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A PEAK TO AVERAGE POWER RATIO (PAPR) REDUCTION IN OFDM SYSTEMS

RAMDAS P.KARHALE [1], PRADEEP N.NARWADE [2]

[1],Student, Electronics and Telecommunication, K.S.I.E.T ,Hingoli ,MH, India
[2] Assistant Professor, Electronics and Telecommunication, K.S.I.E.T ,Hingoli ,MH, India

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Abstract - ***Communication is one of the important aspects of life. With the advancement in age and its growing demands, there has been rapid growth in the field of communications. Signals, which were initially sent in the analog domain, are being sent more and more in the digital domain these days. For better transmission, even single carrier waves are being replaced multi-carriers. In this paper, the scheme of amplitude clipping & filtering method is proposed which shows the significant improvement in case of PAPR reduction while increasing slight BER compare to an existing method. The OFDM signals is proposed, which utilizes the parabolic peak cancellation (PPC) using the truncated kernel signal generated from the inverse fast Fourier transform (IFFT) of the shaped peak reduction tones (PRTs). The proposed scheme only repeats peak canceling in the time domain without iteratively performing IFFT and FFT. Numerical analysis shows that if the shaping parameters of PRTs are chosen properly, out-of-band (OOB) radiation and BER can be improved while the PAPR reduction performance is maintained. In this paper the clipping & filtering, parabolic peak cancellation scheme proposed for reducing the PAPR .An empirical CCDF is the most informative metric used for evaluating the PAPR. PAPR reduction capability is measured by the amount of CCDF reduction achieved. CCDF provides an indication of the probability of the OFDM signal's envelope exceeding a specified PAPR threshold explain with graph. The goal is to convey the fundamental ideas and intuitive understanding of the concept introduced. This is done primarily to give an overview of the various techniques known today for PAPR reduction.***

Key Words: OFDM, BER, PPC, *IFFT, FFT , PRTs ,OOB , CCDF.*

1. OFDM SYSTEM MODEL AND NOTATION
1.1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is an orthogonal multicarrier communication system. Bandwidth efficiency, high data rate and immune to fading makes the OFDM systems preferred choice for modern communication system and are being implemented in many modern communication systems like Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), Wireless Local Area Network (WLAN) and Long Term Evolution (LTE). Although OFDM gives many advantages, it suffers from many technical difficulties. Few of these difficulties include tight frequency synchronization, time offset, peak to average power ratio (PAPR) and channel estimation.[1].In a multicarrier communication system, like OFDM, independent phases of subcarriers may have constructive or destructive effect. When all subcarriers have same phase then the constructive effect gives high peak amplitude and produces high peak to average power ratio (PAPR). If amplitude of the OFDM signal is greater than linear range of transmitter amplifier, the amplifier may operate in saturation region which leads to nonlinear distortion. To mitigate this high PAPR many methods have been used .However, a well known disadvantage of OFDM is the occasional occurrence of high peak-to-average power ratio (PAPR) in the time-domain signal [2].

The simplest technique to mitigate nonlinearity around the peak is clipping technique. Since OFDM signal is bounded in frequency, not in time, clipping technique suffers from in-band and out-bands radiations thereby, destroying the orthogonal among subcarriers. Clipping technique includes clipping and filtering, peak windowing and peak canceling as mentioned . Several techniques have been proposed to mitigate the PAPR problem of the OFDM signals such as clipping, clipping and filtering ,selected mapping (SLM) , partial transmit sequence (PTS) , tone reservation (TR) , active constellation extension (ACE) , and so on [3],[4].Clipping is the simplest method which reduces the amplitude of OFDM signal to the threshold level, but it generates in-band distortion and OOB radiation resulting in bit error rate (BER) degradation and interference to the adjacent channels, respectively.

In the future, OFDM systems are expected to assume greater importance in high speed wireless telecommunications systems, both fixed and mobile. The evolution of the physical layer of such high speed networks points to the use of OFDM systems with a large number of subcarriers with potentially high PAPR. Consequently, mitigation solutions are expected to gain increased interest and spur further research. Although the topic of PAPR reduction has been surveyed in the literature [5],

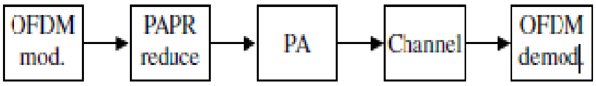

Figure 1.Block diagram of OFDM system.

