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An Overview and Comparative Study of Different PAPR Reduction Techniques in OFDM System

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Abstract: **Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technology used in many wireless digital communication systems. It has many advantages such as bandwidth efficiency, and less impact of Intersymbol Interference (ISI) but one of its drawbacks is high Peak to Average Power Ratio (PAPR). When these high peak signals are passed through power amplifiers they cause the non-linear distortion of the signals. Also they increase the dynamic range of amplifiers. In this paper, PAPR problem is defined and this paper present different PAPR reduction techniques and conclude an overall comparison of these techniques.**

Keywords: **Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Ratio (PAPR).**

I. INTRODUCTION

In high-speed wireless and mobile communications era, OFDM technology is a special Multi-Carriers Modulation transmission scheme which can be seen as either a modulation technology or a multiplexing technology enabling transmission of multiple signals simultaneously, over a single transmission path. In OFDM a high rate data stream is divided into many low data streams and these steams are then multiplied by corresponding carrier frequency signals that are orthogonal to each other. A composite signal so formed by multiplexing these modulated signals is called the OFDM signal. A simple OFDM system is shown in figure. It is advancement over traditional Frequency Division Multiplexing (FDM) technique which is used to carry only one signal over one path.

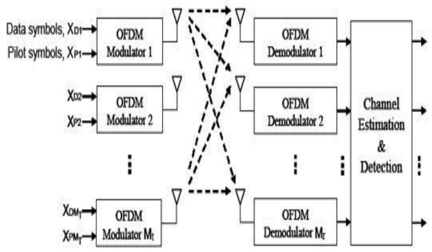

Fig 1: OFDM system [1]

The lower rate data stream so formed from the higher rate data stream (after serial to parallel conversion) has large symbol duration so Inter Symbol Interference (ISI) is reduced in OFDM. In other words, there is less dispersion in time domain due to multipath delay spread as in Time Division Multiplexing (TDM).

The condition for maintaining the orthogonality is that the frequency spacing between the carrier signals must be an integer multiple of the lowest carrier frequency. That is, each sub carrier has an integer number of cycles in time period T. The numbers of cycles in adjacent sub carriers differ by exactly one. This technique provides high data rate even if relatively small frequency bandwidth is available. Also, OFDM based system has other favourable properties such as high spectral efficiency, robustness to channel fading and impulse interference. Because of these advantages, OFDM has been adopted in both wireless and wired applications in recent years . OFDM-based systems are more immune to impulse noise, fast fades and can be of greater pursuit for wireless applications as they eliminate the need for equalizers. Also, efficient hardware implementations can be realized using Fast Fourier Transform (FFT) techniques for small numbers of carriers. So, OFDM has emerged as the standard of choice in a number of important high data applications in past few decades.

II. PEAK TO AVERAGE POWER RATIO

The major drawback of OFDM system High Peak to Average Power Ratio (PAPR).It is one of major practical complications of uncoded OFDM signal. Figure 2 shows OFDM signal with PAPR problem

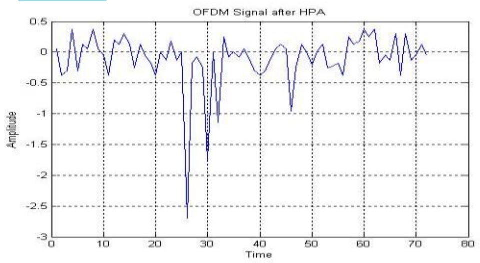

Fig 2: Amplitude of OFDM symbol showing large peak

The PAPR of the transmit signal $x(t)$ is the ratio of the square of maximum instantaneous power and the

average power square [1].

By definition, $$PAPR = \frac{\max|x(t)|^2}{E[|x(t)|^2]}$$

where $E\{.\}$ denotes expectation operator.

x(t) is the transmitted signal.

