Investigating of The Reducing Techniques for The Peak to Average Power Ratio(PAPR) in OFDM Systems

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Abstract

High Peak to Average Power Ratio (PAPR) for OFDM system is still a demanding area and difficult issue. The radio transmitter stations for covering and getting enough transmit power in their desired area have to use High Power Amplifier (HPA). On the other hand, in order the HPA have the most output power efficiency must be designed to work close to the saturation region therefore due to the high PAPR of input signals a factor which is called memory-less nonlinear distortion will be come into the communication channels. We know the OFDM receiver's efficiency is sensitive to the HPA. If the high power amplifier doesn't work in linear region it can cause the out-of-band power to be kept under the specified limits. This condition can cause inefficient amplification and expensive transmitters, thus it is necessary to investigate PAPR reduction techniques for OFDM system. By now, for reducing PAPR in OFDM systems, numerous techniques have been recommended. In this paper the performance and the efficiency of a number of them will be discussed and evaluated and then we proposed our suggested method for a conventional OFDM system.

Key words:
Peak to Average Power Ratio (PAPR), High Power Amplifier (HPA), Orthogonal Frequency Division Multiplexing (OFDM), Clipping and Filtering (CAF)

1. Introduction

The average power ratio is defined as follows:

$$PAPR = 10log_{10}\left[\frac{P_{peak}}{P_{avg}}\right]$$

If we consider our signal tone as $r(t) = Acos(2\pi f_c t)$

$$P_{peak} = max\{|A^2cos^2(2\pi F_c t)|\} = A^2$$

$$P_{avg} = F_c\int_0^T A^2cos^2(2\pi F_c)dt$$

We know $T_c = \frac{1}{F_c}$ therefore:

$$P_{avg} = \frac{F_c}{2}\left\{\frac{A^2}{F_c} + \int_0^{1/F_c} A^2\cos(4\pi F_c t)\,dt\right\}$$

Since $\int_0^{1/F_c} A^2\cos(4\pi F_c t)\,dt = 0$

➡ $P_{avg} = \frac{A^2}{2}$

The PAR will be

$$PAPR = 10log_{10}\left[\frac{P_{peak}}{P_{avg}}\right] = 10log_{10}\left[\frac{A^2}{A^2/2}\right] = 3\ db$$

Now let's consider a signal as:

$$r(t) = Acos(2\pi f_1 t) + Bcos(2\pi f_2 t) \qquad (1)$$

To find its PAPR let's first find its peak and its average.
Its peak can be found by raising it to the power 2 and then taking its derivative and set it equal to zero.

$$\begin{aligned} r^2(t) = \frac{A^2}{2} + \frac{B^2}{2} + \frac{A^2}{2}cos(2\pi f_1 t) + \frac{B^2}{2}cos(2\pi f_2 t) \\ + ABcos(2\pi(f_1 - f_2)t) \\ + ABcos((f_1 - f_2)t) \end{aligned}$$

$$\frac{dr^2(t)}{dt} = 0$$

$$max\left[\frac{dr^2(t)}{dt}\right] = r^2(0) = (A + B)^2$$

The P_{avg} of Eq.1 will be as follows:

$$\begin{aligned} P_{avg} &= \alpha f_0 \int_0^{1/\alpha f_0} [Acos(2\pi f_0 t) + Bcos(2\pi\alpha f_0 t)]^2 dt \\ &= \frac{1}{2}(A^2 + B^2) \end{aligned}$$

Therefore:

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$$PAPR = 10log_{10}\left[\frac{P_{peak}}{P_{avg}}\right] = 10log_{10}\left[2+\frac{4AB}{(A^2+B^2)}\right]$$

Let's consider two scenario, first the amplitude of A is equal the amplitude of B and second the amplitude of A is much bigger than B.

