A REVIEW PAPER ON: THE PAPR ANALYSIS OF ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

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ABSTRACT

OFDM (Orthogonal Frequency Division Multiplexing) has been raised a new modulation technique. Due to its advantages in multipath fading channel e.g. robust against ISI, ICI and some other advantages like best QoS for multiple users, efficient usage of bandwidth it is suggested to be the modulation technique for next generation 4G networks e.g. LTE. But along with all its advantages there are some disadvantages also e.g. High PAPR (Peak to Average Power Ratio) at the transmitter end and BER (Bit Error Rate) at the receiving end. Since OFDM is only used in the downlink of 4G networks. To reduce the problems of OFDM some techniques e.g. SLM, PTS, Clipping, Coding, & Pre-coding etc are suggested but none of them is reduce the PAPR and BER to an acceptable value. This Paper will discuss some techniques of PAPR & BER reduction, and their advantages and disadvantages in detail.

KEYWORDS

PAPR, OFDM, SLM, DHT, DCT

1. INTRODUCTION

OFDM is a new and attractive modulation scheme with strongly efficient in bandwidth usage, immune to multipath fading environment, less ICI and ISI, better spectral efficiency, and power efficiency [**1**] [**2**]. Due to the recent advances in Digital Signal Processing, OFDM gain more popularity with its advantages. Most high speed wireless communication standards adopt OFDM or adopting OFDM for transmission e.g. IEEE 802.11, IEEE 802.16, IEEE 802.20, European Telecommunication Standards Institute, BRAN (Broadcast Radio Access Networks) committee [**3**] [**4**].

Amongst all attractive advantages of OFDM, there are some disadvantages of OFDM e.g. high PAPR (Peak to Average Power Ratio) and BER (Bit Error Rate). The sensitivity of devices used in OFDM transmitter such as DAC (Digital to Analogue Convertor) and HPA (High Power Amplifier) is very harsh to the signal processing loop, which may impair system performance. To achieve high output power efficiency, most radio based system operates HPA at or near its saturation region. The high PAPR may prevent HPA to used in its linear region and may cause OOB (Out of Band radiation), and IB (In Band) distortion. Since this high PAPR may degrade OFDM performance, BER and expensive transmitters [**4**].

To overcome this problem of OFDM based systems, it is necessary to research on the PAPR and its reduction techniques.

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1.1 OFDM Basic

An OFDM the entire bandwidth is divided into sub channels or subcarriers, these subcarriers are transmitted parallel to achieve high data rates, and to increase symbol duration and reduce ISI [**5**] [**6**]. An OFDM signal is the sum of all independent subcarriers, modulated onto the sub channels of equal bandwidth. Let us we have a collection of all data symbols as a vector of X, where , this is a data block of N symbols. The complex representation of subcarriers is given by:

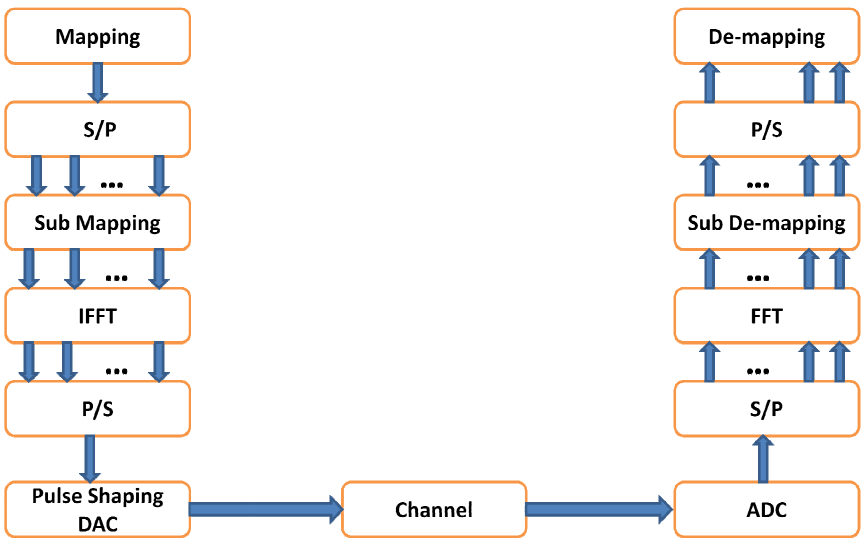

Figure 1: OFDM Block Diagram

Where , is the data block spacing, and denotes subcarriers spacing. For subcarriers to be orthogonal is used [**3**] [**4**]. Symbol duration should be for receiver to detect the original symbol correctly, this is also called the orthogonal constraints of OFDM symbol, since becomes orthogonal to each others [**7**].

