian

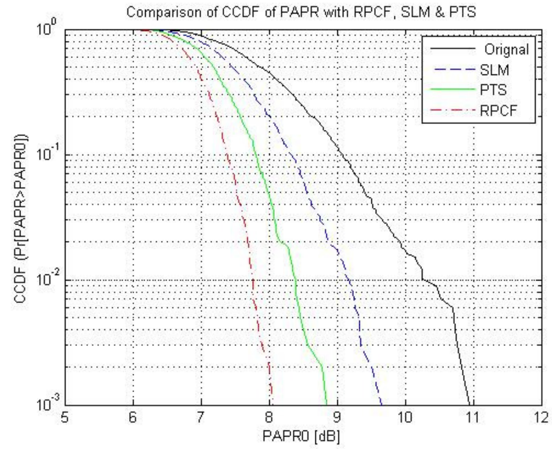

Fig. 3. Comparison of CCDF of PAPR with RPCF, SLM & PTS

Fig.3 shows theComparison of CCDF of PAPR in the RPCF technique with QAM Modulation scheme. It is easy to observe that at 0.0001% of CCDF the PAPR value for the SLM offers 1.3 dB reductions and PTS offers 2.1 dB reductions when compared with actual value of original data blocks. Our proposed technique based on RPCF is shown in this Fig 3. From this we found that RPCF performed better in reduction compared to other schemes it offers 2.9 dB reduction from the original values.

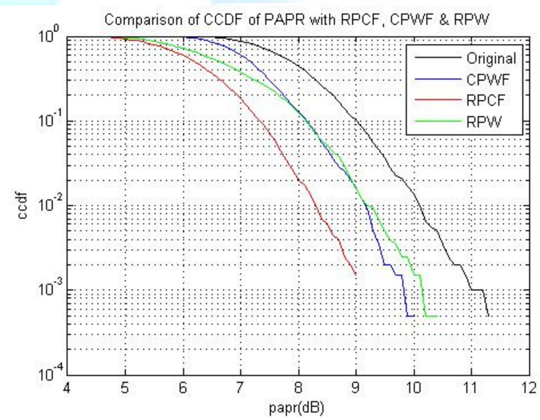

Fig. 4. Comparison of CCDF of PAPR with RPCF, CPWF & RPW

Fig.4 shows the Comparison of CCDF of PAPR in the RPCF technique with QAM Modulation scheme. It is easy to observe that at 0.0001% of CCDF the PAPR value for the CPWF offers 1.1 dB reductions and RPW offers 0.9 dB reductions when compared with actual value of original data blocks. Our proposed technique based on RPCF is also shown in this Fig 4. From this we found that RPCF performed better in reduction compared to other schemes also it offers 2 dB reduction from the original values.

5. CONCLUSION

The performance of OFDM transmission systems in relation to Peak to Average Power Ratio is evaluated using Recursive Phase Correlation Factor. Here we constructed, RPCF using Recursive Phase Weighting and Correlation Phase Weighting Factor. From the simulation results, it is seen that the proposed technique offers better PAPR reduction using RPCF with reduced phase search complexity when compared with conventional schemes such as SLM and PTS. Also the proposed technique does not require the side information to be sent to the receiver for recovery. Further the effect of Out of Band (OBO) distortion can be obtained for the proposed scheme to ensure its required BER performance.

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