COMPARISON OF PAPR REDUCTION TECHNIQUES IN OFDM SYSTEM

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Abstract: In recent years, there is rapid growth in multimedia based application which requires the technology that supports high speed data transmission. To achieve this high speed communication orthogonal frequency division multiplexing (OFDM) is most widely technology. OFDM system contains orthogonal subcarriers for data transmission with efficient usage of available bandwidth. However as number of subcarriers goes on increasing, Peak to average power ratio (PAPR) of OFDM signal also increasing. This high PAPR causes significant distortions when passed through non-linear amplifier. A number of promising techniques have been proposed &implemented to reduce PAPR of OFDM signal with expense of transmitted signal power, Bit error rate (BER), complexity etc. In this paper, amplitude clipping and filtering (ACF), interleaved OFDM (IOFDM) and linear block code (LBC) schemes are implemented and compared for PAPR reduction of OFDM signal at transmitter. We have presented PAPR and BER performance of the system for these PAPR reduction techniques

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Peak to-Average Power Ratio (PAPR), Bit Error rate (BER), Complementary Cumulative Distribution Function (CCDF)

I. INTRODUCTION

Demands on wireless communication services increases rapidly, as wireless communication area improving in the very fastest way. Single carrier scheme is easy to use for low data rates because of its simplicity, accuracy. Single carrier scheme saves more power since there is no need to add guard interval while transmitting the signal. Single carrier scheme may have some drawbacks for high data rates including equalizing complexity. OFDM is used to overcome the drawback of single carrier system. Multicarrier (MC) modulation is a widely adopted technique in wireless communications because of its advantages. Here the orthogonal subcarriers uses Fourier transform without addition inter-carrier interference (ICI).

OFDM system have main drawback of high peak-to-average power ratio (PAPR). An inherent property of MC transmission schemes is the high dynamic range of the transmitted signal. The theoretical value of the PAPR is given by the number of subcarriers in use. The probability of having such high peaks is marginal in systems with enough subcarriers, but still in practice the PAPR of MC signals is much higher than in case of single carrier signals [1]. The high dynamic range of the MC signals causes a problem in most communication systems, since the signal has to be amplified by a power amplifier (PA) at the transmitter. Practical PAs do not maintain linearity over the whole dynamic range of the MC signal, thus amplifying different parts of the signal differently. This distorts the MC signal, resulting in a reduced bit error rate (BER) performance and also in a spectral regrowth, basically radiating energy at frequencies adjacent to the signal and at higher values than originally planned [1].

A number of approaches have been proposed and implemented to reduce PAPR which falls under different categories like signal distortion techniques, multiple signaling and probabilistic techniques and coding techniques with further classification in each category [2].

II. FUNDAMENTALS OF OFDM SYSTEM and PAPR

In this section, we discuss about the basics concept of OFDM systems and overview of PAPR in OFDM, mathematical formula for PAPR & the motivation of reducing PAPR.

A. Basic OFDM

OFDM is a combination of modulation and multiplexing which is also known as special case of multicarrier modulation (MCM) scheme. OFDM system transmits a high-speed data stream by dividing it into a number of orthogonal channels, referred to as subcarriers, each carrying a relatively-low data rate. This procedure partitions the transmission frequency band into multiple narrower subbands, where each data symbol's spectrum occupies one of these subbands. As compared to the conventional frequency division multiplexing (FDM), where such subbands are non-overlapping, OFDM increases spectral efficiency by utilizing subbands that overlap (Fig. 1). To avoid interference among subbands, the subbands are made orthogonal to each other, which mean that subbands are mutually independent [2]. Also guard interval (GI) between consecutive OFDM symbols is inserted to remove effects of ISI, which is usually introduced by frequency selective multipath fading in a wireless environment.