1.2 Subcarriers

Two signals will be orthogonal if the integral of their products is zero at a specific time period. This is proven at the equation below for both continuous and discrete signals cases:

Where m not equal to n.

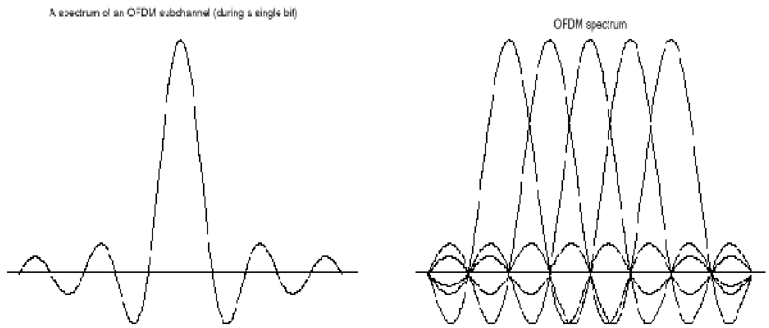

Figure 2: OFDM Subcarriers

Each sub-carrier in an OFDM system is a sinusoid with a frequency that is an integer multiple of a fundamental frequency. Each sub-carrier is like a Fourier series component of the composite signal, an OFDM symbol. The sub carrier's waveform can be expressed as:

$$
\begin{aligned}
s(t) &= \cos(2\pi fct + \theta k) \\
&= an.\cos(2\pi nf0t) + bn.sin(2\pi nf0t) \\
&= \sqrt{an^2 + bn^2}\cos(2\pi f0t + \varphi n)
\end{aligned}
$$

Where $\varphi = \tan^{-1}(bn/an)$. The sum of the sub – carriers is then the baseband OFDM signal:

$$Sb(t) = \sum_{n=0}^{N-1} \{an.\cos(2\pi nf_0 t) - bn.\sin(2\pi nf_0 t)\}$$

1.3 PAPR

Due to IFFT process at the transmitter end, this sums N sinusoids with superposition, some combination of these sinusoids creates large peaks. These peaks creates problem at different stages of OFDM system e.g. word length of IFFT/ FFT, DAC, ADC, and mostly the HPA (which design to handle irregular occurrences of large peaks). Peaks created caused HPA to operate in the saturation region. Saturation creates both IB distortion which causes BER increasing, and OB distortion which causes ACI. The PAPR of an OFDM system is derived as:

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

Where $E[.]$ represents expectation or Average Power, while Nominator is Peak power.

2. PROBLEM

As discussed in the previous section as PAPR is the main problem of OFDM, it also increased the BER of OFDM signal. A lot of work is done in the literature but still no one bring the PAPR and BER curve to an acceptable level. This paper discusses some of PAPR reduction techniques described in the literature, there advantages and disadvantages and results. Remaining paper is organized as: section iii) define the criteria for PAPR reduction in OFDM, section iv) literature review, section v) discuss the conclusion, and section vi) discuss a proposal for future work.

3. CRITERIA FOR PAPR REDUCTION

In this section a criteria is defined for the techniques used for the PAPR, and BER reduction. There are six different techniques and some hybrid techniques (in which two techniques from these six techniques are combined) are used for PAPR and BER reduction. But still no one gave acceptable results. For an acceptable technique, that technique must reduce the PAPR and BER largely plus the following performance factors must be considered for OFDM based system:

3.1 Capability of PAPR Reduction

The primary factor of selecting PAPR reduction technique is the capability of PAPR reduction. A technique is considered best if it reduces PAPR largely. OOB radiation and IB distortion are few considerable factors for selecting a technique.

3.2 Low Average Power

A technique must reduce PAPR as well as the average power of the signal not increased from an acceptable region. If so it will require a large linear region for operation in HPA, which will increase the BER rate of the OFDM system.

3.3 Low Complexity

The technique should also not increase the complexity of the overall system. Complexity includes both time and hardware requirements for implementation of the system.

3.4 Less Bandwidth Expansion

Some techniques e.g. scrambling techniques needs side information, which increase the bandwidth usage. Some coding techniques also expand the bandwidth due to code rate generation. A technique must not increase the bandwidth to value which causes degradation in the throughput.

3.5 Less BER Performance Degradation

The main goal of the PAPR reduction technique is to gain better performance including BER as compared to conventional OFDM system.

3.6 Less Additional Power Need

The technique must no need of additional power for PAPR reduction, as it will degrade BER performance of the system plus power efficiency is the main goal of wireless based systems.

