A STUDY OF PAPR REDUCTION TECHNIQUES IN OFDM SYSTEMS

[1]Jatinder Singh, [2] Dr. Charanjeet Singh
[1]Student, [2]Assistant Professor
[1]Electronics and Communication,
[1,2] Punjabi University Patiala, Punjab, India

Abstract : In communication OFDM is method of encoding digital data on multiple carrier frequencies .OFDM has been developed as a popular scheme for wideband digital communication. It has been adopted for the 4G cellular telecommunications standard like LTE / LTE-A, digital television, DSL internet access and in addition to this it has been adopted by other standards such as WiMAX and many more. OFDM is more resistant to frequency selective fading than single carrier systems and crosstalk between sub bands is eliminated so it does not requires inter carrier bands. Major downside of OFDM system is high PAPR ratio as compared to single carrier system which limits the performance of OFDM systems .PAPR can cause the transmitter's power amplifier to run within a non-linear operating region. This causes significant signal distortion at the output of the power amplifier. In addition, the high PAPR can cause saturation at the digital-to-analog converter (DAC), leading to saturation of the power amplifier. This paper present study of different PAPR reduction techniques and conclude an overall comparison of different techniques.

IndexTerms **-Orthogonal frequency division multiplexing (OFDM), Peak to average power ratio (PAPR), Selective Mapping (SLM), Bit Error Rate (BER), Digital Subscriber Line(DSL), Partial Transmit Sequence (PTS).**

1 INTRODUCTION TO OFDM

Orthogonal frequency division multiplexing (OFDM is one of the most widely used techniques for fourth generation (4G) wireless communication. It effectively tackles the multipath fading channel and improves the bandwidth efficiency. At the same time, it also increases system capacity so as to provide a reliable transmission of digital data [1] [2] [3].OFDM basically uses the principles of existing Frequency Division Multiplexing (FDM).The basic idea used in OFDM is to split a high data rate stream of digital signal into multiple number of lower data rate streams of digital data that are transmitted concurrently over a number of subcarriers. These subcarriers are overlapped and share common bandwidth. The relative amount of dispersion in time due to multipath delay spread is reduced as the symbol duration increases for lower rate concurrent subcarriers. Intersymbol interference (ISI) is reduced to almost zero by providing a guard time in every OFDM symbol. OFDM faces many challenges from which key challenges are-ISI due to multipath- combat by use of guard interval, large peak to average ratio(PAPR) due to non linearity of amplifier, Sensitivity to phase and frequency offset- to avoid phase and frequency offset errors fine tuning of sub-carriers is always required[4]. Large peak-to-average power (PAPR) ratio which causes the signal distortion when the transmitter contains components that are nonlinear such as power amplifiers. Due to nonlinearity of power amplifiers common adverse effects on the transmitted OFDM symbols are inter modulation distortion, spectral spreading, and changes in the signal constellation. We can say nonlinear distortion causes both in-band and out-of-band signal interferences. Therefore the Power amplifiers needed a back off which is almost equal to the PAPR for distortion-free transmission of data .This technique decreases the efficiency for amplifiers subsequently. Therefore reducing the PAPR of the signal before the signal is transmitted is of practical interest [2]. There are number of techniques available to reduce PAPR of the signal being transmitted to an adequate level but some extra computational complexity is added to the system [3]. Some methods are based on use of redundancy, such as coding, selective mapping with implicit or explicit side information, tone reservation. The main effect of using techniques based on redundancy for PAPR reduction is the decreased transmission rate. For PAPR reduction extended signal constellation techniques may be used, such as tone injection .The drawback associated with them is the implementation complexity increased power. In this work, we review all the PAPR reduction techniques used for OFDM.

2 PAPR in OFDM system

OFDM is basically a modulation technique which uses multiple-carrier signals. This multi-carrier signal share obtained from the summation of independent orthogonal sub-carriers. Therefore, multi-carrier signal envelope varies noticeably. Peak value to the average value of the signal is the measure of variation in the envelope of the resultant signal and it is called as peak-to-average power ratio (PAPR) of the signal. PAPR is the one of the biggest constraints of the OFDM system.