Figure 1 shows the system under consideration. The PAPR reduction block aims to reduce the effect of the PA. Several PAPR reduction schemes have been suggested in the literature [6]. In particular, signal clipping has been suggested as a simple and effective reduction scheme [7], [8]. This paper evaluates the effectiveness of clipping when taking into account the presence of the PA. It is argued that a PAPR reduction scheme should provide one of the two equivalent enhancements: 1) a reduced error floor at a given back off, or 2) a reduced required IBO to achieve a target BER. This paper addresses the later by measuring the total degradation (TD) of the OFDM system, at various IBO and various clipping ratios. It is shown that clipping, while offering substantial PAPR reduction, doesn't improve total degradation. In fact, it is shown that the unclipped system outperforms the clipped system .

1. 2. CONCEPTUAL MODEL OF OFDM SYSTEM

OFDM is a special form of multicarrier modulation with densely spaced subcarriers with overlapping spectra, thus allowing multiple-access. It works on the principle of transmitting data by dividing the stream into several bit streams, each of which has a much lower bit rate and by using these sub-streams to modulate several carriers.

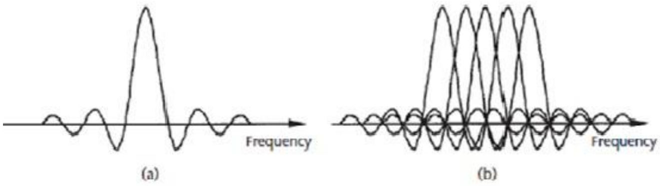

Figure 2. Frequency spectrum a)Single carrier b) multicarrier

In multicarrier transmission, bandwidth divided in many non-overlapping subcarriers but not necessary that all subcarriers are orthogonal to each other as shown in figure 2 (a) [9]. In OFDM the sub-channels overlap each other to a certain extent as can be seen in figure 2 (b)[10], which leads to an efficient use of the total bandwidth. The information sequence is mapped into symbols, which are distributed and sent over the N sub-channels, one symbol per channel. To permit dense packing and still ensure that a minimum of interference between the sub-channels is encountered, the carrier frequencies must be chosen carefully. By using orthogonal carriers, frequency domain can be viewed so as the frequency space between two sub-carriers is given by the distance to the first spectral null.

1.3 Mathematical Explanation of OFDM Signals

OFDM can be generated using multiple modulated carriers transmitted in parallel. However, this method involves implementation problems and makes transmitters more complex and expensive. This problem can be avoided by the use of the *discrete Fourier transform* (DFT) technique [4]. Consider a data stream with rate R bps where bits are mapped to some constellation points using a digital modulation like the QAM. Let N of these constellation points be stored for an interval of $Ts = N/R$, referred to as the OFDM symbol interval. A serial-to-parallel converter is used to achieve this. Now, each one of the N constellation points is used to modulate one of the subcarriers, then, all modulated subcarriers are transmitted simultaneously over the symbol interval Ts . The OFDM signal $x(t)$ can be expressed as

$$x(t) = \sum_{k=1}^{N-1}(a_k \exp\ (j2\pi(fc + k\Delta f)t)) \qquad (1)$$

$$=\exp(j2\pi fct)a(t) \text{ where ak } 0 \leq k \leq N-1 \qquad (2)$$

where ak, $0 \leq k \leq N - 1$, are complex-valued constellation points representing data and $fk = fc + k\Delta f$, $0 \leq k \leq N - 1$, is the kth subcarrier, with fc being the lowest subcarrier frequency. Δf is the frequency spacing between adjacent subcarriers, chosen to be $1/Ts$ to ensure that the subcarriers are orthogonal. If $a(t)$ is sampled at rate R samples per second, where t is replaced by nTs/N, $n = 0, . . .,N-1$, then $a(t)$ is represented by the sampled function $a[n]$ expressed as

$$a[n] = \sum_{k=0}^{N-1} ak\ e\times p\ (j2\pi\, {}^{kn}/_{N}) \qquad (3)$$

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 [11]. Equations (2) and (3) demonstrate that OFDM can be generated by modulating the IFFT of the sequence $\{a[n],\ 0 \leq n \leq N - 1\}$ by a single carrier of frequency fc instead of by modulating N constellation points by subcarriers. IFFT reduces the computational complexity in comparison to IDFT. The above observation leads us to conclude that IFFT should be the preferred choice for OFDM systems implementation. After demodulating the received signal, the receiver carries out the reverse process of that of the transmitter during each OFDM symbol interval by employing FFT, a parallel-to-serial converter, and a de-mapping to recover the desired data bit stream [3].

