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Peak-to-Average Power Ratio (PAPR) Reduction of OFDM Signals Using a Modified PTS Technique

Monika Phulia[1] and O.P. Sahu [2]

[1]Student, ECE Department, National Institute of Technology, Kurukshetra, Haryana
[2]ECE Department, National Institute of Technology, Kurukshetra, Haryana

Abstract

Orthogonal frequency division multiplexing (OFDM) has been emerging as a standard for various high data rate wireless communication systems due to several benefits, which are spectral bandwidth efficiency, robustness to frequency selective fading channels, etc. Yet one of the major drawbacks in OFDM is its high peak-to-average-power ratio (PAPR) of the transmitted signals, which even results in high out-of-band radiation and bit error rate performance degradation. In this paper, various PAPR reduction schemes has been discussed and, also a different phase factor combination which tend to achieve a lesser peak-to-average ratio compared to conventional PTS with a slight computational complexity is analyzed.

Keywords: OFDM, PAPR, HPA, CCDF.

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is an attractive multicarrier technique for high-bit-rate transmission nowadays. In OFDM, the data is transmitted simultaneously through multiple frequency bands so that the effects of multipath delay spread can be easily minimized. OFDM has been proposed for many radio systems such as high speed mobile communication, wireless LAN, digital audio as well as video broadcasting, and high-speed cellular data [1].

But the main disadvantage of this popular scheme i.e. OFDM is its high peak-to-average power ratio (PAPR) which means when N signals(with same phase) are added, they produces a peak power which is N times the average power. PAPR [2] causes distortion in the signal when it passes from a high power amplifier (HPA) resulting in a lower mean power level. For the reduction of PAPR value, various techniques have been proposed including clipping and filtering, selected mapping(SLM), partial transmit sequence(PTS), coding, companding, tone reservation, tone injection, etc.[2,3].

This paper discusses all the conventional PAPR reduction techniques described above. Section II describes the definition of OFDM and a brief description about PAPR. Section III describes different PAPR reduction techniques and section IV gives the analysis of the performance among various techniques. Section V describes the new modified technique with the simulation results and finally, Section VI gives the conclusion.

2. OFDM signals and PAPR

OFDM is a special case of multicarrier modulation technique in which the high bit stream is divided over several orthogonal subcarriers, each modulated at a lower rate. Subcarriers have minimum frequency separation that maintains orthogonality of their corresponding time domain waveforms. Hence, the available bandwidth (BW) is used very efficiently & effectively.

Peak-to-average power ratio (PAPR) is an important term used in OFDM systems. Basically, the definition describes PAPR as the ratio of peak power to the average power of the signal and it can be written as

$$\text{PAPR} = \frac{\max_{0\le n\le k-1}|x|^2}{E\,\{|x^2|\}} \tag{1}$$

where E{.} denotes expectation. In particular, a baseband OFDM signal with N subcarrier has

$$PAPR_{max} = 10\,log_{10}\,N\ \text{(dB)} \tag{2}$$

As a measure of performance, the complimentary cumulative distribution function (CCDF) is used for the PAPR reduction techniques which denotes the probability that the PAPR of a data block exceeds a given threshold z and is calculated by Monte Carlo Simulation [7] as,

$$\text{P(PAPR>z) = 1- P(PAPR}\le\text{z)} = 1-(1-\,e^{-z})^N \tag{3}$$

where the CCDF for an OFDM system having Rayleigh distribution is given as F(z) = 1- e^{-z}.

3. PAPR Reduction Techniques

In order to reduce the PAPR of an OFDM signal, many techniques are proposed. A brief detailed description of various techniques are as follows:

Clipping and Filtering: The clipping technique is the simplest PAPR reduction scheme, which limits the maximum of the transmit signal to a pre-specified level. And with filtering, out-of-band radiation can be reduced from the clipped signal. However, clipping [4,9,10] yields distortion power, which is called clipping noise, and expands the transmitted signal spectrum, which causes interfering. Since clipping is a non-linear process, it causes in-band noise distortion and degradation regarding system performance.