B. Mathematical Formula Of OFDM Signal

In OFDM systems, a fixed number of successive input data samples are modulated first (e.g., PSK or QAM), and then jointly correlated together using inverse fast Fourier transform (IFFT) at the transmitter side. IFFT is used to produce orthogonal data subcarriers. Let, data block of length Nis represented by a vector, $X=[X_0, X_1 \ldots X_{N-1}]^T$. Duration of any symbol X_K in the set X is T and represents one of the sub-carriers set. As the N sub-carriers chosen to transmit the signal are orthogonal, so we can have, $f_n = n\Delta f$, where $n\Delta f = 1/NT$ and NT is the duration of the OFDM data block X. The complex data block for the OFDM signal to be transmitted is given by [3],

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \, e^{j2\pi n\Delta \mathrm{f t}} \qquad 0 \le t \le NT$$

Where,

$j = \sqrt{-1}$, Δf is the subcarrier spacing and NT denotes the useful data block period.

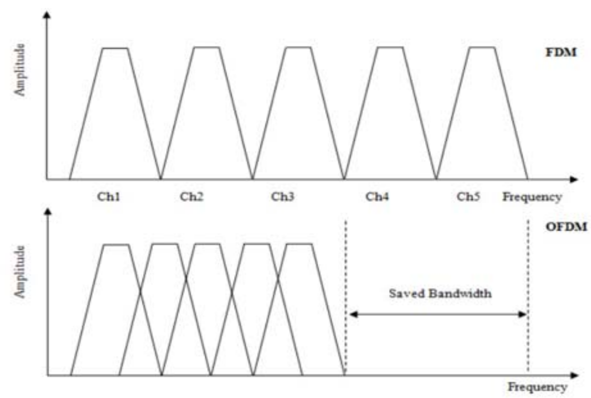

Fig.1. Comparison of the spectral utilization efficiency between FDM and OFDM schemes

C. Overview Of PAPR

When the OFDM signal is transformed to time domain, the resulting signal is the sum of all the subcarriers, and when all the subcarriers add up in phase the result is a peak N times higher than the average power. High PAPR degrades performance of OFDM signals by forcing the analog amplifier to work in the nonlinear region, distorting this way the signal and making the amplifier to consume more power [4].

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 [2],

$$\mathrm{PAPR}(x[n]) = \max_{0 \le n \le N-1} \frac{|x[n]|^2}{E|x[n]|^2}$$

where E [.] is the expectation operator.

III. PAPR REDUCTION TECHNIQUES

A. Simple Clipping And Filtering (ACF) Technique

Clipping and filtering is one of the simplest methods of PAPR reduction in OFDM system. This is the method of clipping the high peaks of the OFDM signal before passing it through the power amplifier (PA). This is done with the help of clipper that limits the signal envelop to the predetermined level known as clipping level(CL),if the signal goes beyond the CL; otherwise clipper passes signal without any change[5]. The clipped signal is given by [2],

$$y[n] = \begin{cases} -CL, & if x[n] < -CL \\ x[n], & if -CL \leq x[n] \leq CL \\ CL\,, & if x[n] > CL \end{cases}$$

Where $x[n]$ is the OFDM signal, CL is the clipping level. Fig.2 shows OFDM signal transmission block diagram using simple clipping and filtering scheme [6].

Clipping is a nonlinear process that causes the distortion as source of noise, which falls in both in-band and out-of-band distortions [7].In –band distortion can degrade the BER performance and cannot be reduced by filtering. 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 [2].While the out of band distortion causes spectral spreading and can be eliminated by filtering the clipped OFDM signal which can preserve the spectral efficiency and, hence, improving the BER performance but it can results in some peak power regrowth.

