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# Effects of High PAPR and PAPR Reduction Techniques in OFDM Systems – A Survey

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***Abstract— Wireless communications have been developed widely and rapidly in the modern world. Recent technologies in wireless communication systems have increased the throughput over wireless channels. The reliability of wireless communication has also been increased. But still the bandwidth and spectral availability demands are endless. The need to achieve reliable wireless systems with high spectral efficiency, low complexity and good error performance results in continued research in this field. Orthogonal Frequency Division Multiplexing (OFDM) has become the modulation choice for high data-rate communication systems. OFDM is tolerant to multipath delay spread and have high spectral efficiency. But OFDM has the disadvantage of having large fluctuations in signal amplitude which has resulted in a high Peak-to-Average-Power Ratio (PAPR). OFDM signal with high PAPR will suffer non-linear distortion due to non-ideal behaviour of High Power Amplifier (HPA) as well as it is detrimental to battery-powered devices. The objective of the survey is to provide a broader understanding of the high PAPR problem in OFDM systems and analyses the solutions to mitigate the problem. PAPR reduction schemes classifies into signal distortion, multiple signalling and probabilistic, and coding techniques. Among which, coding based approaches have inherent error control capability and simplicity of implementation. Survey highlights that the error performance of Low Density Parity Check ( LDPC) codes with higher inversion freedom are more practical. This paper analyses the PAPR reduction capability and Bit Error Rate (BER) performance of LDPC coded OFDM systems.***

***Keywords— PAPR, OFDM, ISI, CCDF, LDPC***

## I. INTRODUCTION

Demand for multimedia services is growing day by day and it requires high data rates. Inter Symbol Interference (ISI) will limit the high data rate conditions. Multicarrier communication is used to mitigate the ISI problem. In Multicarrier modulation the input data stream is divided into several lower rate parallel bit streams and these substreams are modulate using several carriers. The first systems using Multicarrier modulation were military HF radio links in 1960s [2]. A classical Multicarrier modulation system divides the total signal frequency band into N nonoverlapping frequency subchannels. Each subchannel is modulated with a separate symbol and then the N subchannels are frequency multiplexed. Orthogonal Frequency Division Multiplexing is a promising multi carrier modulation technique which is capable for transmitting large amount of digital data. The mathematical relationship between the frequencies of carriers in the system is indicated by the word orthogonal. The carriers are arranged such that the frequency spectrum of the individual carriers overlap and the signals are still received without adjacent carrier interference. In order to achieve this, the carriers are chosen to be mathematically orthogonal. Application of OFDM includes Digital Audio Broadcasting (DAB) and radio Local Area Networks (LANs). OFDM offers high data rate multicarrier transmission in mobile applications.

One of the major drawbacks of OFDM is that it exhibits high Peak-to-Average Power Ratio (PAPR). Unfortunately, the OFDM signal with high PAPR will enters to the nonlinear region of the High Power Amplifiers (HPAs). The nonlinearity introduced in HPA will results in amplitude and phase distortions which cause loss of orthogonality among the subcarriers, and Inter Carrier Interference (ICI) is introduced in the transmitted signal. High PAPR also leads to in-band distortion and out-of-band radiations. Therefore PAPR reduction in OFDM system is very necessary.

Different schemes have been proposed in [1] to reduce PAPR of OFDM systems. PAPR reduction techniques can be broadly classified into signal distortion technique, multiple signalling and probabilistic technique, and coding techniques. Most widely used methods are clipping [3] and peak windowing [4]. These methods distort the OFDM signal and increase the bit error probability. Partial Transmit Sequences [5],[6] and Selected Mapping [7] are non distortion PAPR reduction techniques. These techniques transmit the OFDM signal with the lowest PAPR value among a number of candidates all of which represent the same information. Coding method [9] is also adopted reduce the PAPR. LDPC coded [10] OFDM system will reduce the complexity and provide better PAPR reduction capability and good bit error rate performance. This paper analyses different PAPR reduction methods and make a comparison among them.