3.7 Good Spectral Efficiency

If a technique destroy the ICI, or, immunity to multipath fading or some other advantage related to spectrum should not be considered a good PAPR reduction technique.

3.8 Other Factors

Some other factors like nonlinear devices such as ADC/ DAC convertors, and HPA should be kept into consideration as PAPR reduction avoid nonlinear distortion due to these memories-less devices. Another factor is the cost of these devices.

4. LITERATURE REVIEW

In the literature, a large number of PAPR Reduction Techniques have been proposed. These techniques may be divided in 6 major categories which are:

a) Clipping Techniques
b) Scrambling Techniques
c) Adaptive Pre Distortion Techniques
d) Convex Optimization Techniques
e) Coding Techniques
f) Pre Coding Based Techniques

The illustrations of these techniques are shown in Figure 3. All these techniques are relatively different and impose different constraints e.g. bandwidth expansion, complex optimizations, OOB (out-of-band) radiation, IB (in-band) distortion, side-information, high transmitted power, spectral efficiency reduction, computational complexity, BER (bit-error-rate) degradation and data-rate loss etc.

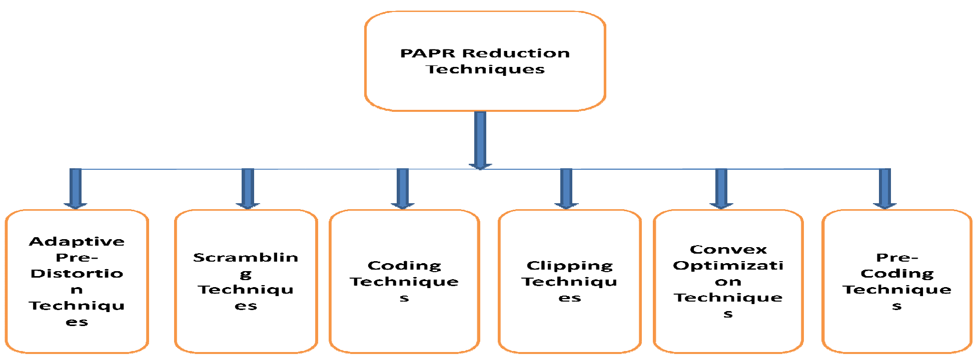

Figure 3: PAPR Reduction Techniques

4.1. Clipping Techniques

Papers [**8**] [**9**] described clipping techniques. A Clip or nonlinear saturation is employ around the peaks to reduce the peaks before HPA to reduce PAPR. This technique is called Clipping Technique. This is simple technique but introduce OOB Radiation and IB Distortion in OFDM Signal. It also destroys the Orthogonality of OFDM subcarriers [**10**] [**11**]. Simple clipping technique, joint clipping and filtering technique, peak windowing technique, block-scaling technique, peak cancellation technique and nonlinear companding transform etc are the types or variation of clipping technique. The signal parts which are above the allowed region are clipped in a simple clipping technique. Joint clipping and filtering technique reduce OOB radiation but IB distortion are still there since this method degrades OFDM system performance e.g. spectral efficiency and BER. Another PAPR reduction technique is Peak Windowing with improved spectral efficiency but it increase OOB radiation and BER [**12**]**.** For PSK (Phase Shift Keying) Modulation Envelop Scaling is used for PAPR reduction due to equality envelop properties of all subcarriers input [**13**]. For QAM (Quadrature Amplitude Modulation) based OFDM system this techniques increases the BER**.** Non Linear Companding transform is discussed in papers [**14**] [**15**] is a good PAPR due to best performance e.g. no bandwidth expansion, less BER degradation, and less complexity. But this technique give worst performance due to boost in average power of transmit signal beyond the saturation region of HPA (High Power Amplifier). Since this technique is not applicable for PAPR reduction.

4.2. Scrambling Techniques

Scrambling Techniques uses the concept of phase rotation. These techniques included SLM (Selective Mapping Technique) & PTS (Partial Transmit Technique), discussed in papers [**16**] [**17**] [**18**] [**19**] [**20**] [**21**]**.** These techniques are very popular technique for PAPR reduction but if number of phase rotation increased these techniques increased complexity. Side information also needed for receiver to decode signal in these techniques.

4.2.1. SLM (Selective Mapping)

A set of V dissimilar data blocks are created at the receiver side which consist identical information and a block with minimum PAPR is selected for transmission. This technique is used in SLM [**16**] [**17**] [**18**] which is shown in figure 4. The figure shows that each data block is multiplied with dissimilar phase sequence V of length N. *v= 1, 2…V*), its result an altered data block. Lets an altered data block for vth phase is

,

v=1, 2… V.