To avoid out-of-band noise, repeated clipping and filtering should be done. Fig.1 shows the block diagram of repeated C&F technique where filtering is done repeatedly so as to avoid peak re-growth of the OFDM signal.

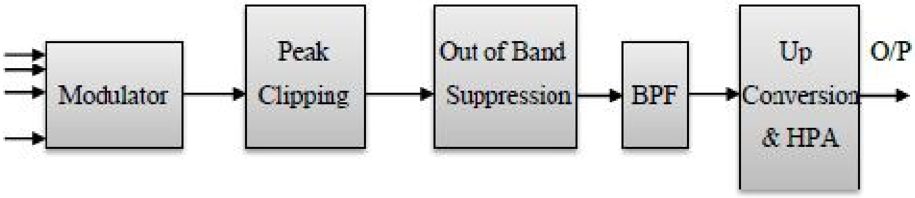


Fig. 1: Block diagram of repeated C&F technique [11]

Selective mapping: Selective mapping is considered as a promising technique for PAPR reduction[3,4] because it does not produce distortion yet maintain the system performance to a great extent.

In this scheme, data blocks are firstly converted into several independent blocks and the block with lower PAPR is sent, in which converting process involves multiplying data sequences to random phase sequences generated. The selected index is called side-information index which must also be transmitted to allow recovery of the data block at the receiver side. SLM leads to the reduction in data rate. In this method, main complexity occurs in recovering the side information.

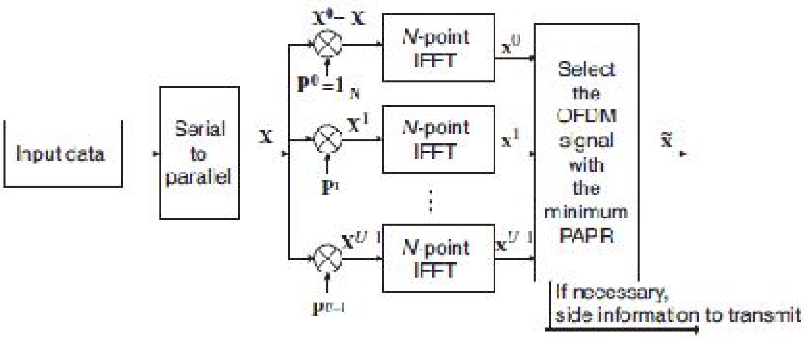


Fig.2: Shows block diagram of SLM technique[6]

In selected mapping method[5], firstly M statistically independent sequences which represent the same information are generated and next the resulting M statistically independent data blocks $\boldsymbol{S}_m=[S_{m,0},S_{m,1},\ldots,S_{m,N-1}]^T, m=1,2,\ldots,M$ are then forwarded into IFFT operation simultaneously. Finally, at the receiving end, OFDM symbols $x_m=[x_1,x_2\ldots,x_N]^T$ in discrete time-domain are acquired, and then the PAPR of these M vectors are calculated separately. Eventually, the sequences with the smallest PAPR will be elected for final serial transmission.

The key point of selected mapping (SLM) method lies in how to generate multiple OFDM signals when the information is same. Fig. 2 shows the detailed block diagram of SLM technique.

Partial transmit sequence: A block diagram of PTS technique[4] is shown in fig. 3 below.