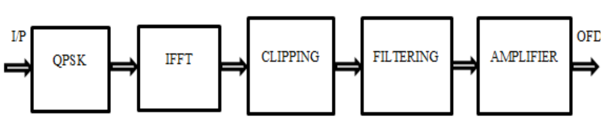

Figure. 2. OFDM signal transmission block diagram with clipping and filtering Technique

As clipping is a nonlinear process, it causes two types of distortions namely, in-band signal distortion and out of band signal distortion. In-band distortion causes BER performance degradation and out-of-band distortion imposes out-of-band interference signals to adjacent channels. Although the out-of-band signals caused by clipping can be reduced by filtering, it may affect high-frequency components of in-band signal (aliasing) when the clipping is performed with the Nyquist sampling rate in the discrete-time domain [8].Filtering the clipped signal can reduce out-of-band radiation at the cost of peak regrowth.

B. Iterative Clipping And Filtering (ICF) Technique

Iterative clipping and filtering (ICF) is a widely used technique to reduce the PAPR of OFDM signals and to overcome the limitations of simple amplitude clipping and filtering method. Fig.3 shows the basic block diagram of the ICF PAPR reduction scheme [9]. However, the ICF technique, when implemented with a fixed rectangular window in the frequency-domain, requires much iteration to approach the specified PAPR threshold in the complementary cumulative distribution function (CCDF) [9].

The proposed clipping is performed by using following formula [9],

$$\hat{x}_m(k) = \begin{cases} C_m e^{j\theta_m k}, & |x_m(k)| > C_m \\ x_m(k)\,, & |x_m(k)| \leq C_m \end{cases}$$

Where $1 \leq k \leq lN$, θ_m represents the phase of x_m , and c_m is the clipping level in the m-th iteration. Here clipping level is recalculated in each iteration according to a constant value known as the clipping ratio (CR) using following formula [9],

$$CR = \sqrt{PAPR_{\max}} = \frac{C_m}{\frac{1}{\sqrt{N}}\left\|x_m\right\|_2}$$

The filtering step is dependent upon a rectangular window with frequency response defined by [9],

$$F_m(i) = \begin{cases} 1, & 1 \leq i \leq N \\ 0, & N+1 \leq i \leq lN \end{cases}$$

The steps for proposed ICF method are described below:

Step 1: Set the value of clipping ratio (CR) and the number of iteration (M)

Step 2: A new OFDM symbol enters to ICF block loop

Step 3: Calculate the clipping level C_m and clip the signal x_m

Step4: Convert the clipped signalto frequency domain using FFT transform

Step 5: Filter the output of step 4

Step 6: Convert filtered signal into time domain using IFFT

Step7: Let, m = m +1, if m > M, reset m = 1 and go to step 2 and start processing the next OFDM symbol.

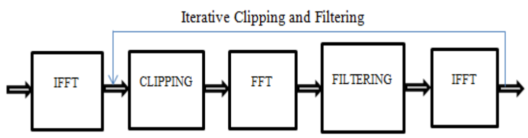

Figure 3.Basic block diagram of the ICF PAPR reduction technique

C. *Interleaved OFDM Technique*

Interleavers are used in this technique for the purpose of generating the multiple OFDM signals and these signals carry the same information [2]. Basically, an interleaver is a device that operates on a block of symbols and permutes or rearrange them in a specific way. These Permutations can be performed on either symbols or bits. To generate a set of different permutations from original signal, multiple interleavers are used so that PAPR at the transmitter of OFDM system decreases substantially [2]. When the interleaver operates on the block of N symbols and perform the permutation then, data block $X=[X_0, X1,\ldots, X_{N-1}]^T$ becomes $X' = [X_{\pi(0)}, X_{\pi(1)}, \ldots, X_{\pi(N-1)}]^T$ where $\{n\} \leftrightarrow \{\pi(n)\}$ is one to one mapping $\pi(n) \in \{0,1,\ldots,N-1\}$and for all n [3]. Here IDFT is calculated individually for each one of the different permutations for generating multiple OFDM signals. Then the OFDM signal which is having the smallest PAPR value is selected for the transmission. Fig.1 shows the block diagram of the interleaved OFDM transmitter.