2.1 Introduction to PAPR

PAPR (Peak-to-Average Power Ratio) is one of main feature to analyze the system performances. An OFDM system which has N different sub-carriers used to transmit data symbols is given by [2]

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=o}^{N-1} X_n e^{j2\pi n \Delta f t}, \quad 0 \le t < NT$$

The analog OFDM signal is given by[2]

$$X = [X_0, X_1, ..., X_{N-1}]$$

Where spacing between sub-carriers is j = √−1, Δf is given for the transmitted signal and its PAPR is specified as[2]

$$PAPR = \frac{\max\limits_{0 \le t \le NT} |x(t))|^2}{\frac{1}{NT}\int_0^{NT} |x(t))|^2 \, dt}$$

Let us examine the OFDM signal padded with (L−1) N zeros by using the nyquist criteria to get the time domain signal. The times oversampled data can be represented as [2]

$$X = [x_0, x_1, x_2, ..x_{NL-1}]^T$$

These NL-1 samples of OFDM signal can be obtained from the inverse discrete Fourier transform (IDFT) is given by

$$x_k = x(\frac{k.T}{L}) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi k \frac{\Delta f n T}{L}}, \quad k = 0, 1, ...NL-1$$

Now, the PAPR of this L times over sampled signal is given by

$$PAPR = \frac{\max\limits_{0 \le k \le NL-1} |x_k|^2}{E[|x_k|^2]}$$

Where E[.] represents the expected response of the given signal [3].

2.2 Analysis of PAPR

The complementary cumulative distribution function (CCDF) can be used to analyze the performance of PAPR reduction techniques. CCDF gives the probability by which PAPR of OFDM symbol passes the given threshold value. For an amplitude sampled signal the cumulative distribution function is given by [2]

$$F(z) = 1 - exp(\gamma_0)$$

Now the CCDF of OFDM signal is given by

$$\begin{aligned} pr(PAPR > \gamma_0) &= 1 - pr(PAPR \le \gamma_0) \\ &= 1 - F(\gamma_0)^N \\ &= 1 - (1 - e^{\gamma_0})^N \end{aligned}$$

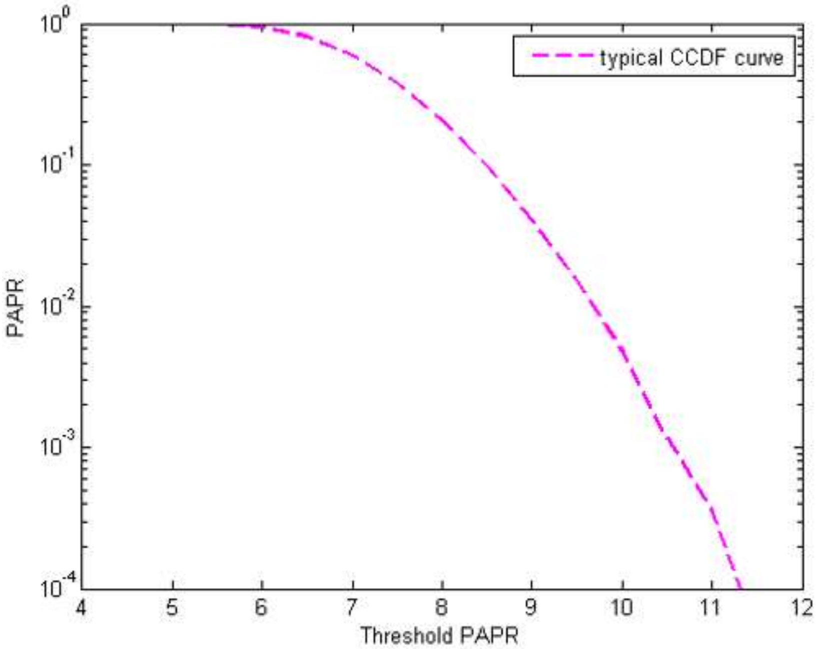

Figure 1 Typical CCDF Curve [2]

2.3 Problems due to PAPR in OFDM [2]

The problem of high PAPR becomes apparent due to summation of large number of sub-carriers in OFDM system. Here data symbols produce a high peak value signal across sub-carriers that are adding up [3].When in the OFDM system the difference between peak value to average value of signal is very large, the signal level goes outside the linear range of the power amplifier. When signal level goes outside the linear range of operation it results in saturation of amplifiers.