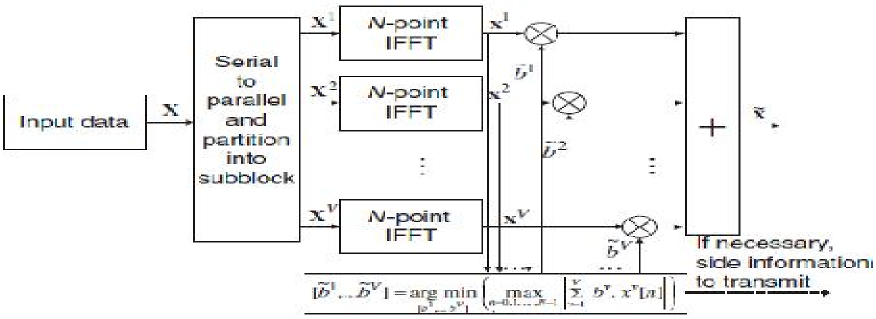


Fig. 3: Shows the block diagram of PTS technique[6]

The idea of partial transmit sequences (PTS) algorithm[5] is to divide the original OFDM sequence into several sub-sequences and for each sub-sequence, multiplied by different weights until an optimum value is chosen. In the PTS approach, the input data block is partitioned into V non overlapping subblocks X(v) which are combined to minimize the PAPR. Each carrier in the subblocks X(v) is multiplied with the same rotation factor b(v) = $e^{-j\varphi(v)}$. The time domain vector can be composed by the IFFT.

$$y = \text{IFFT}(Y) = \sum_{v=1}^{V} b(v)x(v) \quad (4)$$

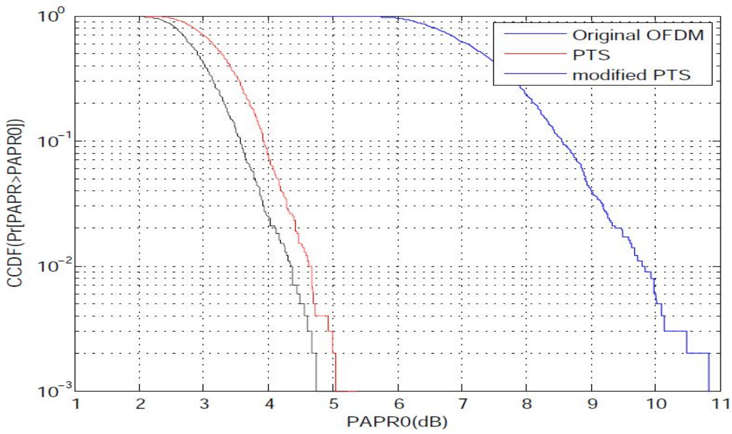
4. Analysis of Different Techniques

The PAPR reduction techniques must be chosen in accordance with the various system requirements, such that system should acquire better performance. Table 1: comparison of various PAPR reduction techniques.

Reduction technique	Distortion	Data loss	Complexity
Clipping & filtering	Yes	No	No
SLM	No	Yes	Yes
PTS	No	Yes	Yes

5. A Modified PTS Technique with the Simulation Results

In the modified PTS technique, analysis of various possible combinations of phase factors has been done. The possible phase factors in weighting optimization can be written as [1, -1, j, -j]. Depending upon the exhaustive search of these various factors, the signal with lesser PAP ratio is selected. The combinations made by these phase factors play a major role in the reduction of peak to average power ratio. It has been analyzed through MATLAB simulations that the factors having a minimum phase shift between contribute to the decreased PAPR rather than those having an increased phase shift. Instead of phase factors having 90 degree angle shifts, those with a lesser degree are supposed to give a high PAPR reduction as compared to conventional PTS technique.



The Fig. 4 shows simulation of PTS method and a modified PTS for OFDM systems.

Simulation results for N=64, L=4 and QPSK modulation scheme with 1000 OFDM symbols are plotted in the above figure.

6. Conclusion

Several techniques have been discussed and their comparision has been shown in the table 1. which gives gives a concrete idea about the functioning of different PAPR reduction techniques regarding various parameters with their advantages and disadvantages. In this paper, simulation of a modified PTS technique alongwith the conventional PTS technique has been shown. From the simulation results, it can be shown that the PAPR of modified PTS is slightly leser than the conventional PTS but it has a computational complexity.

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