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# A Survey of PAPR Reduction Techniques in LTE-OFDM System

**Leman Dewangan, Mangal Singh, Neelam Dewangan**

***Abstract***— ***Orthogonal Frequency Division Multiplexing (OFDM) is one of the most promising technique for today's wireless broadband communication systems.3GPP's LTE was the first to adopt OFDM as its downlink technique. One of the major disadvantageisitshighpeak-to- averagepowerratio(PAPR). In this paper various PAPR Reduction Techniques are discussed along with their advantages, disadvantages and improvements done so far. Techniques like clipping, Companding, Selective Mapping (SLM), Interleaving, Tone Reservation (TR), Tone Injection (TI), Partial Transmit Sequence (PTS), etc.***

***Keywords- OFDM, LTE, PAPR***

## I. INTRODUCTION

Due to various advantages like robustness to multipath fading, high spectral efficiency, immunity to impulse interferences, flexibility and easy equalization over single carriers communication systems, OFDM is currently being deployed in many high speed data communication systems described in [1] after LTE. This paper deals with methods of combating a main disadvantage of OFDM, its high Peak-to-Average Power Ratio (PAPR) which causes distortion in the signal when it passes through High Power Amplifier (HPA) and Digital-to-Analog converter (DAC) which results in lower mean power level.[2].PAPR cannot be increased just by increasing the signal power as many regulatory norms restrict the transmit powers.So, some other methods need to be deployed for the above problem.

To solve the problem of PAPR many techniques have been proposed by various researchers which include Clipping [1][5][7][8][10][11], Companding[14]-[20], Coding [12][13][22], Interleaving [1][10], Selective Mapping[21] [25]-[39], Partial Transmit Sequence [43]-[52], Active Constellation Extension [40]-[42]. Tone Reservation [40][55] and Tone Injection [53][54].Many PAPR reduction techniques result in performance degradation in terms of BER as compared to original OFDM signal.

This paper discusses all the prominent PAPR reduction techniques described above.Section II deals with definition of the OFDM signals and Peak-to-Average Power (PAPR) mathematicalexpression along with the performance measure to calculate PAPR .Section III describes various PAPR reduction techniques and in section IV conclusion is given.

## II. DEFINITIONOFOFDMSIGNALSANDPAPR

OFDM is a multicarrier modulation technique, in which the bit stream is divided over several orthogonal subcarriers, each modulated at a low rate. The block diagram of OFDM system is described in figure1.Orthogonality is assured by choosing appropriate frequency spacing between them. The number of sub-carrier is chosen to insure that each sub-channel has a bandwidth less than the channel coherence bandwidth thereby experiencing flat fading. [3]

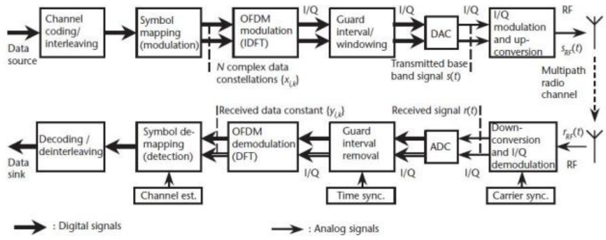


**Figure 1: The block diagram of OFDM system [5]**

ThePAPRofthetransmitted signalis defined as ratio of peak power to the average power of the signal and canbe writtenas [1]

$$PAPR = \frac{\max_{0\leq n\leq k-1} |x_n|^2}{E\{|x_n|^2\}} \qquad (1)$$

As a performance measure, thecomplementary cumulativedistribution function (CCDF) is oneof themostfrequently used for PAPR reduction techniques, which denotesthe probability thatthePAPR of adatablock exceeds agiven threshold z and is calculated by Monte Carlo Simulation[9]. The CCDF of thePAPR of adatablock of N symbolswithNyquistratesamplingisderivedas [5]

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

## III. PAPR REDUCTION TECHNIQUES

**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[5][1].

Clipping also introduces peak regrowth in OFDM signal which can be reduced by Repeated Clipping And Filtering(CAF) method[7][8] , Deep Clipping[6] , combined CAFand Interleaving described in [10].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.