2. PEAK TO AVERAGE POWER RATIO

The PAPR (Peak to Average Power Ratio) is the ratio between the maximum powers of OFDM signal and the average power of that OFDM signal. In a multi-carrier system the various sub-carriers are out of phase where the PAPR occurs. When at different phase values they are different with each other. When all points have the maximum value, it will create envelope in output side to suddenly cause a „Peak" in the envelope output. Due to large number of sub-carriers in an OFDM system is high when comparing to the average value of the OFDM system. The ratio of the peak power within average power is known as PAPR.

2.1PEAK-TO-AVERAGE POWER RATIO AND SYSTEM PERFORMANCE

PAPR is widely used to evaluate this variation of the output envelope. PAPR is an important factor in the design of both high power amplifier (PA) and digital-to-analog (D/A) converter, for generating error-free transmitted OFDM symbols. 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. Consider the OFDM signal $x(t)$ defined in (2) where N subcarriers are added together. If N is large enough, then, based on *central-limit theorem* (CLT), the resulting signal $x(t)$ will be close to a complex Gaussian process [12]. This means that both of its real and imaginary parts are Gaussian distributed

and its envelope and power follows Rayleigh and exponential distributions respectively. The PAPR for the continuous-time signal $x(t)$ is the ratio of the maximum instantaneous power to the average power. For the discrete-time version $x[n]$, PAPR is expressed as

$$\mathrm{PAPR}(x[n]) = \max\frac{|x[n]|^2}{E[|x[n]|^2]} \qquad (4)$$

where $E[.]$ is the expectation operator. It is worth mentioning here that PAPR is evaluated per OFDM symbol. Figure 3 illustrates how a high peak is obtained by adding four sinusoidal signals with different frequencies and phase shifts coherently. The resulting signal's envelope exhibits high peaks when the instantaneous amplitudes of the different signals have high peaks aligned at the same time. Such high peaks will produce signal excursions into nonlinear region of operation of the *power amplifier* (PA) at the transmitter, thereby leading to nonlinear distortions and spectral spreading [13]. Since IFFT is used to generate the OFDM signal, the resulting discrete-time OFDM signal samples are obtained at the Nyquist -rate. The peak value computed using these samples may not coincide with the peak value of the continuous-time OFDM signal. Hence, oversampling by a factor greater than 1 is used to increase the accuracy. It is found that the PAPR of the oversampled discrete-time signal offers an accurate approximation of the PAPR of the continuous-time OFDM signal if the oversampling factor is at least 4 . References [14] and [15] provide a detailed discussion about the relationship between the oversampled OFDM signal's PAPR and the continuous signal's PAPR l. While PAPR considers only the main peak of power, CM accounts for the secondary peaks of power that affect the PA performance due to the cubic term The performance of a PAPR reduction scheme is usually demonstrated by three main factors: the *complementary cumulative distributive function* (CCDF), *bit error rate* (BER), and *spectral spreading*. While CCDF is independent of the characteristics of the PA used at the transmitter, the other two factors are considerably affected. There are also other factors to be considered such as transmitted signal power, computational complexity, bandwidth expansion and data rate loss.

2.2 Complementary Cumulative Distributive Function

In practice, the empirical CCDF is the most informative metric used for evaluating the PAPR. PAPR reduction capability is measured by the amount of CCDF reduction achieved. CCDF provides an indication of the probability of the OFDM signal's envelope exceeding a specified PAPR threshold within the OFDM symbol and is given by

$$\mathrm{CCDF}\,[\mathrm{PAPR}\,(x^n(t))] = \mathrm{prob}[\,\mathrm{PAPR}(\,x^n(t) > \delta)] \qquad (5)$$

where PAPR $(x^n(t))$is the PAPR of the *nth* OFDM symbol and δ is some threshold. Based on the CLT, the envelope of the OFDM signal follows the Rayleigh distribution and consequently its energy distribution[16] becomes an exponential, or equivalently, a central chi-square distribution with two degrees of freedom and zero mean with a CDF given by

$$\mathrm{CDF}\,(\delta) = (1\text{-}e^{\delta}) \qquad (6)$$

The probability that the PAPR of the OFDM signal with N subcarriers is below a threshold δ is the probability that all the N samples are below the threshold

$$\mathrm{Prob}\,(\mathrm{PAPR}<\delta) = \mathrm{CDF}\,[\mathrm{PAPR}\,(x^n(t)] \qquad (7)$$

