An Overview of Peak to Average Power Ratio Reduction Techniques

Gopal Krishan [#1], Dr.Amandeep Singh Sappal [*2]

1. [#] Research fellow, Punjabi University, Patiala (Pb)- India
2. *Assistant Professor, Punjabi University, Patiala(Pb)-India

Abstract *The PAPR plays a vital role in the OFDM communication system. To increase the efficiency the value of PAPR should be minimized. There are several techniques to reduce the value of PAPR but there is a trade off system efficiency, power consumption, BER and computational complexity. This paper discusses there techniques in terms of their application and limitations.*

Keywords *peak to average power ratio, OFDM, Signal distortion, scrambling*

I. Introduction

The Peak to Average Power Ratio as it is the major problem of OFDM signal at the transmitter side and same problem persists at the receiver side. There are various PAPR reduction techniques but broadly we have three different types of techniques: Signal Distortion Techniques, Signal Scrambling Techniques and Coding Techniques. It depends upon the system and the requirements on the basis of which the PAPR reduction techniques are used. Although these methods have various advantages and disadvantages which can be compensated by various alternatives. The PAPR can be reduced but it may increase the computational complexity or may reduce the system efficiency [1-3]. It may also lead to high power consumption and degrade the BER performance. Thus, there is a tradeoff between efficiency, power, complexity and BER. This chapter discusses these techniques in terms of their utility and advancement. The best technique depends upon the application and cost and complexity factors.

II. Signal Distortion Techniques

The signal distortion reduces the PAPR by providing nonlinear distortion which further reduce the amplitude of peak of the transmitted OFDM signal at or around the peaks. This technique can be further divided into following categories: clipping, peak windowing, and peak cancellation.

A. Clipping and Filtering

In this technique the signal is clipped at the peaks thus reduces the PAPR of an OFDM signal and then it is amplified. Thus this is simple and attractive technique in a way that the desired level of clipping can be done to minimize the PAPR. But this clipping technique is nonlinear in nature and it may cause high level of in-band distortion as well as out-of-band noise which may results into low BER performance and further reduces the spectral efficiency. This limitation overcomes the simplicity and attractiveness of this technique. The interference generated into in-band and out-of-band further affects the orthogonality of the OFDM signal. The orthogonality among the subcarriers is reduced significantly which reduces the performance. In the clipping method, the multiplication of rectangular window function and the OFDM signal results into one if the OFDM amplitude is under a fixed threshold and it is less than one if the amplitude is clipped. When the input OFDM spectrum is convolved with the spectrum of the window function it generates same spectrum as the clipped OFDM spectrum. The properties of out-of-band spectral canbe determined by the rectangular window function spectrum. This spectrum has a quite slow roll off which is inversely proportional to the frequency. Finally the filteration of the clipped signal reduce out-of-band noise but unable to reduce the peak. The signal may exceed the clipping level after filtering operation specified for the clipping operation [4].

B. Peak Windowing

The windowing of the high peaks is also a solution to high PAPR. In this technique we multiply large signal peaks with a particular non rectangular window [5]. The clipping technique also reduces the out-of-band distortion. Any better shaped window functions, such as Kaiser Window, the cosine window and Hamming windows can modify the signal to a better extent. The window function should be ideally a narrow window to reduce the out of band interference. Also, the window function should not be too long in time domain because it will indicate that many signal sample are affected, which further increases the BER. Fig.1 shows clipping technique in which large peaks are clipped with the use of windowing technique.

C. Peak Cancellation

The previous techniques have some limitations like the energy leakage of the apparent OFDM band. They also induce non-linear distortions and increases BER. Peak cancellation can reduce the peak power by a method in which it subtracts the peak delta-like bandlimited signal functions with the bandwidth of transmitted OFDM signal. In this technique, usually a sinc function is used because of its property of infinite time support and it is a bandlimited function.