To prevent this, high input back-off is needed in amplifiers but that increases power requirement. When the amplifier move into saturation, it results in
• Out-of-band radiation
• Inter-carrier interference
These two effects increases the Bit Error Rate (BER) at the receiver and degrade the performance of the system[2].

3 PAPR reduction techniques

A large PAPR can push amplifiers at the transmitter into saturation it causes interference between the subcarriers that bring down BER performance. The average power of the signal may be reduced to avoid the cause that drives the power amplifiers into saturation.
However, this solution reduces the BER performance and at the same time reduces the signal-to-noise. Therefore, it is more suitable to reduce the peak power of the signal to solve the problem of high PAPR. PAPR reduction techniques can basically arranged into three main categories [5] [6]:

- 3.1. Signal distorsion techniques,
- 3.2. Multiple Signaling and Probabilistic Techniques
- 3.3. Coding techniques.

3.1 Signal Distortion Techniques

Signal distortion techniques reduce the PAPR before it passes through the power amplifier by distorting the transmitted OFDM signal. The well-known distortion techniques are as:

3.**1.1 Clipping and Filtering:** In this method the signal envelope is limited to a predetermined clipping level by use of a clipper , if the signal surpasses that level; otherwise the signal is passed without change through clipper, as defined by[7] [8]:

$$T(x[n]) = \begin{cases} x[n] & \text{if } |x[n] \le CL| \\ CLe^{\,j\angle x[n]} & \text{if } |x[n] > CL| \end{cases}$$

Where OFDM signal is given by x[n], the clipping level is given by CL and, $\angle x[n]$ is the angle of x[n]. Clipping give rise to both in-band and out-of-band distortions as it is a non-linear process. The out-of-band distortion leads to spectral spreading and that can be removed by filtering the signal after clipping but the in-band distortion cannot be reduced by filtering that degrade the

BER performance . However, by taking longer IFFT oversampling can reduce the in-band distortion effect, as portion of the noise outside of the signal band is reshaped that can be removed after that by filtering [7].

3.1.2 Peak Windowing: In this scheme if the high peak goes beyond a predetermined threshold level which is defined already, then it is multiplied by a weighting function known as window function. Cosine, Hamming, Hanning, Kaiser and Gaussian Windows are the most frequently used window functions. OFDM signal is multiplied with various windows and finally we got the spectrum which is a convolution of the spectrum of the applied window and the original OFDM spectrum[8]. So we require that the windows have to be as narrow as possible. PAPR can be reducing to 4db of each subcarrier by using this technique but the SNR is limited to 3db because of signal distortion. Peak windowing scheme do not use hard clipping and therefore, it gives satisfactory result as compared to clipping technique but still distortion is present cannot be removed completely[8].

3.1.3 Companding Transforms: This scheme basically used for audio signals. Companding employ compression and expansion. After companding, the higher peaks remain constant and lower peak values are increased so average power of OFDM signal is increased. Hence it reduces the peak to average power ratio [4]. Companding transform can be mainly classified into four categories: linear symmetrical transform (LST), linear asymmetrical transform (LAST), nonlinear symmetrical transform (NLST), nonlinear asymmetrical transform (NLAST)[10].

3.2.Multiple Signaling and Probabilistic Technique: This method either generate multiple versions of OFDM signal and then selects and transmit tone of the best or OFDM signal is modified by applying phase shifts, adding carrier for peak reduction or changing points of constellation. Basic techniques used under this category are as follows [6]:

3.2.1 Selective Mapping (SLM)[2][4][12-13]: Selective Mapping reduce PAPR in OFDM system by using Signal Scrambling technique. This technique does not effects the system performance in terms of Bit Error Rate that is its major advantage. The only disadvantage of this technique is its high complexity. In this technique the phase rotation of the modulated data is done prior to perform IFFT operation. After performing IFFT operation , the lowest PAPR signal is selected.