This rest of this survey is organized as follows: Section II describes about an overview of OFDM system. Section III describes the necessity of PAPR reduction and selection criteria for PAPR reduction methods. Section IV presents different PAPR reduction methods. Section V familiarizes less complex PAPR reduction method using LDPC coding. Finally, Section VI concludes this survey.

## II. OVERVIEW OF OFDM SYSTEMS

Orthogonal frequency division multiplexing uses orthogonal subcarriers to convey information. Figure 1 shows a FFT based OFDM system. Data stream with rate *R* bps are modulated using a digital modulation like Quadrature Amplitude Modulation (QAM). Modulated data is grouped with a block length *K*. Time period of *K* bit symbol is represented by *Ts*. Where *Ts* = *K/R*. Here serial to parallel converter is used to achieve subblock partitioning.

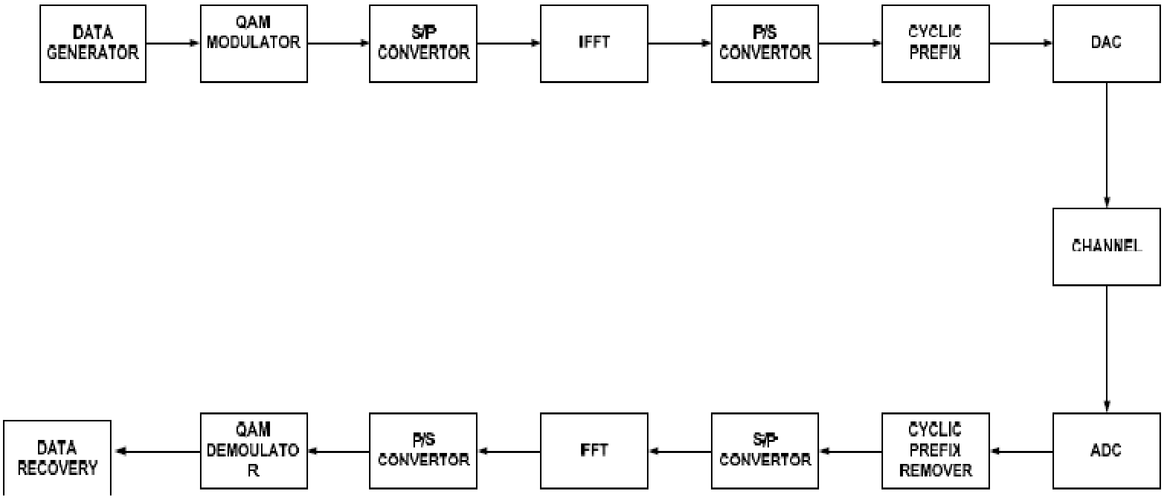


Fig.1 : Block diagram of FFT based OFDM [11]

The OFDM signal $x(t)$ can be expressed as

$$x(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_n(t) e^{j(\varphi n t + \emptyset_n(t))} \quad (1)$$

where N is the number of subcarriers, $A_n(t)$ is the amplitude of each subcarriers, $\varphi = 2\pi f$ and $\emptyset_n(t)$ is the phase of each subcarrier. This equation takes exactly the same form as the Inverse Discrete Fourier Transform (IDFT) and can be implemented efficiently using the Inverse Fast Fourier Transform (IFFT) algorithm. To eliminate even the very small ISI a guard time is introduced for each OFDM symbol. The guard time must be chosen such that it must be larger than the expected delay spread, such that multi-path components from one symbol cannot interfere with the next symbol. It the guard time is left empty, this may lead to inter-carrier interference (ICI)**,** since the carriers are no longer orthogonal to each other. To avoid such a cross talk between sub- carriers, the OFDM symbol is cyclically extended in the guard time. OFDM is basically a combination of multiplexing and modulation. In OFDM the signals are first split into independent channels modulated by data and then re-multiplexed to create OFDM carrier. Since maximum of a subcarrier corresponds to zeros of another subcarrier, each subcarrier can be demodulated independently of the other.