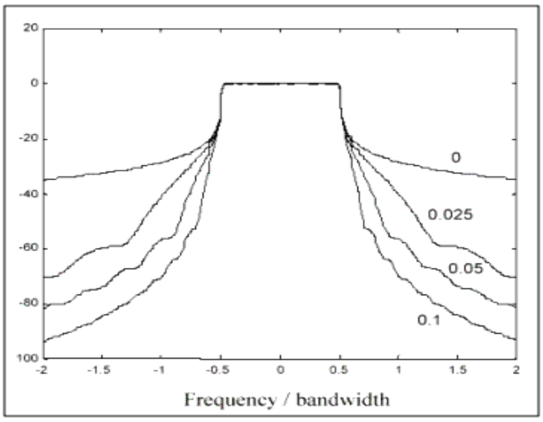

Fig. 1 OFDM signal with Clipping technique with window function[5].

We multiply sinc function by a time-limited raised cosine window and reduced version of this function one or more times to remove the peaks which are more than a fixed threshold to a desired maximum level. This technique has a advantage over other techniques that it generates minimum distortion as compared to peak windowing and clipping. A better performance can be achieved at the cost of half time delay i.e. the time taken by the peak-cancelling time-limited sinc function [6]. The time domain peak cancellations of signals envelop is compared with the normal OFDM symbols envelop and is shown in Fig. 2.

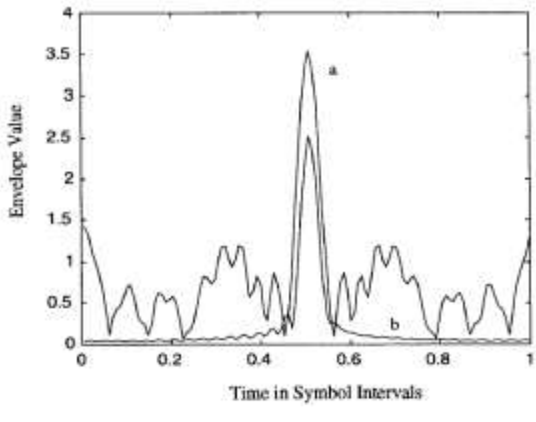

Fig. 2 (a) OFDM symbol envelope, (b) cancellation signal envelope [5].

III. SIGNAL SCRAMBLING TECHNIQUES

The basic principle of scrambling technique is to scramble the input data block. Thus one of the OFDM symbols generated after scrambling is further transmitting with the minimum PAPR such that the probability of high PAPR can be minimized. The PAPR is reduced by choosing proper symbol. That is, the output signal having the lowest PAPR is transmitted. There will be no correlation between OFDM signals and corresponding PAPR and it will be uncorrelated for the uncorrelated scrambling sequences. The out-of-band distortion is also reduced in this technique, but the drawback is that the spectral efficiency decreases and it also make the system more complex with the increases in number of subcarriers. Thus we can say that this symbol scrambling technique is not much efficient for getting a low PAPR but it reduces the chances of having high PAPR. The advantages are that this is very effective distortionless technique and works with random numbers of data signal constellations and subcarriers. Moreover, it does not induce distortion but requires the control channels to transmit the information of side. They also require more bandwidth. It further have two categories: Selected Mapping and partial Transmit Sequences. SLM generates a set of some alternative multicarrier signals, and then selects one of them with the lowest PAPR. Another method optimally combines the Partial Transmit Sequences (PTS) to generate low PAPR.

A. Selected Mapping

As defined above this approach have a set of few signals having similar information and out of those signals the signal with lowest PAPR is selected from OFDM signal [5]. In this technique, as the name suggests, the signals are partitioned into all possible signals of subsets and then a sample is picking up from each subset with the lowest PAPR. Thus, PAPR reduction is achieved by the multiplication of independent phase sequences with the original data and finally finding the PAPR of each combination of phase sequence-data. This technique is complex and has high number of iterations but it is efficient.

As shown in the Fig.3, Multiplication of U distinct, fixed vectors by an OFDM symbol in the frequency domain which results into vectors that are further transformed into time domain, and then analyzed. The last block in the Fig.3 shows the selection of the particular low PAPR signal that is finally transmitted.