Let input data block be represented as[2]

$$X_S = [X_0, X_1, X_2 ... X_{N-1}]^T$$

And independent phase sequence is given by[2]

$$B^U = [B_0^U, B_1^U .....B_{N-1}^U]^T, U = (1,2....U)$$

Where phase sequence is given by B^U, U is the total number of Phase sequences and T denotes the length of input data block. After applying Phase rotation, IFFT is performed to get data block with different PAPR value and phase sequences.

$$X^U = [X_0^U, X_1^U, ...X_{N-1}^U]^T$$

After IFFT operation OFDM symbol generated is denoted by X^u. After this the symbol with lowest PAPR is selected for transmission. CCDF is used for analysis of PAPR.CCDF of PAPR in SLM given as [2]

$$P(PAPR > PAPR0) = (1-(1-e^{-PAPR0})^{\alpha.N})^U$$

Where oversampling factor is denoted by α, N is no. of sub-carrier, U is total no.of independent phase sequences.

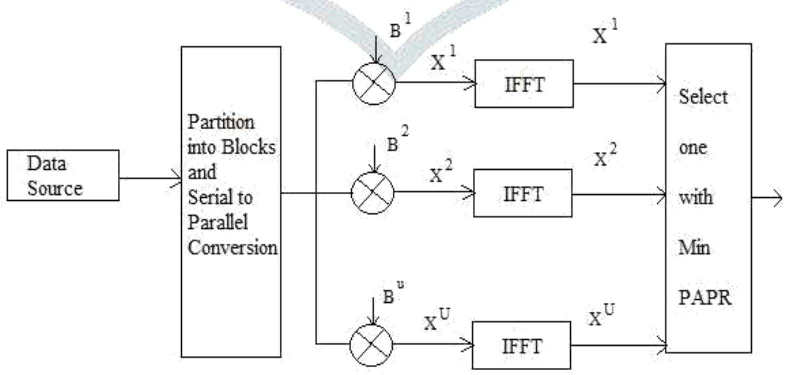

Figure 2 Block diagram of SLM technique [2]

3.2.2 Partial Transmit Sequence (PTS): In PTS, an input data block of length N is divided into a number of sub-blocks. Then sub-blocks generated are padded with zeros and weighted by a phase factor [2][12][16].

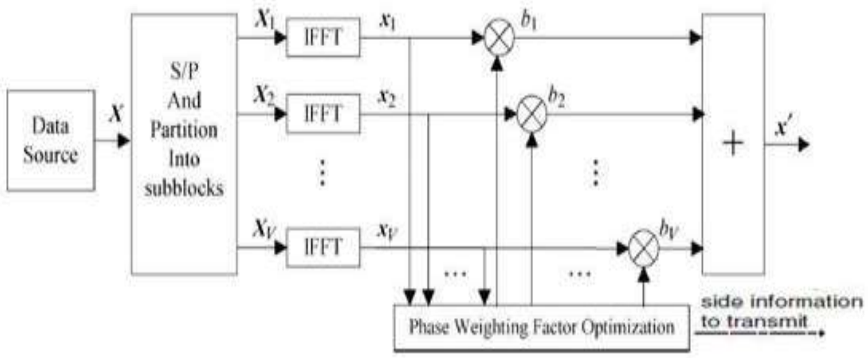

Figure 3 Block Diagram of PTS Technique [12]