$$=(1 - e^{-\delta})^N \qquad (8)$$

2.3 NONLINEARITY AND POWER AMPLIFIER MODELS

Multicarrier modulated signals like the OFDM signal are more sensitive to the nonlinearities encountered in the transceivers than constant envelope signals. The sources of nonlinearity include: nonlinearity in the FFT and IFFT blocks due to the limited binary word length, signal clipping and quantization errors due to the digital-to-analog and analog-to digital conversions, and nonlinearity of the PA. However, due to the high PAPR in multicarrier modulations, the nonlinearity of the PAs have the dominant effect. Therefore, precise models for the characteristics of the PAs must be defined. In general, modeling PAs is complicated, but a common approach is to model them as memory less nonlinearities with frequency-nonselective response [17]. The most efficient operating point for a PA is at the saturation level. However, high peaks encountered in OFDM signals can drive the PA into saturation. The IBO factor is defined as the ratio between the saturation power of the PA and the average power of the input signal. In *decibel* (dB) scale, IBO is given by

$$\mathrm{IBO} = 10 log_{10} \left(\frac{P_{sat}}{P_{AV}}\right) \tag{9}$$

$$= 10 log_{10} \left(\frac{x_{sat}^{2}}{E[1x(t)]^{2}}\right)$$

$$= [P_{sat}]_{dB} - [P_{av}]_{dB} \tag{10}$$

where [*Psat*]*dB* and [*Pav*]*dB* are the saturation and average powers in dB, respectively. To ensure that the amplified peaks of the OFDM signal do not exceed the saturation level, IBO should be at least equal to PAPR. However, such solution forces the PA to work at a reduced efficiency.

3. PAPR Reduction Techniques

There have been many new approaches developed during the last few years. Several PAPR reduction techniques have been proposed in the literature. Some techniques are describe below. The most efficient technique is parabolic peak cancellation

3.1 Peak Cancellation

In this technique, a peak cancellation waveform is appropriately generated, scaled, shifted and subtracted from the OFDM signal at those segments that exhibit high peaks. The generated waveform is band limited to certain peak cancellation tones that are not used to transmit data [18], [19]. Peak cancellation can be carried out after the IFFT block of the OFDM transmitter as shown in Fig. 3 by subtracting the peak cancellation waveform from the OFDM signal whenever a potential peak higher than a certain threshold is detected.

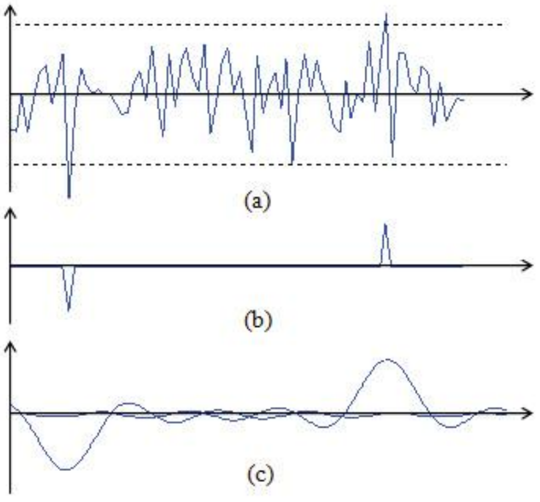

Fig. 3. Peak Cancellation; (a) OFDM signal, (b) identified peaks, (c) scaled and shifted peak cancellation waveform.

Fig. 3(a) illustrates a segment of an OFDM signal with 256 subcarriers. Figure 3(b) shows the detected potential peaks of the signal and Fig. 3(c) shows a randomly chosen *sinc* function as the peak cancellation

3.2 Clipping and Filtering

One of the simplest signal distortion methods is the method of clipping the high peaks of the OFDM signal prior to [16] passing it through the PA. This method employs a clipper that limits the signal envelope to a predetermined *clipping level* (CL) if the signal exceeds that level; otherwise, the clipper passes the signal without change [71], as defined by

$$T(x[n]) = \begin{cases} x[n], & if\,|x[n]| \leq CL \\ CLe^{j\angle x[n]}, & if\,|x[n]| > CL \end{cases} \tag{11}$$