If $A = B$ then we have:

$$PAPR = 10log_{10}\left[\frac{P_{peak}}{P_{avg}}\right] = 10log_{10}\left[2+\frac{4A^2}{(A^2+A^2)}\right]$$
$$= 10log_{10}(4) \cong 6\ db$$

If $A \gg B$ then we have:

$$PAPR = 10log_{10}\left[\frac{P_{peak}}{P_{avg}}\right] = 10log_{10}(2) \cong 3\ db$$

To summarize of the above discussion:

1. The PAPR for the signal that is made of M signal with the same amplitude and the same phase is:

$$PAPR = 20log_{10}(M)$$

2. The amount of PAPR is ruled by the amplitude of the signal.

Now let's consider the signal as a complex sinusoidal signal with the period T, as follows:

$$r(t) = e^{\omega t} = e^{2\pi f t}$$

The PAPR is:

$$PAPR = \frac{Max[r(t)r^*(t)]}{\frac{1}{T}\int_0^T exp^{4\pi f t}\,dt} = \frac{1}{1} = 1$$

Therefore a complex sinusoidal tone has a PAPR equal to one.

Since the OFDM signal is the summation of multiple sinusoidal with the frequency separation equal to $^1/_T$ which each of them modulated with independent a_n. The mathematical form of such a signal can be stated as:

$$r(t) = \sum_{0}^{N-1} a_n e^{\frac{2\pi n j t}{T}}$$

Let's for simplicity consider $a_n = 1$ so in this case the maximum expected PAPR for an OFDM signal with N subcarrier can be stated as follows:

$$PAPR = \frac{Max[r(t)r^*(t)]}{E[r(t)r^*(t)]} = \frac{N^2}{N} = N \qquad (2)$$

The Eq.2 is the max value of PAPR for an OFDM with N subcarrier if and only if all the subcarriers align in phase and modulated similarly and equally.

2. Techniques for reduction PAPR

In order to reduce the PAPR of a transmitted signal, many various techniques have been explored and investigated by now. The most approaches which have been used to reduce PAPR are: Clipping [1]–[2], Selective Mapping (SLM) [3]–[5], coding schemes [6]–[4], nonlinear compounding transforms [7]–[8], Partial Transmission Sequence (PTS), Tone Reservation (TR) and Tone Injection (TI) [9], [10].

These techniques can be divided into three main categories:

(i) Selecting mapping and Partial Transmission Sequence (PTS)
(ii) Clipping and Filtering (CAF)
(iii) Coding techniques

2.1 Selecting Mapping (SLM)

In Selecting Mapping (SLM) technique the multiple transmit signals that generated by multiplication of the different phase vectors with OFDM symbols, are taken and then the one that produce the most less PAPR will be selected. Naturally, when the receiver receives these signals and wants to recover the phase information, it needs to know which phase vector has been used in transmitter, that's why in this technique for letting the receiver to know which phase vector has been selected, sending a separate control signal is necessary. Fig.1 [11], shows the block diagram of the SLM technique.

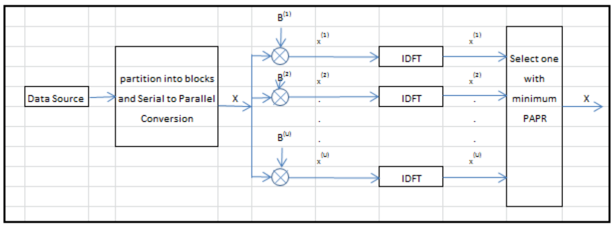


Fig.1 block diagram of the SLM technique [11]

For implementation, the SLM technique needs U IDFT operations, and the number of required side information bits is $\lfloor \log_2^U \rfloor$ for each data block.

2.2 Partial Transmission Sequence (PTS)

In Partial Transmission Sequence technique, the data block to be transmitted is partitioned into disjoint sub-blocks and the sub-blocks are combined using phase factors to minimize PAPR [12].