The data block $X=[X_0,X_1,X_2,\ldots X_{N-1}]^T$ is divided in V separate sets,$\{X_v,v=1,2,..v\}$,using same number of carriers for each group, the different frequency domain signal sequence is denoted by[12]:

$$X' = \sum_{v=1}^{v} X_v b_v$$

Where $bv=e^{j\theta v}$and $\theta v=2\pi i/w$, i=0,1…..w-1 are the phase factors of domain x_v, IFFT of X_v is called partial transmit sequence. The phase factor is selected to get minimum PAPR of candidate signal[12].we have to search W^{V-1} possible combinations for V sub-blocks and W phase weights and first block phase factor is always chosen as 1.So V-1 additions and multiplication takes place to calculate each candidate signal. To reduce the complexity of PTS method various techniques are suggested in literature [14-16]. In a one given scheme it is suggested to updates the set of phase factors one by one until specified threshold limit of PAPR reached [15]. A simple flipping algorithm using multiple iterations is suggested to minimize the complexity of the PTS method in conjunction to a sub-optimal choice of the phase factors. A gradient descent search for phase factors is also proposed in which reduce search complexity but degrade the performance too [16]. Another improved PTS method in which listing the phase factors into multiple subsets table and to reduce computational complexity, utilize the correlation among phase factors in each subset.
Various algorithms are proposed uses partial transmit sequences with complexity reduction technique and marginal performance degradation.

3.2.3 Tone Injection (TI): This technique is based upon the constellation size expansion by such a way that each of the point in the original basic constellation effectively mapped into several identical points in the expanded size constellation. Since mapping a point from basic constellation to a point equivalent in expanded constellation is can be viewed as injection of a tone in the multicarrier signal of the selected frequency and phase ,based on this given technique is also called tone injection. As the each symbol in the data block can be mapped into one of the number of associated points in constellation, So this can be employed for PAPR reduction [17][18] .The extended constellation of constellation point in QPSK/4-QAM is shown in figure 4.

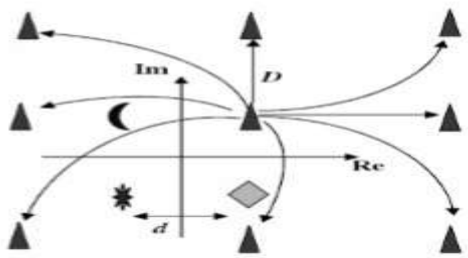

Figure 4 Extended Constellation in QPSK [17]

In Figure[4] d is distance between the constellation point, real and imaginary parts of the symbol Xn can be given by value $(\sqrt{M}-1).d/2$, where M denotes number of levels in M-QAM. Using Tone injection, these points could be extended to new points. D is distance between original and increased point So D is selected such that BER at the receiver remain unchanged. Usually the value of D is $p.\ d\ .\ \sqrt{M}$, where p>=1. D is an important parameter, and lower value of D causes poor BER due to closer constellation points and higher value of D increases the average power but BER will be low.[16]In literature suggestion about a tone injection technique with hexagonal constellation is given instead of QAM, more number of signal points can be spaced uniformly in hexagonal geometry in same given area as compared to QAM constellation and the average magnitude is less than average value, because of that it require less transmission power than QAM. To find optimum constellation and to find out the solution of large number of searches cross entropy method is used [18].

3.2.4 Tone Reservation (TR):A subset of tones having low SNR is reserved in this method for PAPR reduction. These tones added to the existing OFDM symbols so that the resulting symbol has lower PAPR. These tones carry no information data. The complexity of transmitter and required transmission power is increased by finding and optimized the set of peak reduction tones Various literature works are available focusing mainly on complexity reduction of optimization problem.[20] As suggested in truncated IDFT algorithm in which we calculates the maximal IDFT in place of calculating entire IDFT values ,thus reducing complexity of optimization process. The group is divided in in two halves of N/2 and leaving the half with lesser energy and going on similar way till we reach the element of maximum energy .The truncated IDFT scheme is not always give correct maximal energy IDFT element so it may cost in PAPR reduction performance.[21] Another scheme proposed in literature a gradient algorithm where the gradient of clipping noise mean square error is calculated and signal is optimized with respect to clipping noise ratio in place of PAPR and order of complexity is O(N).