The peak to average power ratio (PAPR) is a very important attribute of a communication system as it degrades the performance of High power amplifier (HPA). A low PAPR allows the transmit power amplifier to operate efficiently, where as a high PAPR forces the transmit amplifier to have a large back off in order to ensure linear amplification of the signal. HPA non-linearity introduces out of band and in band distortion, which may result in ACI and BER degradation. Simplest

way to deal with HPA distortion is just to decrease the input back off (IBO) , making HPA operate far from the saturation point and work in the linear region (power back-off technique). This significantly degrades the HPA efficiency. Alternate is to make HPA linearization using algorithms such as Envelop elimination and restoration, Cartesian feedback technique ,feed forward technique, linear amplification with non linear components (LINC). Both approaches resulting in a significant power efficiency penalty. To reduce PAPR, several techniques have been proposed, which basically can be divided in three categories. First, there are signal distortion techniques, which reduce the peak amplitudes simply by nonlinearly distorting the OFDM signal at or around the peaks. Examples of distortion techniques are clipping, peak windowing, and peak cancellation. Second technique scrambles each OFDM symbol with different scrambling sequences and selecting the sequence that gives the smallest PAPR. Third, there are coding techniques that use a special FEC code set that excludes OFDM symbols with a large PAPR. For good performance of OFDM system, clearly it would be desirable to have the average power and peak power values as close together as possible. Depending upon the
reduction in PAPR level and computational complexity, different techniques have been surveyed.

III. PAPR REDUCTION TECHNIQUES

Several PAPR reduction techniques have been proposed in the literature . These techniques are divided into two groups - signal scrambling techniques and signal distortion techniques which are given below:

a)Signal Scrambling Techniques

- Block Coding Techniques
- Block Coding Scheme with Error Correction
- Selected Mapping (SLM)
- Partial Transmit Sequence (PTS)
- Interleaving Technique
- Tone Reservation (TR)
- Tone Injection (TI)

b)**Signal Distortion Techniques**

- Peak Windowing
- Envelope Scaling
- Peak Reduction Carrier
- Clipping and Filtering

One of the most pragmatic and easiest approaches is clipping and filtering which can snip the signal at the transmitter is to eliminate the appearance of high peaks above a certain level. But due to non-linear distortion introduced by this process, orthogonality is destroyed to some extent which results in In-band noise and Out-band noise. In-band noise cannot be removed by filtering, it decreases the bit error rate (BER). Out-band noise reduces the bandwidth efficiency but frequency domain filtering can be employed to minimize the out-band power. Although filtering has a good effect on noise suppression, it may cause peak re-growth.

To overcome this drawback, the whole process is repeated several times until a desired situation is achieved. Here, two signal scrambling techniques are used to overcome these problems.

Signal Scrambling Techniques

The fundamental principle of these techniques is to scramble each OFDM signal with different scrambling sequences and select one which has the smallest PAPR value for transmission. Apparently, this technique does not guarantee reduction of PAPR value below to a certain threshold, but it can reduce the appearance probability of high PAPR to a great extent. This type of approach include: Selective Mapping (SLM) and Partial Transmit Sequences (PTS). SLM method applies scrambling rotation to all sub-carriers independently while PTS method only takes scrambling to part of the sub-carriers.

A. BLOCK CODING TECHNIQUES:

Main objective of this technique is to reduce PAPR using different block coding & set of code words. This scheme is widely used to reduce the peak to mean envelope power ratio. While selection of the suitable codeword many things must be considered like M-ray phase modulation scheme, any type of coding rate, suitable for encoding – decoding & also main thing is that error Correction /error decoding .

B. SUB BLOCK CODING TECHNIQUES:

To reduce PAPR more than 3db sub block coding technique is widely used. But this can be achieved at ¾ code rate. This techniques based on ¾ code rate systematically with added last odd parity checking bit to develop lowest peak envelope power. This coding scheme is termed as systematic odd parity checking coding (SOPC). Large reduction in PAPR can be obtained by the divided large frame into sub block encoded with SOPC.

C. SELECTIVE MAPPING:

The paper that coined the term “selected mapping" was written by Bauml, Fischer and Huber in 1996.Among all the techniques SLM is most promising because it introduces no distortion yet can achieve significant PAPR reduction.

Data blocks are converted into several independent blocks and the one 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 (SI Index), must also be transmitted to allow recovery of the data block at the receiver side. SLM leads to the reduction in data rate.Probability of erroneous SI detection has a significant influence on error performance of the system. In this technique complexity involves in recovering the side information .Moreover, this reduces the data rate of the system because the side information is sent with the data blocks carrying information.Many methods have been proposed to reduce this side information such as Semi-Blind SLM .