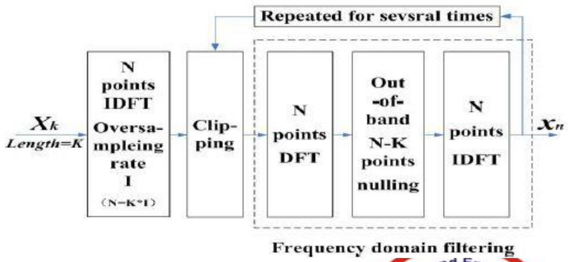


**Figure 2: Repeated Clipping and Filtering [11]**

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Clipping operation is always performed on oversampled signal to reduce in-band distortion [11].

**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.

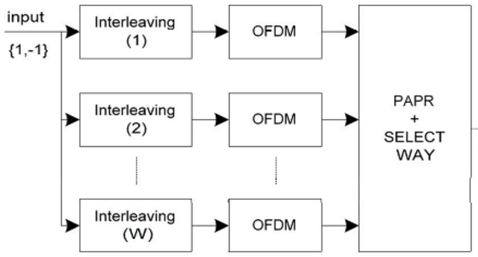


**Figure 3: Interleaving**

Figure 3 shows an interleaver, PAPR Reduction capability depends on the number of interleaver used .To recover the signals the receiver need to know the information about which interleaver is used.[10][1]

**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[22], Reed-Muller codes and Golay complementary codes described in [12][13] can significantly reduce PAPR. Table 1 compares PAPR reduction capability of the coding schemes described above.

**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 [14].Therefore, the average power is increased and thus the Peak-to-Average Power Ratio

| $N$ | $n$ | $R$ | 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 | | |

**Table 1: Comparison of various coding techniques [12]**

(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 [14].Uniform distribution can be achieved by using transforms like trapezium distribution [15], Hadamard transform [23], Discrete Cosine Transform [16], airy function [18], exponential companding [20][19].Companding gives better PAPR performance and also BER degradation is less.

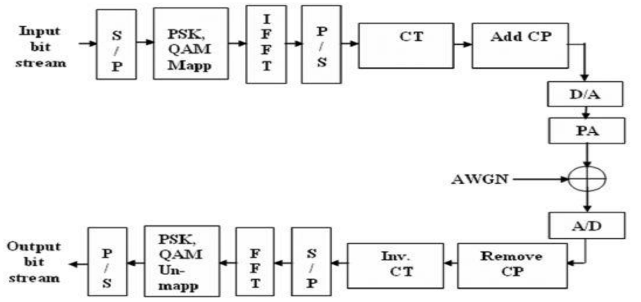


**Figure 4: Companding in OFDM system[17]**

**Selective Mapping:** The paper that coined the term “selected mapping" was written by Bauml, Fischer and Huber in 1996[21].Among all the techniques SLM is most promising because it introduces no distortion yet can achieve significant PAPR reduction

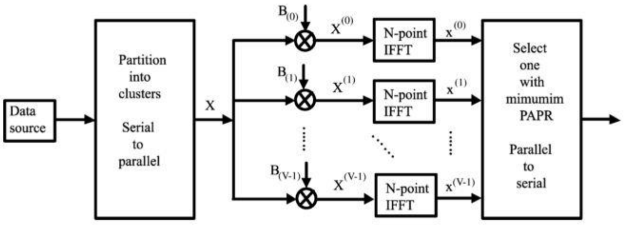


**Figure 4: Selective Mapping**

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 [1][12][24]. 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 described in [25], known phase sequences like chaotic, Hadamard, Riemann and lots of other techniques described in [26] –[39].

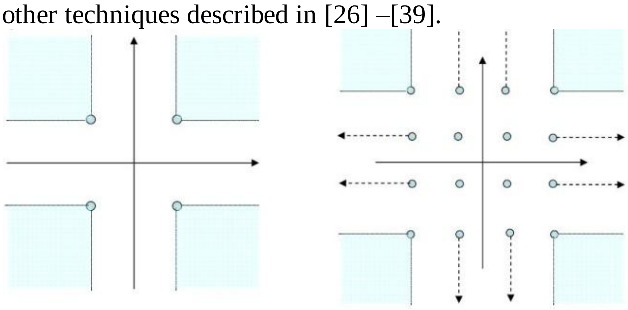

**Figure 5: Active Constellation Extension (a) for QPSK (b) for 16 QAM [40]**

**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 [1][12][40].

Figure 5 shows the points where these constellation points can be extended . is 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[41][42].