Now each data block should be defined as:

.

After SLM the OFDM Signal should be as:

$$= \quad \text{—} \quad , \ n=0,\ 1,\ 2...\ N\text{-}1$$

Where *v = 1, 2… V* with all data blocks *v = 1, 2… V;* the data block with minimum PAPR should be selected for transmission. Side information of the selected phase (v^{th} phase) must be sent to receiver for decoding the received signal.

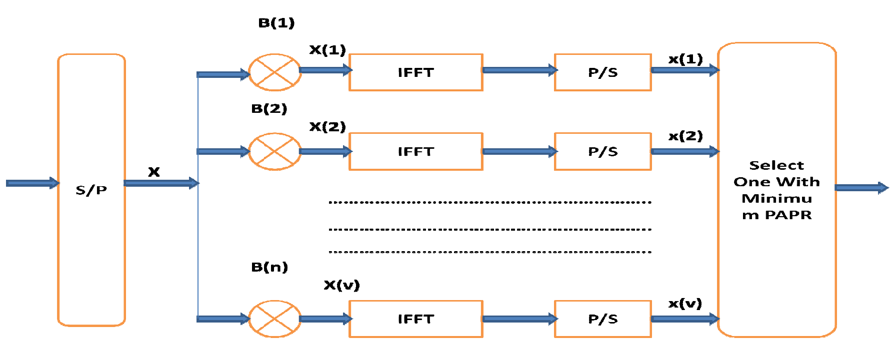

Figure 4: SLM Technique for PAPR Reduction

4.1.2. PTS (Partial Transmit Sequence)

In the literature PTS is another popular PAPR reduction technique, it partitioned the input data blocks into dissimilar data blocks of N symbols then weighted these subcarriers dissimilar blocks with phase sequence. The block diagram of PTS based OFDM system is shown in figure 5. PTS is described in papers [**19**] [**20**] [**21**] these papers defined the PTS as it reduces PAPR of combined (OFDM signal & dissimilar data blocks) with proper selection of phase factors. PTS system divides the X data blocks into dissimilar M sub data blocks as follow:

,

,

Such that .

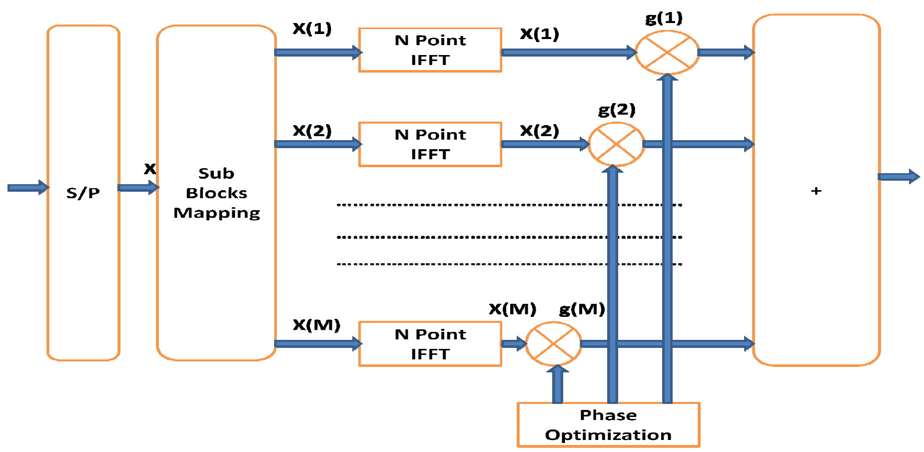

Figure 5: Block Diagram of PTS based OFDM system

4.1.3. TR (Tone Reservation)

A data block dependent time domain signal is added to the original multi carrier signal at the transmitter end, which reduces peaks. In this technique transmitter does not send small subset of data for PAPR optimization [**22**] [**23**]. The main goal is to find a proper time domain signal which reduces PAPR. Lets a we have a frequency domain vector , and an original multi carrier signal, then new time domain signal will be the original signal and time domain signal must be disjoint, i.e. if then . This is good technique for PAPR reduction as not destroy Orthogonality but increase searching complexity of time domain signal and bandwidth wastage problem arises due to some unused subcarrier.

4.1.4. TI (Tone Insertion)

The main idea of this technique is to expand the constellation so that each point in the original constellation map with several equivalent points in the expanded constellation [**22**]. Thus we have some extra number of mapping points which used for PAPR reduction. This technique increase complexity for finding the appropriate symbols space, it also increase the signal power due to injected signal.