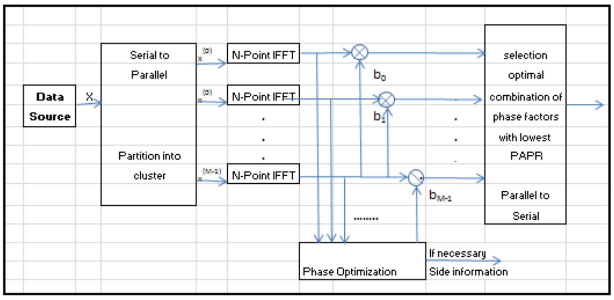


Fig.2 Block diagram of partial transmission sequence (PTS) approach

Fig.2 [13]; shows the block diagram of partial transmission sequence (PTS) approach. As it can be seen from Fig.2, PTS requires M IFFT operations for each data block, and the number of the required side information bits is $\lfloor M\log_2^M \rfloor$, where $\lfloor x \rfloor$denotes the smallest integer that does not exceed. Considering the method that PTS technique uses to reduce the PAPR reduction, two important issues come to the table, firstly high computational complexity for searching the optimal phase factors and then sending the information that the receiver must have them, in order to be able to do the correct decoding of the bit sequence that is transmitted from transmitter, but obviously, complexity will be the main point of view. In short, PTS in compare with SLM has less computational complexity and has a better PAPR reduction but SLM needs less bits of the side information.

2.3 Clipping and Filtering (CAF)

This technique by assigning a set point level, clips the time domain signal to the pre-assigned set point level. (See Fig. 3)

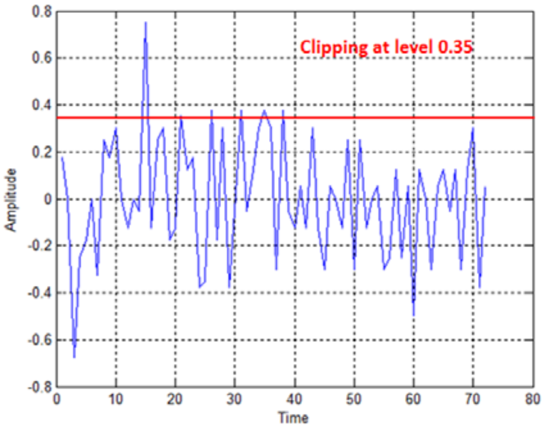


Fig.3 Time domain OFDM signal

Among the techniques that have been used for reducing PAPR, the common and easiest technique is clipping and filtering (CAF), in this technique the part of signal that is not in permitted region will be clipped. Clipping and filtering happens in transmitter side but in order that the receiver will be able to compensate it, needs to know two parameters, i.e. size of clipping and its location. It was shown that the CAF of amplitude would lead to the expense of in-band distortion and out-of-band radiation [1], which causes to degrade the system performance. The way of reducing the out-of-band radiation is to apply filtering after clipping. Since the out-of-band can interferes with the communications in adjacent frequency band, out-of-band is more critical. Among them, the clipping and filtering-based method is very powerful from the viewpoint of the tradeoff between the PAPR reduction and error rate [21]. The Fig.4 illustrates the OFDM transmitter using clipping scheme.

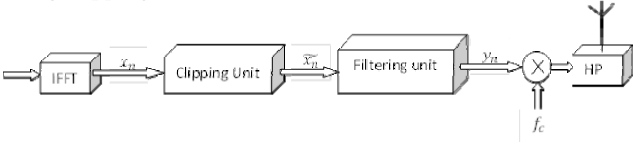


Fig.4 OFDM transmitter using clipping and filtering

2.3.1 Types of Clipping Techniques

There are four clipping techniques for PAPR reduction which are:

(i) Classical-Clipping (CC)
(ii) Heavy side-Clipping (HC)
(iii) Deep- Clipping (DC)
(iv) Smooth-Clipping (SC)