**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 [1][12][43]-[52].

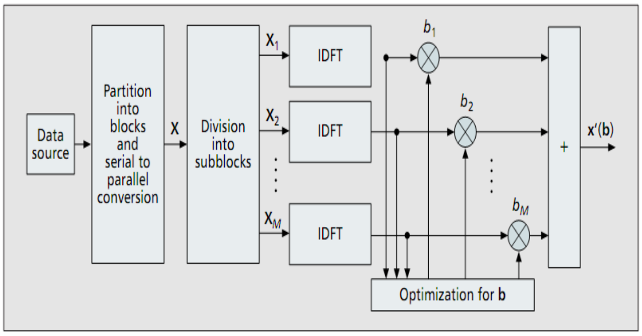


**Figure 6: Partial Transmit Sequence [1]**

**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[40][55] 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 [53][54] 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 [55].

| 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 |

**Table 2: Comparison of PAPR Reduction Techniques**

## IV. CONCLUSION

Table 2 depicts comparision between various PAPR Reduction schemes for OFDM signal that has been discussed along with their advantages and disadvantages in this paper .Also, various advance methods which has been discussed in various papers to overcome these disadvantages of the schemes have also been suggested. All the PAPR reduction techniques results in some BER performance degradation when compared to original OFDM signal. Efficient PAPR reduction scheme is one which reduces the PAPR to minimum without affecting much to the performance and also with low implementation cost.

## REFERENCES

1. SeungHee Han, Jae Hong Lee, “An overview of peak-to-average power ratio reduction techniques for multicarrier transmission”, Wireless Communications, IEEE, Vol.12, Issue 2, pp.56–65, April, 2005
2. RashidaAkter, Mohammad Rakibul Islam and Ju Bin Song , “PAPR in 3rd Generation Partnership Project Long Term Evolution : An Overview to find the Impact” IETE Technical Review , vol 27 ,issue 6 , Nov-Dec 2010
3. Suma M N, Kanmani.B, “Developments in Orthogonal Frequency Division Mutiplexing (OFDM) system – A Survey”, IEEE, 2011
4. Hyung G. Myung, Junsung Lim, and David J. Goodman, "Single Carrier FDMA for Uplink Wireless Transmission"; IEEE Vehicular Technology Magazine, September 2006, pp. 30-38
5. Ramjee Prasad, “OFDM for Wireless Communication System”, Arctech House, 2004
6. Satoshi Kimura, Takashi Nakamura, Masato Saito and Minoru Okada, “PAR Reduction for OFDM signals based on Deep Clipping” ISCCSP 2008, Malta, 12-14 March 2008
7. Jean Armstrong, “New Peak to Average Power Reduction Technique,” Proc IEEE VTC 2001 .Spring , Rhodes Greece,2001
8. Jean Armstrong, “New Peak to Average Power Reduction Technique,” IEEE Electronic Letters vol .38 No.5 , February 2008
9. 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
10. Josef Urbaf, Roman Marsalek, “PAPR Reduction by Combination of Interleaving with Repeated Clipping and Filtering in OFDM” IEEE Explore, 2007
11. Deng Qing, ZhongHongsheng, “An Improved Algorithm to Reduce PAPR BasedClipping-and-Filtering” IEEE Explore, 2008
12. Tao Jiang, Member, IEEE, and YiyanWu, Fellow, IEEE, “An Overview: Peak-to-Average Power RatioReduction Techniques for OFDM Signals”IEEE Transactions on Broadcasting, vol. 54, no. 2, June 2008
13. Dae-Woon Lim, Seok-JoongHeo, and Jong-Seon , “An Overview of Peak-to-Average Power Ratio Reduction Schemes for OFDM Signals”, Journal of Communications and Networks, vol. 11, no. 3, June 2009 229
14. YasirRahmatallah, NidhalBouaynaya and Seshadri Mohan, “On The Performance Of Linear And Nonlinear Companding Transforms In Ofdm Systems” IEEE 2011
15. Shiann-ShiunJeng, Member, IEEE, and Jia-Ming Chen, Student Member, IEEE, “Efficient PAPR Reduction in OFDM Systems Based on a Companding TechniqueWith Trapezium Distribution”, IEEE Transactions on Broadcasting, vol. 57, no. 2, June 2011
16. Zhongpeng Wang, “Combined DCT and Companding for PAPR Reduction in OFDM Signals”, Journal of Signal and Information Processing, 2011, 2, 100-104
17. Sulaiman A. Aburakhia, Ehab F. Badran, and Darwish A. E. Mohamed, Member, IEEE, “Linear Companding Transform for the Reduction ofPeak-to-Average Power Ratio of OFDM Signals”IEEE Transactions on Broadcasting, vol. 55, no. 1, March 2009
18. Yuan Jiang, “New Companding Transform for PAPR Reduction in OFDM”, IEEE Communications Letters, vol. 14, no. 4, April 2010
19. Jun Hou, JianhuaGe, DeweiZhai, and Jing Li, “Peak-to-Average Power Ratio Reduction of OFDM SignalsWith Nonlinear Companding Scheme”, IEEE Transactions on Broadcasting, vol. 56, no. 2, June 2010