For the comparison of PAPR of original data block with PAPR of M different OFDM signals, M-1 interleavers and M IDFT blocks are required [2]. Further in this technique, transmission of $[\log_2 M]$ side information bits to the receiver is required since to recover the original data block the receiver need to know which interleaver was used to generate selected low PAPR signal for transmission. According to the received side information then receiver of system evaluates FFT of received signal and performs de-interleaving operation. The permutation indices have to be stored in both the transmitter and receiver [2]. In this method, the amount of PAPR reduction depends upon two factors that are, the number of interleavers (M-1) and the design of interleaver [3].

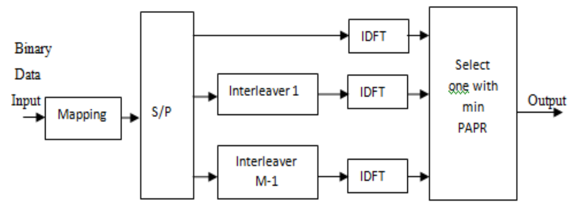

Fig.4. Block Diagram of Interleaved OFDM Transmitter

D. *Linear Block code (LBC)*

In coding theory, a linear code is an error correcting code and in this coding scheme any linear combination of codeword's is also a codeword. Linear codes allows for more efficient encoding and decoding algorithms as compare to other codes. Basically linear codes are used in forward error correction and are used in methods for transmitting symbols or bits on communication channel. Hence if any errors occur in the communication, some errors can be detected or corrected by the recipient of a message block. The codeword's in a linear block code are simply blocks of symbols which are encoded using more symbols than the original value to be sent. A cyclic code is a block code, where the circular shifting of each codeword results in another word that belongs to the code. Here PAPR is calculated for each codeword and the codeword wit low PAPR is selected for transmission. The block diagram of OFDM transmitter using linear block code scheme is shown in fig. 5.

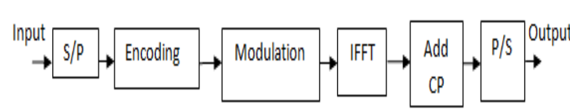

Fig.5. Block Diagram of OFDM Transmitter with LBC

IV. RESULTS AND DISCUSSION

The parameters used for simulation are based on IEEE 802.11a standard as shown in table.1.

The simulations are conducted first for simple clipping and filtering method to reduce PAPR value of OFDM signal with QPSK modulation and a clipping ratio(CR) of 1dB, 5dB and 7dB.The CR is related to the clipping level by the expression [2],

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

Where E[x[n]] is the average of OFDM signal x[n]. The empirical CCDF is the most regularly 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 [2],

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

Where PAPR ($x^n(t)$) is the PAPR of the n^{th} OFDM symbol and δ is some threshold.

Table I. Parameters Used for Simulation

Parameters	Value
RF Band	5 GHz
Channel Bandwidth	20 MHz
Modulation	QPSK
Number of subcarriers	52
Subcarrier spacing	312.50 KHz
FFT size	64
Channel model	Rayleigh channel
Noise model	AWGN

Fig. 6 shows the empirical CCDF versus PAPR plot for simple amplitude clipping and filtering method with different values of CR. From fig.6, it is found that as CR goes on decreasing from 7dB to 1 dB, empirical CCDF is decreasing and hence more reduction in PAPR from 7dB to 1 dB. The performance of a modulation technique can often be measured in terms of required signal-to-noise ratio (SNR) to achieve a specific bit error rate (BER). Fig. 7 shows the BER versus SNR plot for simple amplitude clipping and filtering method with different values of CR. Clipping the high peaks of the OFDM signal causes a substantial in-band distortion that leads to degradation in the BER performance. As shown in fig. 7, as CR goes on decreasing from 7dB to 1 dB, the BER is increasing.

Secondly, we evaluate the performance of Iterative clipping and filtering (ICF) technique. Fig.8 shows the CCDF versus PAPR plot of the iterative clipping and filtering with FFT/IFFT. The ICF scheme gives better performance compared with simple amplitude clipping and filtering techniques.