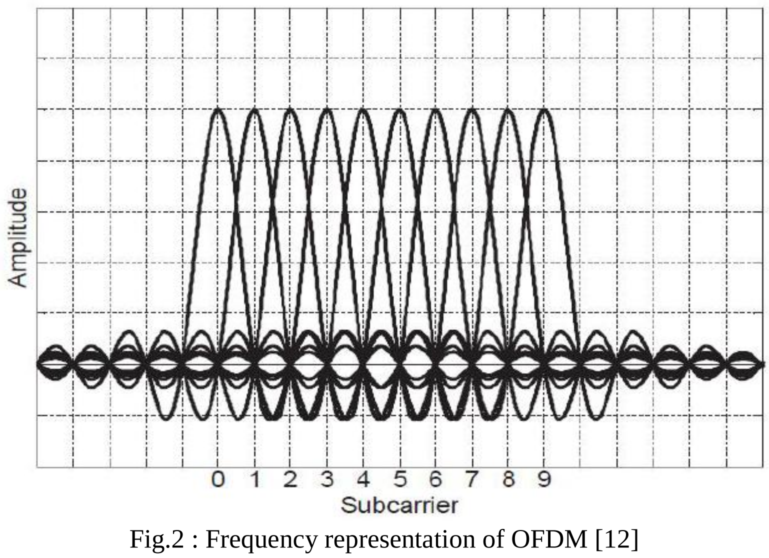


Fig.2 : Frequency representation of OFDM [12]

A major disadvantage that arises in multicarrier systems like OFDM is the resulting non-constant envelope with high peaks. When the independently modulated subcarriers are added coherently, the instantaneous power will be more than the average power.

## III. PEAK-TO-AVERAGE POWER RATIO AND SYSTEM PERFORMANCE

### *A. Peak-to-Average Power Ratio*

The PAPR is the relation between the maximum power of a sample in an OFDM symbol divided by the average power of that OFDM symbol. PAPR will be high for multicarrier system having different sub carriers and which are out of phase with each other. At each instant the phase value of the subcarrier will be different. At some points few subcarriers achieve the maximum value simultaneously; this will cause the output envelope to suddenly shoot up which causes a 'peak' in the output envelope. OFDM system consist of large number of independently modulated subcarriers, therefore the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio (PAPR). PAPR can be expressed as

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

where x(t) is the OFDM signal and *E*[.] denotes the expectation operator.

### *B. Problems of High PAPR* High

High PAPR will reduce BER performance of the system. If a signal has large PAPR, its average input power must be reduced. If the input power is not reduced then signal distortion will occur which can result in out-of-band distortion which in turn results in spectral regrowth. High power amplifiers efficiency will be high at its saturation operation region. So input power back off will be depends up on the efficiency of the High power amplifiers. If the input power is not reduced then signal distortion will occur which can result in out of- band spectral re-growth of signal as the signal will be amplified in the non-linear region of high power amplifier. In order to avoid clipping of the transmitted waveform, the power-amplifier at the transmitter front end must have a wide linear range to include the peaks in the transmitted waveform. Building power amplifiers with such wide linear ranges is very costly.

High PAPR tends to cause non-linear distortion in the RF power amplifier that transmits the radio frequency signal via the antenna. To avoid distortion, the power amplifier needs input power reduction, which leads to poor power efficiency and shorter battery life. Battery life represents a key concern in the mobile communication field. As device miniaturization is progressing at a faster rate than battery technology optimization, battery life often places a limitation on the utility of the mobile devices. The RF power amplifier has the highest power consumption within the mobile device. Therefore, in order to ensure that mobile devices use as little battery power as possible, efficient operation of the RF amplifiers base station to the mobile device, the transmitter is placed in the base station, where power supply is not a problem. Whereas in the uplink, the signal is transmitted from the mobile device to the base station, and the transmitter is placed in the mobile device, which has limited power resources. is required. However, this problem is not as much of a concern in the downlink as in the uplink. In the downlink, where the signal is transmitted from the mobile device to the base station, and the transmitter is placed in the mobile device, which has limited power resources.

The digital to analog and analog to digital converters complexity also increased with increase in PAPR. ADC and DAC are design with large storage capacity to store the high peak value. PAPR reduction has become a subject of numerous studies and various schemes have been developed to address this issue. Reduction scheme should reduce PAPR with optimization in BER, spectral efficiency, transmitter and receiver complexity.