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20. Tao Jiang, Yang Yang, Member, IEEE, and Yong-Hua Song, Senior Member, IEEE, “Exponential Companding Technique for PAPR Reduction in OFDM Systems”, IEEE Transactions on Broadcasting, vol. 51, no. 2, June 2005
21. Bauml, R., Fischer, R., and Huber, J., "Reducing the peak-to-average power ratioof multicarrier modulation by selected mapping," IEE Electronics Letters, vol. 32, pp. 2056 -2057, Oct. 1996.
22. 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
23. Zhongpeng Wang, Shaozhongzhang, binqingqiu, “PAPR Reduction of OFDM Signal by UsingHadamard Transform in Companding Techniques” IEEE Explore, 2010
24. Kee-Hoon Kim, Hyun-BaeJeon, Jong-Seon No, and Dong-Joon Shin, “A New Low-Complexity Selected Mapping Scheme Using Cyclic Shifted IFFT for PAPR Reduction in OFDM Systems” IEICE International Symposium on Information Theory and its Applications, March 2012
25. Ehab F. Badran and Amr. M. El-Helw, “A Novel Semi-Blind Selected Mapping TechniqueforPAPRReductioninOFDM” IEEE Signal Processing letters, vol. 18, no. 9, September 2011
26. N.V. Irukulapati, V.K. Chakka and A. Jain, “SLM based PAPR reduction of OFDM signal using new phase sequence”, Electronics letters 19th November 2009 vol. 45 no. 24
27. Stephane Y. Le Goff, Samer S. Al-Samahi, Boon KienKhoo, charalampos C. Tsimenidis, and Bayan S. Shari, “Selected mapping without side information for PAPR reduction in OFDM”, IEEE Transactions on Wireless Communications, vol. 8, no. 7, July 2009
28. Mahmoud FerdosizadehNaeiny and FarokhMarvasti, Senior Member, IEEE, “Selected Mapping Algorithm for PAPR Reductionof Space-Frequency Coded OFDM SystemsWithout Side Information”IEEE Explore, 2008
29. Yuh-Ren Tsai, Member, IEEE, Chi-Hung Lin and Yen-Chen Chen, Student Member, IEEE, “A Low-Complexity SLM Approach Based on Time-domainSub-block Conversion Matrices for OFDM PAPR Reduction”IEEE Explore, 2011
30. Hyun-BaeJeon, Jong-Seon No, Senior Member, IEEE, and Dong-Joon Shin, Senior Member, IEEE, “A Low-Complexity SLM Scheme UsingAdditive Mapping Sequences for PAPRReduction of OFDM Signals”, IEEE Transactions on Broadcasting, vol. 57, no. 4, December 2011
31. ThitaphaChanpokapaiboon, PotcharaPuttawanchai, and PrapunSuksompong, “Enhancing PAPR Performance of MIMO-OFDMSystems Using SLM Technique with CenteringPhase Sequence Matrix”, Communication Systems Wireless Mobile Communications & Technologies
32. Y. Wu, IEEE member, K. L. Man, IEEE member, Y. Wang, IEEE student member, “Optimum Selective Mapping for PAPRReduction” IEEE Explore, 2011
33. Jingru Zhou, XiaodongXu, and Xuchu Dai, “A Constellation Extension Based SLM Scheme forPAPR Reduction of OFDM Signals” IEEE Explore, 2011
34. Sang -Woo Kim, Jin-Kwan Kim and Heung-GyoonRyu, “A Computational Complexity Reduction Scheme UsingWalsh Hadamard Sequence in SLM Method” IEEE Explore, 2006
35. Athinarayanan Vallavaraj1, Brian G Stewart2, David K Harrison2, Francis G McIntosh1, “Reducing the PAPR of OFDM Using a Simplified Scrambling SLM Techniquewith No Explicit Side Information”, 14th IEEE International Conference on Parallel and Distributed Systems, 2008
36. S. Mohammady, R. M. Sidek, P. Varahram, M. N. Hamidon, and N. Sulaiman, “A new DSI-SLM method for PA_P R reduction in OFDM systems”, IEEE International Conference on Consumer Electronics (ICCE), 2011