4.2. Adaptive Pre-distortion Technique

These techniques are described in papers [**24**] [**25**] [**23**] these techniques could reduce the high PAPR problem of OFDM system or in other words compensates the non linear effects of HPA (High Power Amplifier). Through automatic adjusting of the input constellation with the help of least hardware; the non linear HPA deviation could be handled. The convergence time of pre-distorter and the MSE (Mean Square Error) can be decreased through broadcasting techniques with the help of suitable training signal design.

4.3. Convex Optimization Technique

These techniques are described in papers [**26**] [**27**] [**28**]**.** These techniques the constellation errors and constraints on permissible OOB (Out of Band) noise make a convex optimization problem. Some known algorithms are used to achieve global optimal results with low complexity. With this technique first of all the PAPR gain is defined then constraints are described for the transmitted OFDM symbol, which should be detected by the receiver.

4.4. Coding Techniques

Coding techniques are popular techniques for PAPR reduction as these techniques does not initiate any OOB radiation and IB distortion. These techniques are described in papers [**29**] [**30**] [**31**]. The disadvantages of coding techniques are increased complexity in case subcarrier increased; and also if the code rate is reduced, these techniques suffer from bandwidth efficiency.

4.5. Pre-Coding Techniques

The most popular and attractive techniques for PAPR reduction in OFDM and OFDMA based system. These techniques are defined in papers [**32**] [**33**] [**34**] [**35**] [**36**] [**37**] [**38**] [**39**] [**40**]. Pre-coding based techniques include: WHT (Walsh Hadamard Transform), DHT (Discrete Hartly Transform), DCT (Discrete Cosine Transform), ZCT (Zadoff Cho Transform) etc. the description of these techniques are described in the below section.

4.5.1. Walsh Hadamard Transform

This is an orthogonal linear transform and could be implemented as a butterfly structure of FFT. It means that Hadamard Transform does not increase the system complexity. Mathematically Hadamard Transform [**41**] could be written as:

$$H_1 = [1]$$

$$H_2 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$H_{2N} = \frac{1}{\sqrt{2N}}\begin{bmatrix} H_N & H_N \\ H_N & H_N^{-1} \end{bmatrix}$$

Where H_N^{-1} is the binary complement of H^N.

4.5.2. Discrete Hartly Transform

This is a type of linear transform. In this technique N real numbers $x_0, x_1, \dots, x_{N-1}$ transformed into N real numbers $H_0, H_1, \dots, H_{N-1}$. DHT is defined in paper [**42**] as:

$$H_k = \sum_{n=0}^{N-1} x_n \left[cos\left(\frac{2\pi nk}{N}\right) + sin\left(\frac{2\pi nk}{N}\right)\right]$$

$$= \sum_{n=0}^{N-1} x(n).\ cas\left(\frac{2\pi nk}{N}\right)$$

Where $cas\,\theta = cos\,\theta + \ sin\,\theta$ and k = 0, 1… N-1

$$p_{m,n} = cas\left(\frac{2\pi mn}{N}\right)$$

DHT is invertible transform means x_n is recordable from H_k through inverse transformation. For inverse transformation simply multiply $\frac{1}{N}$ with DHT of H_k.

4.5.3. Zadoff-Chu Transform

ZCT is a ploy phase sequence with optimal periodic autocorrelation and constant magnitudes. ZC sequences are defined in [**43**] as:

$$a_n = \begin{Bmatrix} e^{\frac{j2\pi r}{L}\left(\frac{k^2}{2}+qk\right)} & ;where\ L\ is\ even \\ e^{\frac{j2\pi r}{L}\left(\frac{k(k+1)}{2}+qk\right)} & ;where\ L\ is\ odd \end{Bmatrix}$$

Where $k = 0,1,2, \dots, L-1$, q is any integer and r is a prime integer relative to *L.* the kernel of ZCT is defined in as:

If N is of size $L \times L$, and $\sqrt{-j}$, the ZCT matrix A of size $L^2 = L \times L$, could be obtained with reshaping ZC sequence as: $k = mL + l$, the resulting Matrix transform would be:

$$A = \begin{bmatrix} a_{00} & a_{01} & \cdots & a_{0(L-1)} \\ \vdots & \vdots & \ddots & \vdots \\ a_{(L-1)0} & a_{(L-1)1} & \cdots & a_{(L-1)(L-1)} \end{bmatrix}$$

Here *m* defines rows while *L* defines columns.