### *C. Criteria for PAPR Reduction Method Selection*

The criteria of the PAPR reduction are to find the approach that it can reduce PAPR largely and at the same time it can keep the good performance in terms of the following factors as possible. The following criteria should be considered in using the techniques:

i. PAPR reduction capability: The high capability of PAPR reduction is primary factor to be considered in selecting the PAPR reduction technique with as few harmful side effects such as in-band distortion and out –of-band radiation.

ii. Low average power: the method should not increase the power of transmitted signal. Although it also can reduce PAPR through average power of the original signals increase, it requires a larger linear operation region in HPA and thus resulting in the degradation of BER performance.

iii. No BER performance degradation: The aim of PAPR reduction is to obtain better system performance including BER than that of the original OFDM system. Therefore, all the methods, which have an increase in BER at the receiver, should be paid more attention in practice.

iv. No bandwidth expansion: The bandwidth expansion directly results in the data code rate loss due to side information Moreover, when the side information are received in error unless some ways of protection such as channel coding employed. Therefore, when channel coding is used, the loss in data rate is increased further due to side information. Therefore, the loss in bandwidth due to side information should be avoided or at least be kept minimal.

v. Computational complexity: Computational complexity is another important consideration in choosing a PAPR reduction technique. However, in practice, both time and hardware requirements for the PAPR reduction should be minimal.

Other considerations: Many of the PAPR reduction techniques do not consider the effect of the components in the transmitter such as the transmit filter, digital-to-analog (D/A) converter, and transmit power amplifier. In practice, PAPR reduction techniques can be used only after careful performance and cost analyses for realistic environments.

 

### *D. Complementary Cumulative Distribution Function of PAPR*

The Cumulative Distribution Function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. In the literature, the Complementary CDF (CCDF) is commonly used instead of the CDF itself. A CCDF curve shows how much time the signal spends at or above a given power level [13]. The power level is expressed in dB relative to the average power. A CCDF curve is basically a plot of relative power levels versus probability. Mathematically CCDF can be explained with a set of data having the probability density function (PDF). To obtain the Cumulative Distribution Function (CDF), the integral of the PDF is computed. Then inverting the CDF results in the CCDF. It concludes that the CCDF is the complement of the CDF or CCDF = 1 – CDF. CCDF measure the efficiency of any PAPR technique. The CCDF of the PAPR of the data block is desired to compare outputs of various reduction techniques. This is given by

$$P(PAPR>Z) = 1-P(PAPR\leq Z) \tag{3}$$

Where Z is the threshold power level.

## IV. PAPR REDUCTION METHODS

Numerous studies are focused on PAPR reduction based on that various schemes have been developed to address this issue. These schemes mainly classified as PAPR reduction technique with signal distortion and PAPR reduction without signal distortion. Signal distortion methods are easy to implement and which are used in situation where BER degradation is acceptable. PAPR reduction without signal distortion is subdivided into probabilistic methods and coding methods.

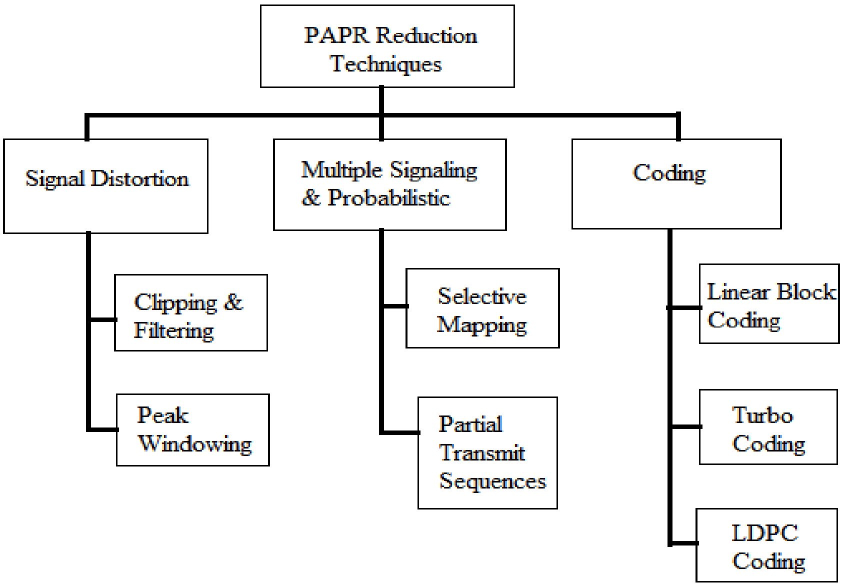


Fig. 3 : Classification of PAPR reduction techniques.