37. Amr M El-Helw, Ehab F. Badran andHesham Y. Al-Kafrawy, “A New Sequence for Embedding Side Informationin SLM for PAPR Reduction in OFDM” Japan-Egypt Conference on Electronics, Communications and Computers, 2012
38. HimanshuBhusanMishra,Madhusmita Mishra, Sarat Kumar Patra, “Selected Mapping Based PAPR Reduction inWiMAX Without Sending the Side Information” 1st Int’l Conf. on Recent Advances in Information Technology ,RAIT-2012
39. Jamal Mountassir, AlexandruIsar, “Precoding Techniques in OFDM systemsFor PAPR Reduction”IEEE Explore, 2012
40. Robert J. Baxley, “Analyzing Selected Mapping for Peak-to-Average PowerReduction in OFDM”, School of Electrical and Computer Engineering Georgia Institute of Technology,May 2005
41. KitaekBae, Student Member, IEEE, Jeffrey G. Andrews, Senior Member, IEEE,and Edward J. Powers, Life Fellow, IEEE, “Adaptive Active Constellation Extension Algorithm forPeak-to-Average Ratio Reduction in OFDM”, IEEE Communications letters, vol. 14, no. 1, January 2010
42. B. S. Krongold and D. L. Jones, “PAR reduction in OFDM via active constellation extension,” IEEE Trans. Broadcast., vol. 49, no. 3, pp. 258–268, Sep. 2003.
43. Kamal Singh, ManoranjanRaiBharti, SudhanshuJamwal, “A modified PAPR reduction scheme based on SLM and PTS Techniques” IEEE Explore 2012.
44. Di-xiao Wu, “Selected Mapping and Partial Transmit Sequence Schemes to Reduce PAPRin OFDM Systems” IEEE Explore 2011.
45. Alok Joshi, Davinder S. Saini, “PAPR Analysis of Coded- OFDM System andMitigating its Effect with Clipping, SLM and PTS” Proceedings of the 5th International Conference onIT & Multimedia at UNITEN (ICIMU 2011) Malaysia
46. Stefan H. Muller and Johannes B. Huber, “A Comparison of Peak Power Reduction Schemes For Ofdm” IEEE Explore 1997.
47. Josef URBAN, Roman MARSALEK, “OFDM PAPR Reduction by Partial Transmit Sequences and Simplified Clipping with Bounded Distortion”IEEE Explore 2008
48. ByungMooLee ,RuiJ.P.deFigueiredo, YoungokKim, “A computationally Efficient Tree-PTS Technique for PAPR Reduction of OFDM Signals” Wireless PersCommun (2012) 62:431–442
49. Robert J. Baxley and G. Tong Zhou, “Comparing Selected Mapping and Partial Transmit Sequence for PAR Reduction”, IEEE Transactions on Broadcasting, vol. 53, no. 4, December 2007 797
50. G. Lu, P. Wu and C. Carlemalm-Logothetis, “Peak-to-average power ratio reduction in OFDM based on transformation of partial transmit sequences” Electronics Letters 19th January 2006 Vol. 42 No. 2
51. Bader HamadAlhasson, and Mohammad A. Matin, Senior Member, IEEE, “PAPR Distribution Analysis of OFDM signals with Partial Transmit Sequence”, Proceedings of 14th International Conference on Computer and Information Technology (ICCIT 2011) 22-24 December, 2011, Dhaka, Bangladesh
52. LingyinWang and Ju Liu, Senior Member, IEEE, “PAPR Reduction of OFDM Signals by PTS With Grouping and Recursive Phase Weighting Methods”, IEEE Transactions on Broadcasting, vol. 57, no. 2, June 2011
53. UmerIjaz Butt, “A Study On The Tone-Reservation Technique For Peak-To-Average Power Ratio Reduction In Ofdm Systems”, Univeraal Publication, 2008
54. Yong Soo Cho, JaekwonKim , Won Young Yang , Chung Gu Kang, “MIMO-OFDM WIrelessCOmmunication s with MAtlab”Jhon Wiley and Sons, 2010
55. SaeedGazor and RuhallahAliHemmati, “Tone Reservation for OFDM Systems byMaximizing Signal-to-Distortion Ratio” IEEE Transactions on Wireless Communications, vol. 11, no. 2, February 2012