4.5.4. Discrete Cosine Transform

DCT is defined in paper [**44**] as:

$$X_k = \sum_{i=0}^{N-1} x_i cos\left[\frac{\pi}{N}\left(n+\frac{1}{2}\right)k\right]$$

The DCT matrix D of $L \times L$ can be created by the following formula:

$$D_{ij} = \begin{cases} \frac{1}{\sqrt{N}} & ,i = 0, \quad ,0 \le j \le N-1 \\ & \quad ,1 \le i \le N-1 \\ \sqrt{\frac{2}{N}} cos\frac{\pi(2j+1)i}{2N} & \quad ,0 \le j \le N-1 \end{cases}$$

The kernel of DCT matrix transforms with $N = L \times L$, and $j = \sqrt{-1}$, using above equation may obtain as:

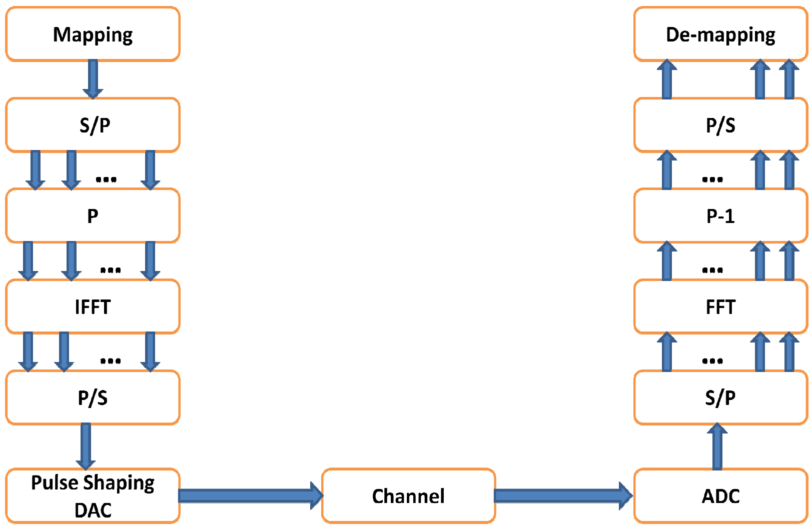

Figure 6: Pre-coding based OFDM System

Figure 6 shows Pre-coding based OFDM system. Pre-coders (WHT, DHT, DCT, and ZCT etc) are used in the pre-coding block as a matrix A of dimensions. This matrix is multiplied with parallel data blocks before IFFT operation to reduce the correlation amongst all sub carriers. If ^{T} is a complex vector of size L after S/P block, and a pre-coder matrix A of size is multiplied with this matrix, the new vector of size L could be $Y=AX= [Y_0, Y_1, Y_{2...} Y_{L-1}]^T$, and Y is: , and means m^{th} row and l^{th} column of matrix A. Now with N subcarriers complex baseband signal is described as:

, n=0,1,2,...,N-1.

Pre-coding based techniques are merged with scrambling techniques, clipping techniques, ACE etc to get best performance.

5. CONCLUSION

In this paper, a survey on PAPR reduction techniques has been discussed. Each technique of PAPR reduction in OFDM based system are different from each other and impact different constraints e.g. bandwidth expansion, OOB radiation, IB distortion, reduction of spectral efficiency, BER reduction, high peak power, high average power, and overall system complexity.
This is concluded that Scrambling techniques give good performance but it needs side information for receiver to recover original data block, also it increases complexity. Pre-coding based techniques results good with no need of side information and works with less complexity. Hybrid techniques Pre-coding plus other give best result for PAPR reduction.

6. FUTURE WORK

A survey paper on PAPR reduction in OFDM based system is presented in this paper. In future a Pre-coder will be combined with any Scrambling technique and the system performance will be compared with already work done for Next Generation Vehicular Ad-hoc Networks (NG-VANET).

7.REFERENCES

[1] Y.Wu and W. Y. Zou, "Orthogonal frequency division multiplexing: A multi-carrier modulation scheme," IEEE Trans. Consumer Electronics, vol. 42. no. 3, pp. 392-399, August 1995.

[2] W. Y. Zou and Y. Wu, "COFDM: An overview," IEEE Trans. Broadcasting, vol. 41 no.1, pp. 1-8, March 1995.

[3] JAE HONG LEE SEUNG HEE HAN, "AN OVERVIEW OF PEAK-TO-AVERAGE POWER RATIO REDUCTION TECHNIQUES FOR MULTICARRIER TRANSMISSION," IEEE Wireless Communications, pp. 56-65, April 2005.

[4] Yiyan Wu Tao Jiang, "An Overview: Peak-to-Average Power Ratio Reduction Techniques for OFDM Signals," IEEE TRANSACTIONS ON BROADCASTING, VOL. 54, NO. 2, JUNE 2008, vol. 54, no.2, pp. 257-268, June 2008.