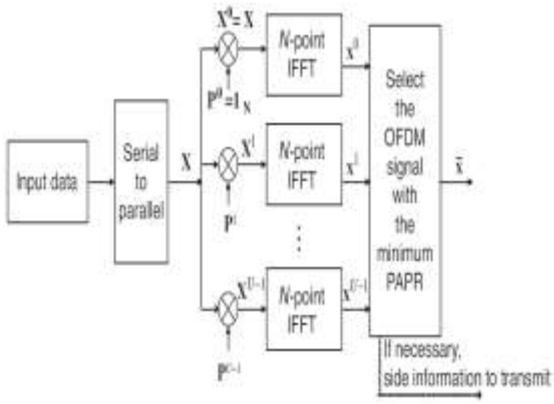

Fig. 3 Block diagram of selective mapping (SLM) technique for PAPR reduction [5].

In the Fig.3 the input data block can be expressed as $X = \{X^0, X^1, ..., X^{U-1}\}$

the U different phase vectors can be written as

$$P^{(u)} = \left\{P_0^{(u)}, P_1^{(u)}, ..., P_{n-1}^{(u)}\right\},\ u = (1, ..., U)$$

Both are then multiplied and produce the modified data block. Further, the IFFT of U modified independent codes are used to generate the output

$$x^u = \left\{x_{(0)}^u, x_{(1)}^u, ..., x_{(n-1)}^u,\right\}$$

Out of these the signal with the lowest PAPR is selected and transmitted. The receiver will be able to recover original data block if the information of the selected phase sequence $P^{(u)}$ is transmitted as side information. The number of operations used for the SLM technique implementation is U IFFT operations. And the side information can be given as $\lceil \log_2 U \rceil$ bits for each block of data [7].

The selected mapping is not upto the mark as it has high complexity and computational burden and a lot of IFFT stages and complex optimization procedure is also required. Thus to reduce the computational complexity, $P_i^{(u)}$ sequences should be chosen properly, but still there is requirement of a number of IFFTs. In order to recover the data at receiver, it is important to transmit side information (SI) of *u* of vector $P^{(u)}$ which is chosen to minimize the PAPR of a particular OFDM symbol. To protect the side information we can use a technique of the channel coding so that it should not be lost.

B. Partial Transmit Sequence

Another type of scrambling technique is PTS scheme in which the sequence is structurally modified. By rotation of phase independently to every subblock scrambling is implemented unlike the SLM technique which provides scrambling of data block to all subcarriers. The basic principle of this method is partitioning of OFDM symbol $X = \{X^0, X^1, ..., X^{V-1}\}$ to generate non-overlapping, random sub blocks of same size. Now these subblock are multiplied by a complex phase factor b^v subsequently and its IFFT is done to further generate a signal:

$$x = IFFT\left\{\sum_{v=1}^{V-1} b^v X^v\right\} = \sum_{v=1}^{V-1} b^v x^v$$

here $\{x^v\}$ is the partial transmit sequence (PTS).

A kind of optimization algorithm is used to reduce the PAPR which results into complex phase. So, by adding obtained PTS signals it could be finally generate a signal which represents all information of original OFDM symbol. The basic principle of rotation is applied to receiver side also, the demodulation of the information of the applied rotation parameters is required only then it could be recovered at receiver.

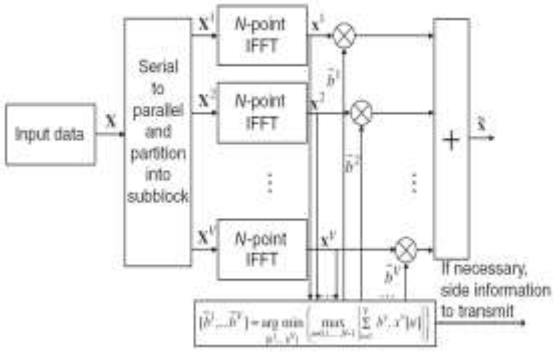

Fig. 4 Block diagram of partial transmit sequence (PTS) technique for PAPR reduction[5].