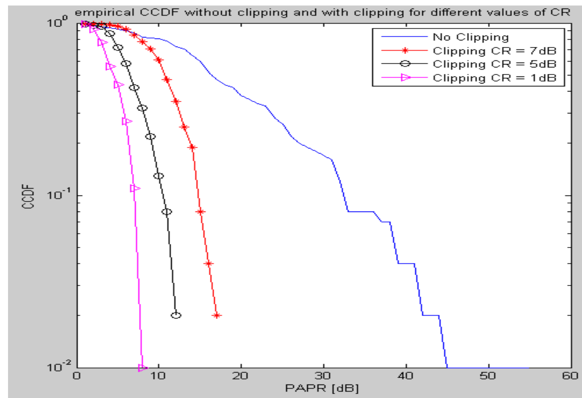

Fig.6. Empirical CCDF without clip and with clipping and filtering

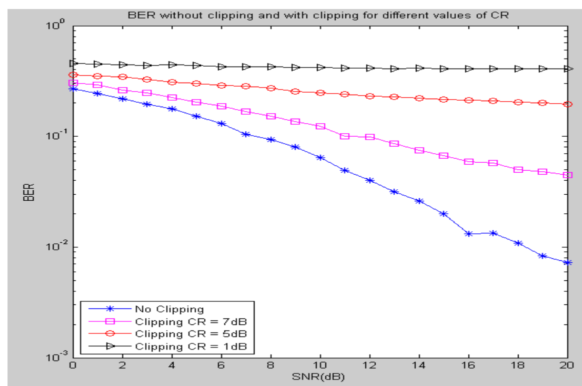

Fig.7. .BER without clipping and with clipping and filtering

Fig. 9 shows the BER performance and fig. 10 shows ccdf vs. PAPR plot for Interleaving technique. Interleaved OFDM technique gives better BER Performance but less PAPR reduction in comparison with previous PAPR reduction techniques.