### *A. Clipping and Filtering*

Clipping method [3] is the simplest way to reduce PAPR. This method clip the signal such that the peak amplitude becomes limited to a desired level. Clipping is the simplest solution in terms of algorithm complexity.

$$y(n) = \begin{cases} -CL, & if\ x(n) < -CL \\ x(n), & if -CL \leq x(n) \leq CL \\ CL, & if\ x(n) > CL \end{cases} \tag{4}$$

where *y(n)* is the signal obtained after applying clipping and filtering, *x(n)* is the OFDM signal with high PAPR and *CL* is desired power level. Main drawback of the clipping is that it is a nonlinear process and leads to both in-band and out-of-band distortions [14]. In –band distortion introduces BER performance degradation and cannot be limited by filtering. However, oversampling by taking longer IFFT can reduce the in-band distortion. While the out of band distortion causes spectral spreading this can be eliminated by filtering the clipped OFDM signal. Filtering will preserve the spectral efficiency and, hence, improving the BER performance but it can results in some peak power regrowth.

Different methods are proposed to mitigate the harmful effects of the amplitude clipping. In [15] a method is proposed in which the signal is iteratively reconstruct before clipping is done. This method is based on the fact that clipping noise effect will be mitigated when decisions are made in the frequency domain. When the decisions are converted back to the time domain, the signal is recovered from the harmful effects of clipping, although this may not be perfect. An improvement can be made by repeating the above procedures. Performance degradation from clipping is also compensate by reconstruct the clipped samples based on the other samples in the oversampled signals. In [16] oversampled signal reconstruction is used to compensate for signal-to-noise ratio (SNR) degradation due to clipping for low values of clipping threshold. In [17] BER performance is improved by iterative estimation and cancellation of clipping noise. This technique is developed on the fact that clipping noise is generated by a known process that can be recreated at the receiver and subsequently removed.

 

### *B. Peak Windowing*

The main difference between peak clipping and peak windowing is that clipping will hard limit the peak that exceed a predetermined threshold, peak windowing limits such high peaks by multiplying them by a weighting function called a window function. Many window functions can be used in this process. Window function should have good spectral properties [4]. The most commonly used window functions include Hamming, Hanning and Kaiser windows. To reduce PAPR, a window function valley is multiplied by the signal peaks while its higher amplitudes are multiplied by lower amplitude signal samples around the peaks. This action attenuates signal peaks in a much smoother way compared to hard clipping. Peak windowing will reduce the distortion compare to peak clipping method.

### *C. Selective Mapping*

Selective Mapping method (SLM) is a distortion less PAPR reduction method [7]. In this technique, the transmitter generates a set of sufficiently different candidate data blocks, all representing the same information as the original data block, each block is multiplied with u different phase vectors and selects the most favourable for transmission.

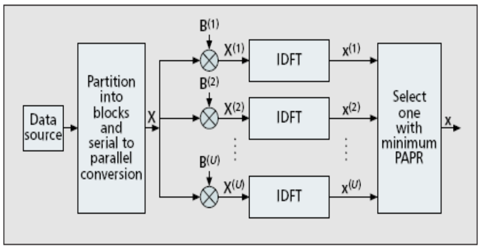


Fig. 4 : Block diagram of SLM techniques [1]

Information about the selected phase sequence should be transmitted to the receiver as side information to allow the recovery of original symbol sequence at the receiver, which reduces the data transmission rate. SLM needs to transmit $\lfloor log2U \rfloor$ bits as side information, where $\lfloor y \rfloor$ denotes the smallest integer that does not exceed *y*, and *U* IDFT operations for each data block. This approach is applicable with all types of modulation and any number of subcarriers. The amount of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences

### *D. Partial Transmit Sequence*

Partial Transmit Sequence (PTS) technique [5] is another method for PAPR without signal distortion. In this technique the input data block of *N* symbols is partitioned into disjoint subblocks. The subcarriers in each subblock are weighted by a phase factor for that subblock. The phase factors are selected such that the PAPR of the combined signal is minimized. Thus Peak to average power ratio has been reduced in OFDM using partial transmit sequence.

