Peak-to-Average Power Ratio (PAPR) Reduction Methods in OFDM Systems

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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. In spite of these favourable properties, 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. The reason is non-linear nature of high power amplifier. In this paper, a review of various PAPR reduction schemes has been done and, also the analysis of conventional techniques which tend to achieve the low computational complexity and provide better performance has been done. This paper discusses the advantages and limitations of important PAPR reduction schemes such as Clipping & Filtering, Partial Transmit Sequence, Selected Mapping, Coding, Tone Reservation, etc.**

Index Terms **– OFDM, PAPR, HPA, CCDF**

I. 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 simulation results and finally, Section VI gives the conclusion.

II. OFDM SIGNALS & 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. The block diagram of an OFDM system is described in fig. 1.

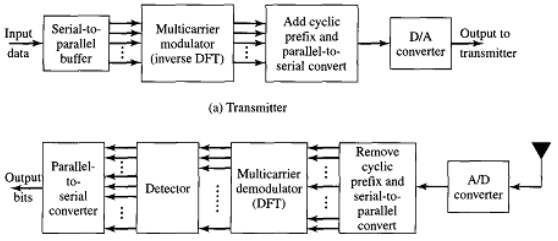

Fig. 1 shows block diagram of an OFDM system [8]

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

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

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

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

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,

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

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

III. PAPR REDUCTION TECHNIQUES

In order to reduce the PAPR of an OFDM signal, many techniques are proposed. Brief detailed descriptions 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.2 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.

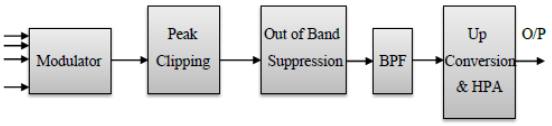

Fig.2. Block diagram of repeated C&F technique [11]

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.

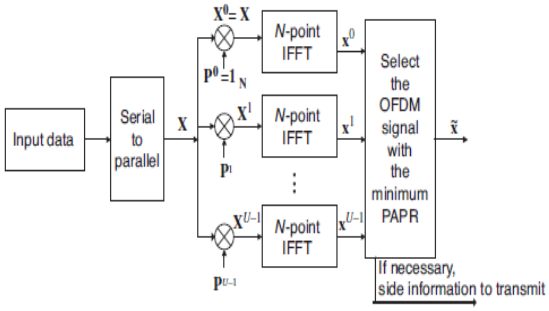

Fig.3 shows block diagram of SLM technique [6]

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 $\boldsymbol{S}m=[Sm,0,Sm,1,\ldots,Sm,N-1]T, m=1,2,\ldots,M$ are then forwarded into IFFT operation simultaneously. Finally, at the receiving end, OFDM symbols xm =[$x1,x2\ldots$,xN]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. 3 shows the detailed block diagram of SLM technique.

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

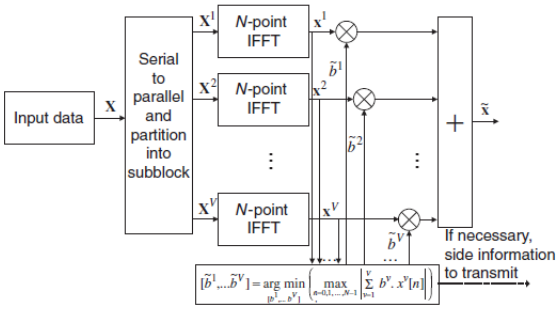

Fig. 4 shows the block diagram of PTS technique [6]

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.

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

Coding : Coding technique[4][12] proposes that the codes not only help to reduce PAPR but also has error correction capability. When forward correction codes are used to neglect the effect of distortion techniques, the OFDM is termed as COFDM to nullify the effect of signal degradation. A PAPR of the maximum 3dB for the 8-carrier OFDM system can be achieved by 3/4-code rate block coding. Various coding techniques are there such as Simple Odd Parity Code (SOBC), Cyclic Coding (CC), Simple Block Code (SBC), Complement Block Coding (CBC) and Modified Complement Block Coding (MCBC), Reed-Muller codes and Golay complementary codes.

Interleaving technique: This method is also called as Adaptive Symbol Selection Method[3][4][5]. In this technique as shown in fig. 5, multiple OFDM symbols are generated using interleaving bit-by-bit. The basic idea is to use many interleaving ways, say N and then selecting one with a lower PAPR. It is less complex than PTS but gives comparable results. Also, the PAPR reduction capability depends upon the number of interleavers used in the system.

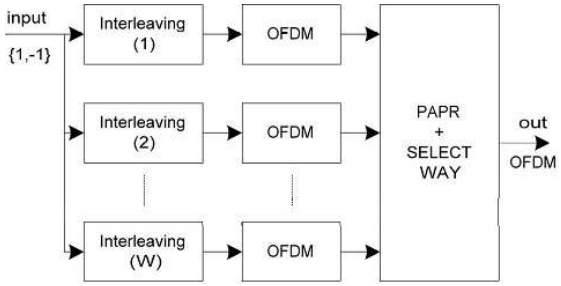

Fig. 5 shows block diagram of interleaving technique [3].

Tone reservation & Tone injection: Tone reservation method of PAPR reduction is very simple. In this scheme, a set of reserved tones are used which are added to the message signal in order to decrease the large peaks[3][4]. It is mandatory to have a small set of reserved tones for PAPR reduction. These tones bear no information and are orthogonal to one another. The amount of PAPR reduction depends on some factors including number of reserved tones, location of tones, power owned by tones, etc. Tone injection technique is based on general additive method for PAPR reduction which uses a set of constellation points to reduce PAPR and achieves PAPR reduction of multicarrier signal without any data rate loss. These techniques have some drawbacks also which tend to make it a little complex for functioning.[5]

IV. OVERALL 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
Coding	No	Yes	No
Interleaving	No	Yes	No
Tone reservation	No	No	No
Tone injection	No	No	No

V. SIMULATION OF OFDM SYSTEM WITH PTS TECHNIQUE

The simulation of an OFDM system with PTS technique has been done in fig. 6.

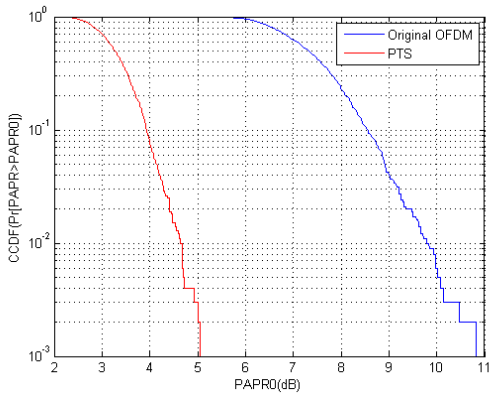

Fig. 6 shows simulation of PTS method for OFDM systems

Simulation results for N=128 and QAM modulation scheme are plotted in the above figure.

VI. 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 conventional PTS technique has been shown. From the simulation results, it can be shown that the PAPR of original signal is greater than that of signal incorporated with PTS .

From the final performance analysis of these techniques at the receiver, we can deduce that there is some BER degradation as compared to original OFDM. The reduction technique should be the one which efficiently decrease the PAPR along with without affecting much to the performance of the system. It must also possess a low implementation cost.

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