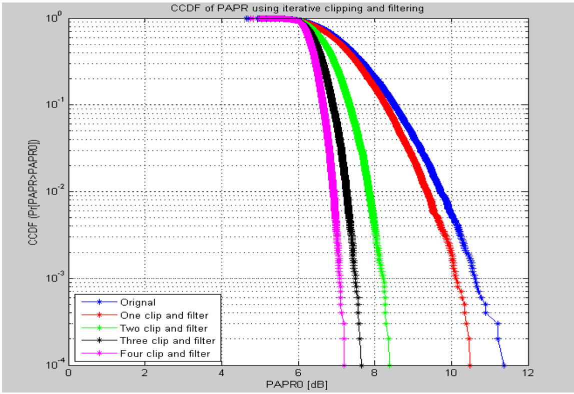

Fig.8. CCDF of PAPR using Iterative Clipping and filtering technique

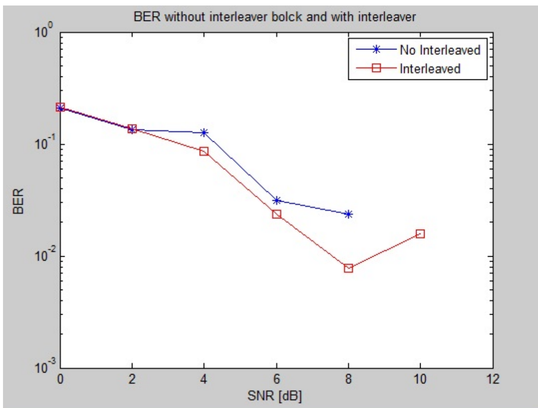

Fig.9.BER vs SNR without interleaving and with interleaving technique

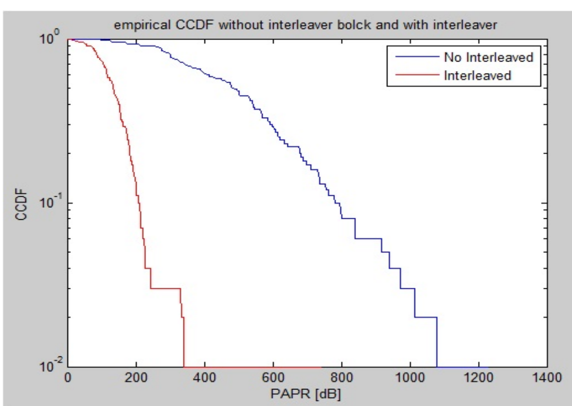

Fig.10. Empirical CCDF without interleaver and with interleaver

Next, the performance of linear block code scheme is evaluated with BPSK modulation and remaining parameters are same as given in table 1. Fig. 11 shows the ccdf vs. PAPR plot and fig.12 shows the BER performance of LBC technique. This technique gives better BER performance than clipping and filtering technique.

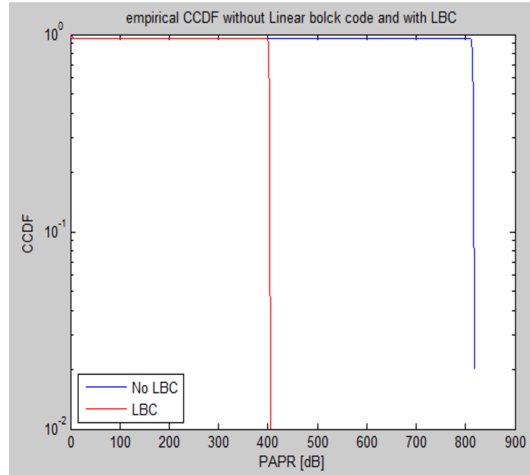

Fig.11. Empirical CCDF without LBC and with LBC technique

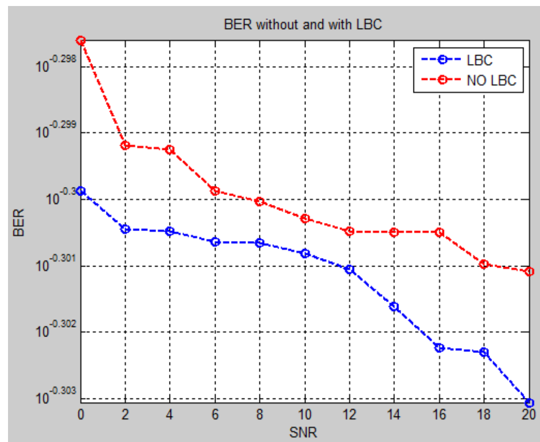

Fig.12. BER vs SNR without LBC and with LBC technique

V. CONCLUSION AND FUTURE WORK

OFDM is an efficient multicarrier modulation technique for both wired and wireless applications due to its high data rates and spectral efficiency. The major drawback in OFDM system is high peak-to-average power ratio. This high PAPR drives the transmitter's power amplifier into saturation, causing nonlinear distortions and spectral spreading. In order to minimize the effects of high PAPR in OFDM systems, clipping & filtering is a simple solution among all other PAPR reduction techniques. Simple amplitude clipping and filtering method causes the in band distortion which cannot be reduced by filtering .Filtering used to reduce out of band distortion results in peak power regrowth. Hence Iterative Clipping and Filtering (ICF) technique used to reduce both in- band distortion and peak power regrowth. It can be observe that OFDM signal has higher PAPR and after applying this method, PAPR reduces significantly. Also it is observed that as the number of clip and filter is increasing from one to four levels, PAPR value goes on decreasing. Interleaved OFDM technique gives better BER performance than clipping and filtering technique but results in much complexity. One can also use ICF with DCT/IDCT transformation to improve performance. Linear block code technique gives better BER performance but comparably less reduction in PAPR. Further one can go for combination of two or three techniques to overcome the problems and improve performance.

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