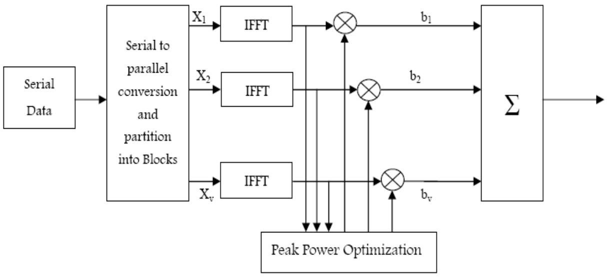


Fig. 5: Block Diagram of PTS Techniques [5]

Main drawback of the this technique are searching complexity increases exponentially with the number of subblocks and its need to transmit the phase factor information as side information to the receiver to extract the original signal.

### *F. Coding Method*

PAPR of the OFDM signal can be also reduced by encoding. Only a small fraction of all possible OFDM symbols have a high PAPR value. This statement suggests solution to the high PAPR problem based on coding. The PAPR value can be reduced by using a code that only produces OFDM symbols for which the PAPR value is below some threshold. Different coding scheme are used for encoding. Block codes [9] and Turbo codes [8] are commonly used. Drawbacks of coding method are it needs to perform exhaustive search and need large look up table to store the code words. The exhaustive search of a good code for OFDM systems with a large number of subcarriers is intractable, which limits the actual benefits of coding for PAPR reduction in practical OFDM systems. So an effective technique has to be developed to reduce PAPR with optimization in BER and transmitter and receiver complexity.

## V. PAPR REDUCTION USING LDPC CODES

The concept of coding technique helps to reduce the high peak of OFDM signal. Coding technique not only applicable for reducing the PAPR in OFDM systems but it also well suited for error correcting performance. The highlights of Low-density parity-check (LDPC) codes are they shows the theoretical limit values attain closer to the Shannon limit and perform good role in the PAPR reduction of OFDM systems.

LDPC codes are a class of linear block codes. They were first introduced by Gallager [18] in 1960. The name L comes from the characteristic of their parity-check matrix which contains only a few 1's in comparison to the amount of 0's. Like all linear block codes LDPC codes can also be described via matrices. Encoding and decoding steps of LDPC codes are described in [18]. LDPC codes shows better performance than Turbo codes [19].LDPC codes shows good block error correcting performance, low error flow and they suitable for parallel implementation. LDPC codes are equally suited for both low data rate as well high data rate applications depend upon the modulation being used.

New families of LDPC codes are introduced to reduce PAPR in OFDM systems. This will reduce the complexity and provide better PAPR performance. In [10] Invertible Subset LDPC (IS-LDPC) systems are introduced to reduce the PAPR in OFDM systems. An IS-LDPC code has a number of disjoint invertible subsets, and each invertible subset can be independently inverted to generate other valid code words of the LDPC code. Simulation result from [10] shows that IS-LDPC codes has higher PAPR reduction capability and error control capability than normal LDPC.

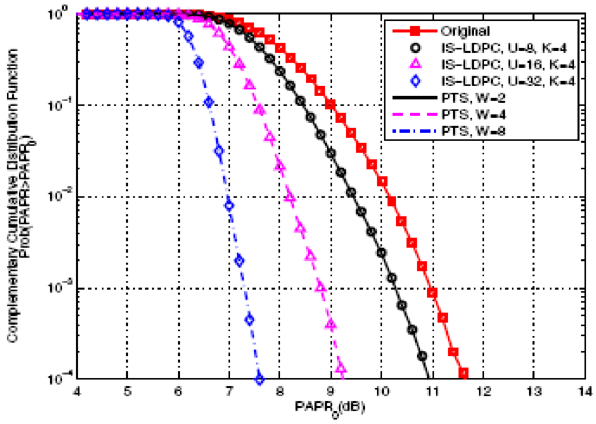


Fig. 6 : PAPR Performance of IS-LDPC Coded OFDM Systems [10]

In [21] Quasi Cyclic LDPC (QCLDPC) codes are used for PAPR reduction. QCLDPC will reduce the encoding complexity than LDPC codes.