These four techniques can be compared with each other regarding their PAPR reduction, average power variation and total degradation. The clipped signal $\tilde{x}_n$ is expressed as [14]:

$$\tilde{x}_n = f(x_n)e^{j\varphi_n}$$

Where $f(r)$is the clipping function, the clipping functions for CC (Eq.3), HC (Eq.4), DC (Eq.5), and SC (Eq.6). Clipping techniques in order are defined as follows [14]:

$$f(r) = \begin{cases} r & , \quad r \le A \\ A & , \quad r > A \end{cases} \tag{3}$$

$$f(r) = A, \quad \forall r \ge 0 \tag{4}$$

$$\begin{cases} r & , \quad r \le A \\ A - \alpha(r - A) & , \quad A < r < \frac{1+\alpha}{\alpha}A \\ 0 & , \quad r > \frac{1+\alpha}{\alpha}A \end{cases} \tag{5}$$

$$\begin{cases} r - \frac{1}{b}r^3 & , \quad r \le \frac{3}{2}A \\ a & , \quad r > \frac{3}{2}A \end{cases} \tag{6}$$

Where in these functions, the clipping level is A, the clipping depth factor is α, and $b = \frac{27}{4}A^2$

The Fig.5 [14] shows the clipping on base of the mentioned clipping function.

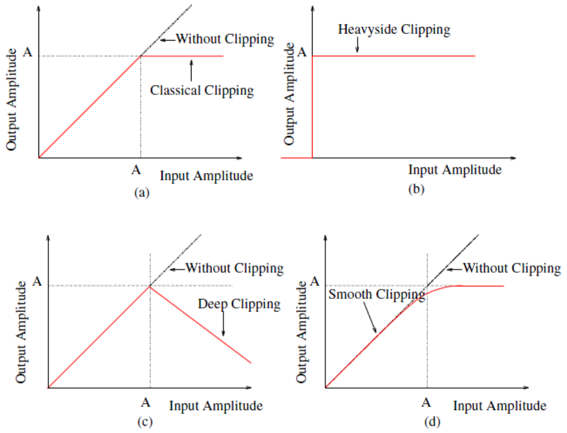


Fig.5 Functions-based clipping for PAPR reduction for [14]
(a) CC (b) HC (C) DC (d) SC

Figures 6, 7 and 8 [14] show the simulation results for the average power performance, BER performance and PAPR reduction for the mentioned techniques side by side.
Considering the results for CC, HC, DC, and SC clipping technique, except the HC which is the worst technique among the four, the other three are almost the same so it is very hard to say which of the three one is the best.

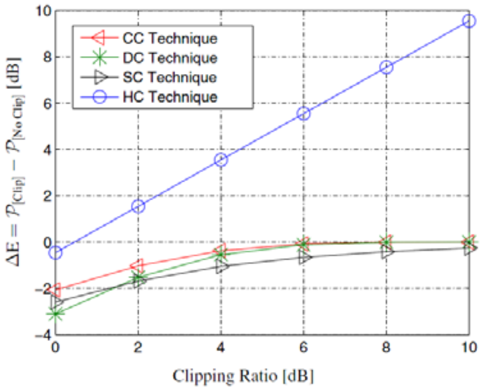


Fig.6 Average [14]

However, even though the clipping is the simplest method but clipping can produce some peak re-growth, this peak re-growth shows itself after the clipping and filtering and can cause the signals exceed from the set point of clipping in some spots. The offered solution for this problem in some papers are repeating the clipping and filtering although this solution fixes the re-growth problem but it will increase the cost of computational complexity.