D. Partial Transmit Sequence (PTS):

Block diagram of PTS is shown in Figure 6. In the PTS technique, an input data block of N symbols is partitioned into disjoint subblocks and then the signal is transmitted. Another factor that may affect the PAPR reduction performance in PTS is the subblock partitioning, which is the method of division of the subcarriers into multiple disjoint subblocks .There are three kinds of subblock partitioning schemes :adjacent, Interleaved and pseudo-random partitioning. The PTS technique works with an arbitrary number of subcarriers and any modulation scheme. Advantage is that works with an arbitrary number of subcarriers any modulationscheme. But, this scheme includes complexity and side information like SLM .

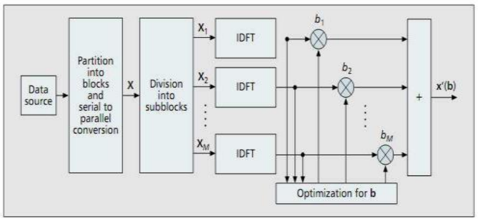

Figure 3: Partial Transmit Sequence

E. INTERLEAVING :

This method is also termed as Adaptive Symbol Selection Method .Multiple OFDM symbols are created by bit interleaving of input sequences .The basic Idea is to use W interleaving ways and selecting one with the lowest PAPR.

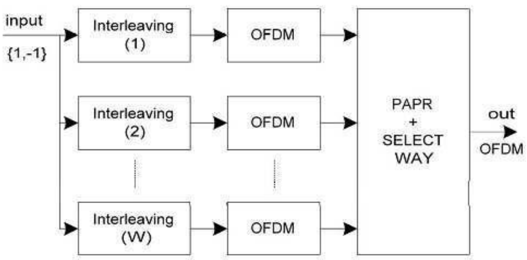

Figure 4: Interleaving

Figure 3 shows an inter leaver, PAPR Reduction capability depends on the number of inter leaver used .To recover the signals the receiver need to know the information about which inter leaver is used.

F. CODING:

When FEC codes are used to mitigate the effect of the distortion techniques, the OFDM is termed as COFDM so that the signal degradation can be made less. The basic concept is that when N signals are added in phase they add up to the signal power, such arrangements can be made with different coding schemes like Simple Odd Parity Code (SOBC), Cyclic Coding (CC), Simple Block Code (SBC)Complement Block Coding (CBC) and Modified Complement Block Coding (MCBC), Reed-Solomon, Simplex codes, Reed-Muller codes and Golay complementary codes described in can significantly reduce PAPR. Table 1 compares PAPR reduction capability of the coding schemes described above.

G. Companding :

The idea of companding came from the companding of speech signal and that the OFDM signal is similar to it from the fact that large signals occur very infrequently. Companding are of two types- linear and non-linear.

Linear companding focuses on expanding small signals only while non-linear companding enlarges small signals as well as compresses the large ones thereby obtaining uniform distribution of signals .Therefore, the average power is increased and thus the Peak-to-Average Power Ratio

Table 1: Comparison of various coding techniques

N	n	R	PAPR Reduction (dB)				
			CBC	SBC	MCBC	SOPC	CC
4	1	3/4	3.56	3.56	-	3.56	3.56
8	1	7/8	2.59	2.52	-	2.52 (R = 7/8)	3.66 (R = 3/4)
	2	3/4	2.67	3.72	2.81		
16	1	15/16	2.74	1.16	-	1.18 (R = 15/16)	3.74 (R = 3/4)
	2	7/8	2.74	2.52	-		
	3	13/16	2.74	-	-		
	4	3/4	2.74	2.98	3.46		
32	1	31/32	1.16	0.55	-	0.58 (R = 31/32)	-
	2	15/16	1.16	1.16	-		
	3	29/32	2.75	-	-		
	4	7/8	2.50	2.51	-		
	5	27/32	2.75	-	-		
	8	3/4	2.75	3.00	3.45		

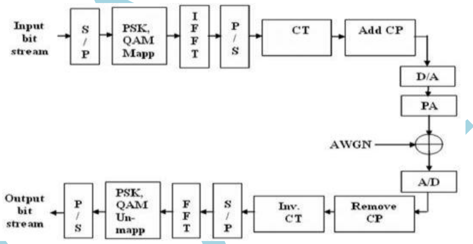

Figure 5: Companding in OFDM system[17]

(PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) systems can be reduced, which in turn helps in increasing the efficiency of the power amplifiers. In terms of BER Linear companding performs well .Uniform distribution can be achieved by using transforms like trapezium distribution ,Hadamard transform, Discrete Cosine Transform, airy function,exponential companding. Companding gives better PAPR performance and also BER degradation is less.