where *x*[*n*] is the OFDM signal, *CL* is the clipping level and ∠*x*[*n*] is the angle of *x*[*n*]. Clipping is a nonlinear process that leads to both in-band and out-of-band distortions [20]. While the latter one causes spectral spreading and can be eliminated by filtering the signal after clipping, the former can degrade the BER performance and cannot be reduced by filtering [21]. However, oversampling by taking longer IFFT can reduce the in-band distortion effect as portion of the noise is reshaped outside of the signal band that can be removed later by filtering. Filtering the clipped OFDM signal can preserve the spectral efficiency by eliminating the out-of band distortion. The impact of clipping on PAPR reduction and channel capacity is studied in [21]. Reference [22] presented a modified repeated clipping and filtering scheme which limits the distortion on each tone of the OFDM to achieve both low PAPR and low BER with fast convergence. The simulations are conducted for the OFDM signal without clipping and when clipping is used with a *clipping ratio* (CR) of 1dB and 5dB. The CR is related to the clipping level by the expression

$$\mathrm{CR}=20log_{10}\left(\frac{CL}{E\,|x[n]|}\right) \tag{12}$$

where $E[x[n]]$ is the average of the OFDM signal $x[n]$. The results presented in Fig. 9 show that as the CR is reduced, the CL is lowered down and more parts of the OFDM signal are clipped and hence, the BER is increasing and the empirical CCDF is decreasing.

3.3PARABOLIC PEAK CANCELLATION USING SHAPED PRTs

Assume that input symbols a_k are independent and identically distributed random variables. Then a[n] 's are also mutually independent when they are sampled at the Nyquist-rate[3]. However, a[n] 's may not be mutually independent if the OFDM signals are oversampled. It is known that clipping noise of continuous-time OFDM signals can be approximated as a series of parabolic pulses and each parabolic pulse has one local minimum or maximum if CL is large enough [23]as shown in figure 4. In [23], it is also proven that the correlation coefficient of continuous-time OFDM signal x(t) is given as

$$\rho_a(\Delta t)=\frac{\sin(\pi N\Delta t/T)}{N\sin(\pi\Delta t/T)}e^{-j\pi\Delta t/T} \tag{13}$$

Therefore, oversampled discrete OFDM signal a[n] can be expressed by replacing Δt withnT_s/JN in (1)where is the oversampling factor, and the resulting correlation coefficient of a[n] is given as

$$E[a[n]a^*[n+r]]=\frac{\sin(\pi\tau/J)}{N\sin(\pi\tau/JN)}e^{-j\pi\tau/JN} \tag{14}$$

and the magnitude becomes

$$|\rho_a(\tau)| = \left|\frac{\sin(\pi\tau/J)}{N\sin(\pi\tau/JN)}\right| = \left|\frac{\sin(\pi\tau/J)}{\pi\tau}\right| \tag{15}$$

when $^{\pi\tau}/_{JN}$ is very small. It implies that the samples within the range of $\pm Ja[n]$ of a[n] are correlated. Since the clipping noisec_n= a[n]-a$[n]$ with parabolic shape is also portion of a[n] , it can be said that the non-zero samples within the range of $\pm J$ of are also correlated. Since the samples within the mainlobe of kernel signal are also correlated, applying peak canceling to each sample in a parabolic pulse is costly inefficient and even degrades the peak reduction performance. Instead, it is enough to apply only one peak canceling to the sample with the largest amplitude in each parabolic pulse.

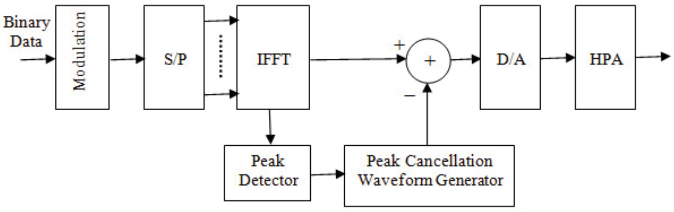

Fig. 4. Peak cancellation in OFDM transmitter

The number of parabolic pulses in an OFDM signal sequence can be estimated from the level-crossing theory [23], [24]. That is, the number of upward crossings of the threshold level CL is equivalent to the number of parabolic pulses if is CL large enough. However, it is not true for small CL because there can be more than one adjacent parabolic pulses for one upward crossing, which means that the amplitude of OFDM signal may have more than one local maxima in one upward crossing. Therefore, the number of parabolic pulses is defined as the number of all local maxima among a[n] 's having the amplitude larger than CL. Now, a new peak cancellation scheme named PPC is proposed, where peak signals in are reduced by applying one peak canceling to each parabolic pulse. Suppose that the number of parabolic pulses is N_r and $T=\{l_{0,\dots,\dots,}l_{N_r-1}\}$ is the ordered set of indices a[n] of satisfying the following condition The peak canceling is applied to the samples with the indices in T. Then the peak reduced OFDM signal is represented as

$$a[n1]=a[n]+p[n] \tag{16}$$

$$=a[n]+\sum_{r=0}^{n_r-1}\alpha l_r\,g(n-l_r) \tag{17}$$

The PPC in (13) can also be repeated to achieve the desired PAPR reduction performance as the simulation results in Section 4 show that two or three repetitions of are enough to reduce the PAPR to the moderate PAPR threshold level .