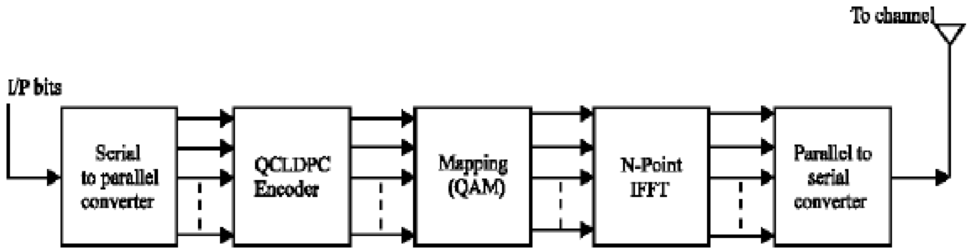


Fig.7 : Transmitter block Diagram of QCLDPC Encoder [21]

LDPC encoding is based on parity matrix 'H' where as QCLPDC codes can be constructed by applying circular shift. The H matrix is divided in to two matrices having equal number of rows and columns. Each row of these two matrices are obtained by applying one time cyclic shift of the previous row. The required memory size for storing party check matrix is reduced in QCLDPC by the use of circulant matrix.

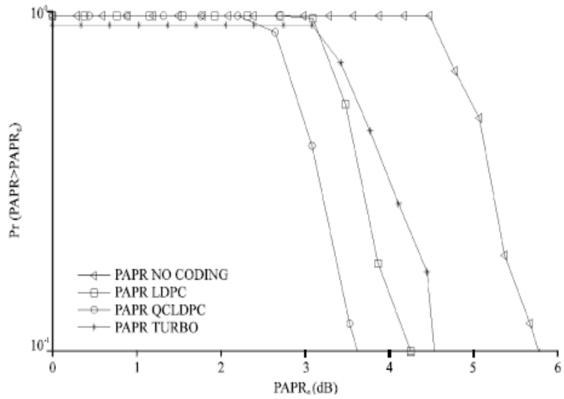


Fig. 8 : CCDF plot of PAPR reduction [20]

## VI. CONCLUSION

OFDM is an efficient multicarrier modulation technique for both wired and wireless applications due to its high data rates, robustness to multipath fading and spectral efficiency. Despite these advantages, it has the major drawback of generating high PAPR, which drives the transmitter's power amplifier into saturation, causing nonlinear distortions and spectral spreading. There are many different methods proposed for the purpose of reducing the PAPR of an OFDM signal.

 

The methods include Clipping, Partial Transmit Sequence, Selective Mapping and Coding. Amplitude clipping will reduce PAPR to desired value but as a result of this data loss will occurs. Partial Transmit Sequence and Selective Mapping techniques are distortion less PAPR reduction methods. Main drawback of these technique are searching complexity increases exponentially with the number of subblocks and its need to transmit the phase factor information as side information to the receiver to extract the original signal.

Channel coding in OFDM system can effectively reduce the PAPR. Ease of implementation and inherent error handling capability are the key benefits of coding based PAPR reduction. But this method has limitations like an exhaustive search to find the best codes and to store large lookup tables for encoding and decoding. Linear Block codes, Turbo codes and LDPC codes are commonly used to encode OFDM systems. LDPC codes exhibit better PAPR reduction than Block codes and Turbo codes.Modified LDPC codes such as IS-LDPC and Quasi cyclic LDPC shows better performance than LDPC. Survey highlights that the error performance of LDPC codes with higher inversion freedom are more practical. IS-LDPC codes also provide high bit error performance than LDPC. Quasi Cyclic LDPC codes reduce the PAPR effectively.

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