Clipping noise is studied for designing the peak cancelling signal in [21] literature and to get desired peak cancellation signal several repetitions of clipping and filtering is used. [22]An adaptive-scaling algorithm and constant-scaling algorithm for tone reservation is proposed in literature [21]. There is a another method known as LSA-TR is proposed with fast convergence. This method is based on least square approximation and find the peak cancelling signal faster than clipping control TR method [20][21].

3.3 Coding Techniques: This technique is based upon selecting a code word which reduces the PAPR ratio of transmitted signal. A forward Error Correction code is given by value (n,k),n represents data bits and redundant bits are given by k, So in order to minimize PAPR value redundant bit are added. Forward Error Correction codes are divided in two categories, block codes and run length codes. Block code uses block of data bits together to encode whereas run length codes use dynamic memory and low value of n. Linear block codes, Golay complementary codes, Reed Mullar, low density parity check (LDPC) are few block codes which have been used for PAPR reduction. Turbo codes which are derived from convolution codes are also discussed in literature [29][30] for PAPR reduction [24][25].

3.3.1.Linear Block Coding: A simple linear block coding (LBC) was suggested in literature in which 3 bits are mapped into 4 bits .Another simple rate- ¾ cyclic code can reduce PAPR by more than 3 dB for any number of subcarriers that is a multiple of 4. A combined (8,4) linear block coding is also suggested in literature to provide error control capability and reduce PAPR of a multicarrier modulation by 4 dB. In one another scheme interchanging code word with only simple bit, PAPR can be reduced affectively. In this proposed scheme a simple LBC based on the observation point in spite of the number of subcarriers, code words with equal odd and even bit values used.[25] In another technique of LBC in which in the middle of the information bits a few complement bits are added to get reduced PAPR codeword. The method given as modified SLM in which standard arrays of linear block codes are used in for PAPR reduction. So different technique employed to reduce PAPR of OFDM using linear block coding method as basic [27][25].

3.3.2.Golay Complementary Sequences: In this method to modulate the subcarriers of the OFDM systems Golay Complementary Sequences are used as a code, the signal resulting from this is of PAPR with an upper bound of 2.To achieve low PAPR of almost 3dB the relation between Golay complementary sequences and second order Reed-Mullar code is utilized. Golay codes are studied in [28] literature for various constellation sizes such as 16-QAM and 64-QAM for PAPR reduction [28].

3.3.3.Turbo Coding: These codes as a capacity oriented codes are very popular and also used for PAPR reduction in OFDM systems.[29In literature three turbo code system is suggested for PAPR reduction in OFDM, where m-sequences for PAPR reduction and short codes for side information, used in first scheme, interleaving is used in second and third combines first two schemes.[30]In literature a tail-biting turbo coded OFDM system is suggested without need of side information protection to generate candidates in a selective mapping scheme.

4 CONCLUSION

OFDM is one of most desirable candidate for multicarrier transmission of digital data. OFDM used for both wired and wireless communication. It has many advantages over other traditional single carrier techniques such as high data rate, immunity to multipath fading and high spectral efficiency. But with number of advantages it has some limitations also and PAPR ratio resulting due to summation of large no of sub carrier is one of major limitation of OFDM technique that limits the performance. A number of PAPR reduction techniques are proposed in literature and studied in this paper so far. Such as clipping and filtering in which clipping is done at peaks to reduce the PAPR ratio but it also introduces distortion in signal. Signal scrambling techniques, scramble the input data sequence and select the signal with lowest PAPR for transmission ,techniques under this category are Partial transmit sequence(PTS), Selective mapping (SLM) and Tone injection. These techniques reduce the PAPR by good extent but at the same time increase the system complexity as no of sub carrier increases. Coding techniques in which linear block codes(LBC), Turbo codes, Golay codes can also used for PAPR reduction, but these codes reduces the bandwidth efficiency due to larger overhead and also increase the complexity of the system. As discussed, all the techniques reduces the PAPR ratio by good extent but with some limitation such as loss of data rate, increases in transmission power, increases in computational complexity, reduction in bandwidth efficiency. So PAPR reduction technique should be selected carefully according to system requirement.

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