The number of the rotation and other information like its appropriate representation has to be transmitted to the receiver side. The PTS technique requires V number of IFFT operations for each block of data as shown in Fig.4 and side information of $\lceil \log_2 W^V \rceil$ bits [8]. The main factors which affect the performance of system to reduce the PAPR are the number of the allowed phase factors, W, and the number of subblocks, V and the subblock partitioning.

IV. Coding Technique

The other distortion techniques discussed so far has a main limitation of more degradation, and they are more prone to the errors. To reduce this effect various coding technique like FEC coding can be implemented across few OFDM symbols which results into the correction of the errors within symbols due to large degradation by the surrounding symbols. The basic principle of this method is to choose those code words that reduce or minimize the PAPR for transmitted signal. If we provide IFT (Inverse Fourier Transform) on certain sequences among all possible input sequences they generate in signals having reduced PAPR. It is very difficult to find such codes with a reduced PAPR and then to store them into a lookup table for the operation of encoding and decoding. One more disadvantage is that with the increase in the number of carriers the task become more difficult and exhaustive, the associated overhead and search of a best code would also increases exponentially. Also the data rate reduces to a low level, but due to its low BER, it is the most used technique for research purpose.

Thus this technique of coding needs an complex search to identify the best sequences, requires large look-up tables for encoding and decoding, and leaves the problem of error correction decision less. Once the required codes are constructed having low PAPR sequence then we will be able to develop codes having forward error correction capability with reduced PAPR levels. Thus we will be able to generate a highly efficient OFDM system [9]. Another suitable coding technique is GCS for OFDM transmission, but they do not have unexceptional essential structure to develop a practical coding scheme. It is also found that the specific part of the Golay complementary sequences generates a class of codes which have the property of reducing PAPR as well as it has good error correction capabilities. The achievable code rate reduces for increase in code length. Thus the length of codes could be taken small in order to maintain a suitable rate and to encode a bigger number of OFDM sub-channels.

The other coding techniques is second order Reed-Muller (RM) codes which was introduced by [9]can be used as it has the big sets of binary length Golay complementary pairs can be produced from certain second-order cosets of the typical first order RM code. The block codes having exceptionally efficient encoding and decoding method having very low error rate which can be combined with power control properties of the GCS.

V. CONCLUSION

The main point in selecting the PAPR reduction technique for a system under test is to make balance between the depth of PAPR reduction and other important factors such as decrease in throughput, BER degradation, increase in power consumption and high computational complexity. The study of various typical methods of PAPR reduction has been discussed in this chapter and all of these methods have some advantages and disadvantages.

The first technique is simple Clipping method which is used to reduce the high peaks but being a distortion type method it produces in band as well as out of band radiation. Thus this method is not much efficient and increases the probability of error and reduces the system performance. The system performance is negatively affected in peak cancellation by the reference signal subtraction. Filtering can remove the out-of-band radiation, but at the same time it induces peak regrowth. The second technique, SLM has high complexity and computational burden because of a lot of IFFT blocks and high complex optimization process. However, PTS technique generates additional complexity and a small reduction in the spectral efficiency because of the insertion of the side information within the channel. Thus, both of these techniques need more than one N-point IFFT for the appropriate analysis to produce the minimum PAPR sequence and transmission of side information.

The Coding technique is the more safe and efficient way of minimizing the PAPR. The generalized Reed-Muller codes and complementary Golay codes have a good PAPR reduction property and they can be also applicable for M-PSK OFDM systems. An excellent example of coding method is Golay codes which can minimize the PAPR up to a level of 3dB. Coding method reduces PAPR to higher level as well as it has the benefit of error correction associated with it. In this way, an efficient method of PAPR reduction is the block codes with their especially efficient encoding, decoding and low error rate which is combined with the power control properties of the GCS.

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