H. Active Constellation Extension (ACE):

This technique deals with extending the constellation points outside the signal constellation which is then used to cancel the time domain peaks. This technique has several advantages like no loss of data, no degradation in system performance , lower BER as compared to other techniques and bears no side information like SLM. Some variations of this method like clipping-based ACE and Adaptive ACE in which repeated CAF and in later an adaptive control has been used to optimize the performance.

I. TONE RESERVATION (TR) AND TONE INJECTION (TI):

In this Technique some set of tones are reserved called as peak reduction carriers and these are added to the data signal to isolate energy to cancel large peaks.These tones does not bear any information and are orthogonal to each other while Tone Injection technique reduces the PAPR without reducing the data rate similar to ACE some constellation points are extended outside the signal constellation but in a different way than in ACE . Extra flexibility is provided by mapping points of original constellation into extended constellation and then by combining the data signal and Peak reduction carrier so generated .By maximizing signal-to-distortion ratio error probability can be increased for the same transmit power and same order of computational cost in the tone Reservation method .

Table 2: Comparison of PAPR Reduction Techniques

Technique	Complexity	Distortion	Data loss	Power Increase
Clipping	no	yes	no	no
Interleaving	no	no	yes	no
Coding	no	no	yes	no
Companding	no	no	yes	yes
ACE	no	no	no	no
SLM	yes	no	yes	no
PTS	yes	no	yes	yes
TR and TI	no	no	no	yes

SIGNAL DISTORTION TECHNIQUES:

A. CLIPPING AND FILTERING:

Clipping and filtering techniques is mostly effective techniques to reduce the high PAPR in OFDM system. Here clipping is the nonlinear process in which increase the band noise distortion, also increase in the bit error rate also decrease the spectral efficiency. Here using with filtering this techniques will give better performance. Filtering after clipping will reduce out of band radiation. This technique will reduce the PAPR without spectrum expansion. Here if the OFDM signal is over sampled then the scheme of correction is suitable with the clipping so that each sub carrier generated with the interference. So for proposed this scheme each signal must be over sampled by factor of four. This scheme is more compatible with the PSK modulation scheme.

B. PEAK WINDOWING:

Here peak windowing technique is very similar to the clipping technique bit it will give better performance with adding some self interference and increasing in BER (bit error rate). Due to this out band radiation is also increased in this method we multiply different windows with large signal peaks like Gaussian shaped window, cosine, Kaiser and Hamming window. OFDM signal is multiplied with several of these windows, the resulting spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Means the windows should be narrow as possible. By using this technique PAPR can be reducing to 4db of each subcarrier.SNR is limited to 3db due to signal distortion .

C. ENVELOPE SCALING:

This technique is related to scaling means before OFDM signals sent to the IFFT all sub carrier is scaled the input envelope. In this technique 256 sub carrier is used so all sub carrier will remains equal. Main idea is that to scheme is that the input envelope in some sub carrier is scaled to achieve the smallest amount of PAPR at the output of the IFFT. Here receiver does not need any side information at the receiver end for decoding. This scheme is suitable for the PSK modulation. When it is applied with the QAM high degradation is occurred in the BER.

D. Clipping and Windowing:

Clipping is by far simplest technique for PAPR Reduction in which signal above a predetermined threshold level is clipping which introduces both in-band and out-of-band distortion which can destroy orthogonality of the subcarriers .For the later windowing of the clipped signal can be done which should be ideally as narrow as possible.