[5] Jr L. J. Cimini, "Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing," IEEE Trans. Communication, vol. COM-33, no. 7, pp. 665-675, July 1985.

[6] Y. G. Li and G. Stüber, "Orthogonal Frequency Division Multiplexing for Wireless Communications," Boston, MA: Springer-Verlag, January 2006.

[7] Chenyang Yang,Gang Wu, Shaoqian Li, and Geoffrey Ye Li Taewon Hwang, "OFDM and Its Wireless Applications: A Survey," IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, vol. 58, NO. 4, pp. 1673-1694, May 2009.

[8] R. O'Neill and L. B. Lopes, "Envelope Variations and Spectral Splatter in Clipped Multicarrier Signals ," IEEE Processing PIMRC 95 Toronto, Canada, pp. 71-75, September 1995.

[9] X. Li and Jr L. J. Cimini, "Effect of Clipping and Filtering on the Performance of OFDM," IEEE Communication Letter, vol. 2, no. 5, pp. 131-133, May 1998.

[10] D. Kim and G. L. Stüber, "Clipping Noise Mitigation for OFDM by Decision–Aided Reconstruction," IEEE Communication Letter, vol. 3, no. 1, pp. 4-6, January 1999.

[11] H. Saeedi, M. Sharif, and F. Marvasti, "Clipping Noise Cancellation in OFDM Systems Using Oversampled Signal Reconstruction ," IEEE Communication Letter, vol. 6, no. 2, pp. 73-75, February 2002.

[12] Sungkeun Cha, Myonghee Park, Sungeun Lee, Keuk-Joon Bang, and Daesik Hong, "A new PAPR reduction technique for OFDM systems using advanced peak windowing method," IEEE Transactions on Consumer Electronics, , vol. 54, no. 2, pp. 405-410, May 2008.

[13] P. Foomooljareona nd W.A.C. Fernando, "PAPR Reduction in OFDM Systems," Thammasat Int. J. Sc. Tech, vol. 7, no. 3, pp. 70-79, December 2002.

[14] Jiang Tao and Guangxi Zhu, "Nonlinear companding transform for reducing peak-to-average power ratio of OFDM signals," IEEE Transactions on Broadcasting, vol. 50, no. 3, pp. 342-346, September 2004.

[15] N. Bouaynaya, and S. Mohan Y. Rahmatallah, "Bit error rate performance of linear companding transforms for PAPR reduction in OFDM systems," in Proc. IEEE GLOBECOM, Houston, TX, USA, December 2011.

[16] Muller S. H. and Huber J. B, "A novel peak power reduction scheme for OFDM," the 8th IEEE International Symposium on in Personal, Indoor and Mobile Radio Communications, 1997.

[17] M. Breiling, S.H. Muller-Weinfurtner, and J.B Huber, "SLM peak-power reduction without explicit side information," IEEE Communications Letters, vol. 5, no. 6, pp. 239-241, June 2001.

[18] Chin-Liang Wang, Sheng-Ju Ku, and Chun-Ju Yang, "A Low-Complexity PAPR Estimation Scheme for OFDM Signals and Its Application to SLM-Based PAPR Reduction," IEEE Journal of Selected Topics in Signal Processing, vol. 4, no. 3, pp. 637-645, June 2010.

[19] S.H. Muller and J.B Huber, "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences," IEEE Electronics Letters , vol. 33, no. 5, pp. 368-369, February 1997.

[20] Han Seung Hee and Jae Hong Lee, "PAPR reduction of OFDM signals using a reduced complexity PTS technique," IEEE Signal Processing Letters, vol. 11, no. 11, pp. 887-890, November 2004.

[21] Dae-Woon Lim, Seok-Joong Heo, Jong-Seon No, and Habong Chung, "A new PTS OFDM scheme with low complexity for PAPR reduction," IEEE Transactions on Broadcasting, vol. 52, no. 1, pp. 77-82, March 2006.

[22] J. Tellado, "Peak to Average Power Reduction for Multicarrier Modulation," Ph.D. dissertation, Stanford Univ, 2000.

[23] B. S. Krongold and D. L. Jones, "An Active Set Approach for OFDM PAR Reduction via Tone Reservation," IEEE Transaction Signal Processing, vol. 52, no. 2, pp. 495-509, February 2004.

[24] D L Jones, "Peak power reduction in OFDM and DMT via active channel modification," in Proc. Asilomar Conference on Signals, Systems, and Computers, vol. 2, pp. 1076-1079, 1999.

[25] B. S. Krongold and D. L. Jones, "PAR Reduction in OFDM via Active Constellation Extension," IEEE Transaction on Broadcasting, vol. 49, no. 3, pp. 258-268, September 2003.