4. Simulation Results for PAPR Reduction

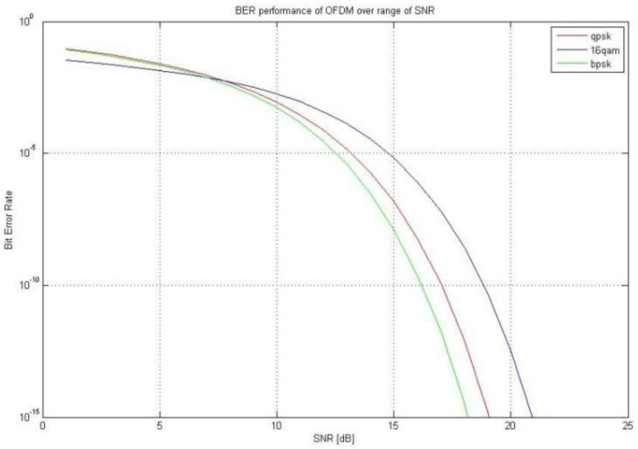

Figure 5 .BER Performance of OFDM signal with SNR

In this section, the theoretical analysis is verified by ATLAB simulations. The OFDM system is with a total number of sub-carriers *N* =64 and an over-sampling factor *J* . For peak cancellation, the is a sinc function with the normalized amplitude threshold . In Figure 1, the SNR via BER of peak-cancellation combined with OFDM is investigated over AWGN channel through QPSK ,16QAM,BPSK modulation. It is shown that the theoretical and empirical results match well. Furthermore, the BER performance becomes worse with the decrease of the normalized amplitude threshold γ. In this case, lower PAPR is achieved at the cost of more nonlinear distortion.

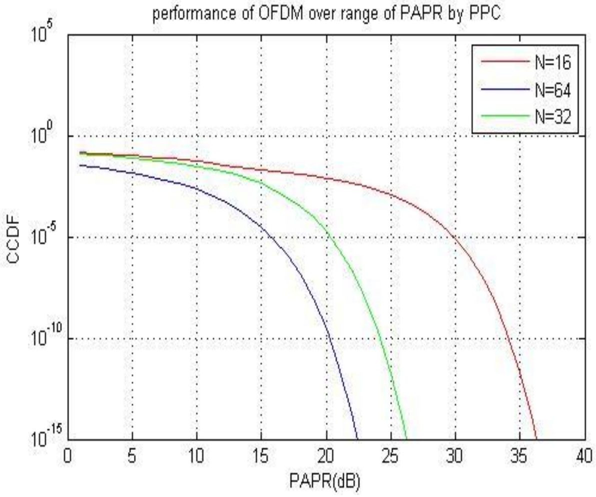

Figure 6 . Performance of OFDM over PAPR

In Figure 6, the PAPR via *CCDF* is investigated through 16QAM modulation for different sub carriers in N=16,32,64. On the one hand, the performance by using parabolic peak cancellation ,degradation of peak cancellation gets much severer with the decrease of constellation distance. On the other hand, the theoretical results match with the simulation results very well.

5. CONCLUSIONS

In this paper, a scheme of parabolic peak cancellation based PAPR reduction technique has been analyzed where PAPR reduces significantly compare to an existing method with slightly increase of BER. At first phase, simulation has been executed for existing method with QPSK ,16QPSK,BPSK modulation and number of subscriber N =64and then executed for the proposed method for same parameter and observed that PAPR reduces significantly. Next, the simulation has been performed for 16QAM modulation & various N values and result shows the considerable improvement in case of16 QAM also. Then, the proposed method results for 16 QAM. In the present simulation study, ideal channel characteristics have been assumed. In order to evaluate the OFDM system performance in real world, multipath fading will be a consideration in future. The increase number of subscribers (N) & other parameters can be another assumption for further study.

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