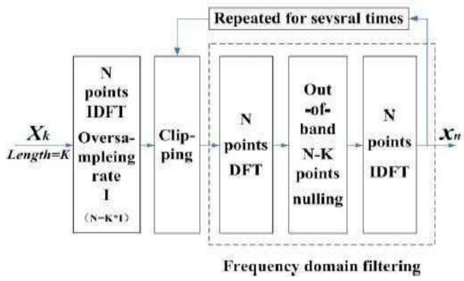

Figure 6: Repeated Clipping and Filtering Clipping operation is always performed on over sampled signal to reduce in-band distortion .

Clipping also introduces peak regrowth in OFDM signal which can be reduced by Repeated Clipping And Filtering(CAF) method , Deep Clipping , combined CAFand Interleaving described in .Block diagram of repeated CAF is shown in figure 2 where the filtering process is repeated several times to remove peak re-growth of the signal.

IV. OVERALL ANALYSIS OF DIFFERENT PAPR REDUCTION TECHNIQUES IN OFDM

The PAPR reduction technique should be chosen with awareness according to various system requirements. We have studied several techniques in the previous section. Each technique has their own advantages and disadvantages. We have studied different PAPR reduction techniques in OFDM, such techniques are selective mapping (SLM), Partial transmit sequence (PTS), Block coding, Interleaving, Tone reservation, Tone injection, Sub block coding, Linear block coding.

Reduction technique	Parameters			Operation required at transmitter(Tx) and Receiver(Rx)
	Decrease distortion	Power raise	Defeat data rate	
Clipping and filtering	No	No	No	Tx: Clipping Rx: Noise
Selective mapping (SLM)	Yes	No	Yes	Tx: M times IDFT's operation Rx: side information extraction, inverse SLM .
Block coding	Yes	No	Yes	Tx: coding or table searching Rx : decoding or table searching.
Partial transmit sequence (PTS)	Yes	No	Yes	Tx: V times IDFT's operation. Rx: side information extraction, inverse PTS.
Interleaving	Yes	No	Yes	Tx: D times IDFT's operation and D-1 times interleaving. Rx: side information extraction and deinterleaving.
Tone Reservation	Yes	Yes	Yes	
Tone Injection	Yes	Yes	No	

Table 2: Comparison of PAPR techniques [4]

These are the Signal Scrambling Techniques. Signal clipping and filtering, Peak windowing, Envelope Scaling are the Signal distortion techniques which are used to reduce peak average to power ratio (PAPR) in an Orthogonal Frequency Division Multiplexing (OFDM). Table 2: shows the different PAPR reduction techniques. This table shows the parameters of different PAPR techniques on which the reduction of PAPR depends. These parameters are decrease distortion, Power raise, Defeat data rate

Table 2.A. shows that comparisons between three main PAPR reduction techniques i.e amplitude clipping , selected mapping and partial transmit sequence. According

to the above table the highest complexity for the implementation is in the Partial Transmit sequence. And there is no any bandwidth reduction in the selected mapping technique.

Data loss is very less in the clipping and filtering technique but there is no boost up in the BER rate in this technique

Parameters	(PAPR) Reduction Techniques		
	Amplitude Clipping & filtering	Selected mapping	Partial Transmit sequence
Implementation complexity	LOW	LOW	High
BW reduction	Yes	No	YES
Distortionless	No	Yes	Yes
Data Loss	No	Yes	Yes
Power increases	No	No	No
Requires processing at Tx or Rx	Tx: Amplitude clipping, Filtering Rx: None	Tx- UIFFT Rx: Side information extraction, inverse interleaving	peak reduction sub carriers are assigned to each user in the TR for PAPR reduction
Reduced data rate	No	Yes	Yes
Boosted BER	No	Yes	Yes

Table 2.A.Comparison of PAPR Reduction Techniques

V. CONCLUSION

In this paper, peak to average power ratio and its various reduction techniques are reviewed. Orthogonal frequency division multiplexing technique is modulation technique which provides high speed communication in both wired and wireless systems. PAPR is major drawback of Orthogonal Frequency Division Multiplexing technique which degrades the performance of OFDM. Various techniques are developed to improve PAPR reduction and all these techniques have its own advantages and disadvantages. Basically as per the information about all above described techniques to reduce the PAPR in OFDM system all techniques is different in their way and using each technique PAPR will be reduced at some level. To reduce the PAPR, Partial transmit technique can be used. Research is going on to further improve PAPR reduction and improving the performance of OFDM systems.