[26] S. Pino-Povedano and F.J Gonzalez-Serrano, "PAPR reduction for OFDM transmission using a method of Convex Optimization and Amplitude Predistortion," International Workshop on Satellite and Space Communications, IWSSC 2009, pp. 210-214, 9-11 September 2009.

[27] C. Nader, P. Handel, and N Bjorsell, "Peak-to-Average Power Reduction of OFDM Signals by Convex Optimization: Experimental Validation and Performance Optimization," IEEE Transactions on Instrumentation and Measurement, vol. 60, no. 2, pp. 473-479, February 2011.

[28] Lung-Sheng Tsai, Wei-Ho Chung, and Da-shan Shiu, "Lower Bounds on the Correlation Property for OFDM Sequences with Spectral-Null Constraints," IEEE Transactions on Wireless Communications, vol. 10, no. 8, pp. 2652-2659, August 2011.

[29] J.A. Davis and J Jedwab, "Peak-to-mean power control and error correction for OFDM transmission using Golay sequences and Reed-Muller codes," Electronics Letters, vol. 33, no. 4, pp. 267-268, February 1997.

[30] J.A. Davis and J Jedwab, "Peak-to-mean power control in OFDM, Golay complementary sequences, and Reed-Muller codes," IEEE Transactions on Information Theory, vol. 45, no. 7, pp. 2397-2417, November 1999.

[31] Jiang Tao and Guangxi Zhu, "Complement block coding for reduction in peak-to-average power ratio of OFDM signals," IEEE Communications Magazine, vol. 43, no. 9, pp. S17-S22, September 2005.

[32] Heeyoung Jun, Jaehee Cho, et.al Myonghee Park, "PAPR reduction in OFDM transmission using Hadamard transform," ICC 2000, pp. 430-433, 2000.

[33] Xiang-Gen Xia, "Precoded and vector OFDM robust to channel spectral nulls and with reduced cyclic prefix length in single transmit antenna systems," IEEE Transactions on Communications, vol. 49, no. 8, pp. 1363-1374, August 2001.

[34] Yuan-Pei Lin and See-May Phoong, "BER minimized OFDM systems with channel independent precoders," IEEE Transactions on Signal Processing, vol. 51, no. 9, pp. 2369-2380, September 2003.

[35] Zhengdao Wang, Shengli Zhou, and G.B Giannakis, "Joint coding-precoding with low-complexity turbo-decoding," IEEE Transactions on Wireless Communication, vol. 3, no. 3, pp. 832-842, May 2004.

[36] Yew Kuan Min, M. Drieberg, and V Jeoti, "On PAPR Reduction in OFDM Systems: A Technique using Normalized Complex Hadamard Transform," IEEE Region TENCON 2005, pp. 1-4, 21-24 November 2005.

[37] I. Baig and V Jeoti, "PAPR analysis of DHT-precoded OFDM system for M-QAM," International Conference on Intelligent and Advanced Systems (ICIAS), pp. 1-4, 15-17 June 2010.

[38] I. Baig and V Jeoti, "DCT precoded SLM technique for PAPR reduction in OFDM systems," International Conference on Intelligent and Advanced Systems (ICIAS), 2010, pp. 1-6, 15-17 June 2010.

[39] I. Baig and V Jeoti, "PAPR Reduction in OFDM Systems: Zadoff-Chu Matrix Transform Based Pre/Post-Coding Techniques," Second International Conference on Computational Intelligence, Communication Systems and Networks (CICSyN), 2010, pp. 373-377, July 2010.

[40] A. Joshi, D. Bhardwaj, and D.S Saini, "PAPR reduction in OFDM with FEC (RS-CC and Turbo coding) using DHT preceding," International Symposium on Instrumentation & Measurement, Sensor Network and Automation (IMSNA), vol. 1, no. 1, pp. 14-18, 25-28 August 2012.

[41] N. Ahmed and K.R. Rao, "Orthogonal transforms for digital signal processing," Berlin: Springer-Verlag, 1975.

[42] R.N. Bracewell, "Discrete Hartley transform," Journal of the Optical Society of America, vol. 73, no. 12, pp. 1832-1835, 1983.

[43] B.M Popovic´, "Spreading sequences for multi-carrier CDMA systems," In IEE Colloquium CDMA Techniques and Applications for Third Generation Mobile Systems, pp. 1-8, 1997.

[44] N. Ahmed, T. Natarajan, and K.R and Rao, "Discrete cosine transform," IEEE Transactions on Computers, C-23(1), pp. 90-93, 1974.

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