REFERENCES

[1] Bingham J A C, "Multicarrier Modulation For Data Transmission: An Idea Whose Time Has Come", IEEE Comm. Mag., May 1990, pp. 5-14.

[2] Yang zhi –xing, “effect of papr reduction on HPA predistortion”, Ai bo , IEEE truncation on consumer electronics, vol. 51 , No.4 , November 2005.

[3] Malhar Chauhan and Hardik Patel, “Different techniques to reduce PAPR in OFDM system” , International journal of engineering research and application, vol.2,Issue 3,May-Jun 2012,pp. 1292-1294.

[4] Md.Ibrahim Abdullah and Md. Nurul Islam, “Comparative study of PAPR reduction techniques in OFDM’’, vol.1, No.8, November 2011.
V. Vijayarangan, Dr. (Mrs) R. Sukanesh , “An Overview of Techniques For Reducing Peak to Average Power Ratio and Its Selection Criteria For Orthogonal Frequency Division multiplexing Radio Systems” Journal of Theoretical and Applied Information Technology, Year 2009, Vol-5, No-5, EIssn-1817-3195/Issn-1992-8645.

[5] Umar Izaz Butt, “A Study on Tone Reservation Technique for PAPR Reduction in OFDM” Year 2010 Dissertation .Com Boca Raton, Florida ISBN-10:1- 59942-360-X, ISBN-13: 978-1-59942-360-9 Thesis:

[6] Mohammad Zavid Parvez Md. Abdullah Al Baki “Peak To Average Power Ratio (PAPR) Reduction in OFDM Based Radio Systems”, Master Of Science Thesis Blekinge Institute Of Technology May 2010.

[7] Abdulla A. Abouda, “PAPR Reduction of OFDM Signal Using Turbo Coding And Selective Mapping” Helsinki University of Technology Proceedings of the 6th Nordic Signal Processing Symposium – Norsig 2004 June 9 - 11, 2004espoo Finland.

[8] Abhishek Arun Dash “OFDM Systems and PAPR Reduction Techniques in OFDM Systems”, Bachelor Thesis, Department Of Electronics and Communication Engineering National Institute of Technology, Rourkela 2006 – 2010.

[9] Lin CHEN, Xuelong HU, “Research on PAPR Reduction in OFDM Systems”, Journal of Computational Information Systems 6:12 (2010) 3919-3927.

[10]Md. Ibrahim Abdullah, Md. Zulfiker Mahmud, Md. Shamim Hossain, Md. Nurul Islam, “ Comparative Study of PAPR Reduction Techniques in OFDM”, ARPN Journal of Systems and Software, VOL. 1, NO. 8, November 2011 ISSN 2222-9833.

[11]Yong Soo Cho, Jaekwon Kim,Won Young Yang, Chung G.Kang,“MIMO-OFDM WIRELESS COMMUNICATIONS WITH MATLAB”, Copyright: 2010.

[12]M. M. Rana, Md. Saiful Islam and Abbas Z. Kouzani, “Peak to Average Power Ratio Analysis for LTESystems” EEESecond International Conference on Communication Software and Networks, 2010.

[13]John G. Proakis and Masoud Salehi,” Multicarrier Modulation and OFDM”, Copyright: 2002, ISBN: 0-13-061793-8, 2006.

[14]Jean Armstrong, “New Peak to Average Power Reduction Technique,” Proc IEEE VTC 2001 .Spring , Rhodes Greece,2001.

[15]Jean Armstrong, “New Peak to Average Power Reduction Technique,” IEEE Electronic Letters vol .38 No.5 , February 2008.

[16]Sumeet Singh, Mr. Karamjeet Sandha, “OFDM PAPR REDUCTION WITH LINEAR CODING”, 2012.

[17]Robert F. H. Fischer, Member, IEEE, and Christian Siegl, Student Member, IEEE, “Reed–Solomon and Simplex Codes for Peak-to-Average Power Ratio Reduction in OFDM”, IEEE Transactions on Information Theory, vol. 55, no. 4, April 2009.