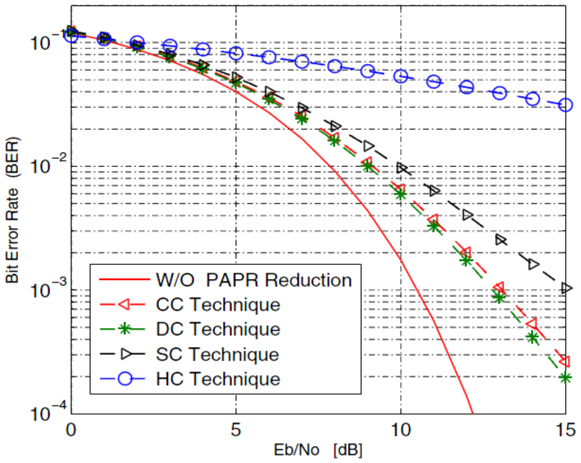


Fig.7 BER performance [14]

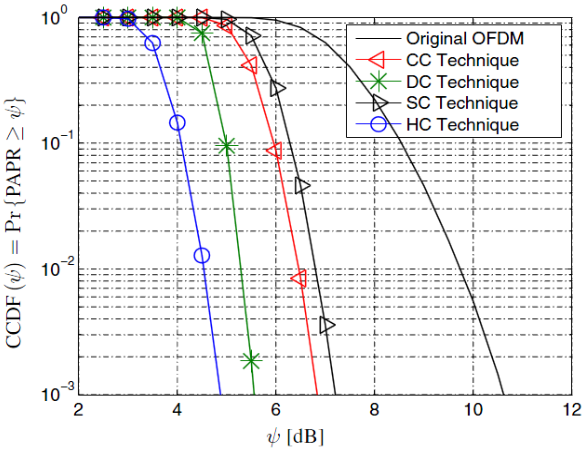


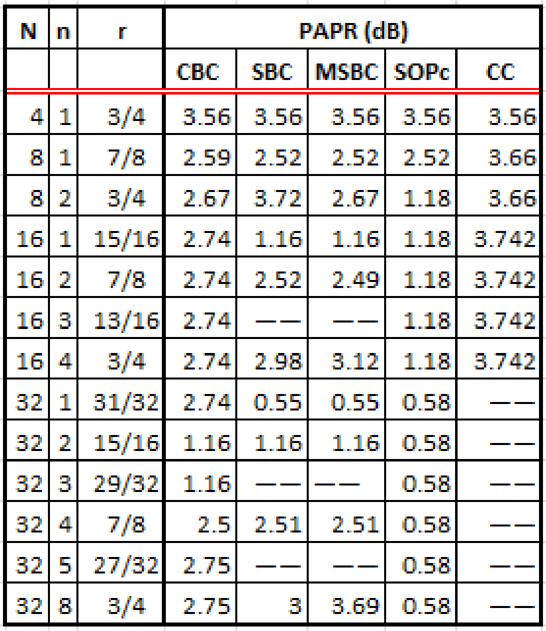
Fig.8 PAPR reduction performance [14]

2.4 Coding techniques

Coding techniques works on the base of finding the code words among a set of code words that produce the lowest PAPR and then use it for mapping the input data. In this technique if the number of subcarriers (N) is small, the lookup table has to be considered to be used.
A.E. Jones [6] in his paper “Block coding scheme for reduction of peak to mean envelope power ratio of multicarrier transmission schemes” offered the idea of mapping three bits data into 4 bit code word which the added bit is the odd parity code which is added to the last bit across the channel. The big drawback of this method is that, it is only good to reduce the PAPR for a 4 bit code word. After a while, in the publication “Multicarrier transmission peak-to-average power reduction using simple block code”. S. Fragiacomo, C. Matrakidis and J.J.

O'Reilly suggested a very simple but efficient block code for reducing PAPR. In their technique a simple added bit code applies across the channels of a multicarrier system for reducing the PAPR [15], even though this reduction achieves with the minimum increase in complexity and is effective regardless of the number of channels present, but it is done at the expense of reducing bandwidth. If the frame size gets large the proposed technique will not be effective.

However, for deleting the problem in Fragiacomo’s method, i.e. frame size, Tao Jiang and Guangzi Zhu [16] proposed a new coding scheme as Complement Block coding (CBC) which they claimed it would reduce the PAPR without any restriction for frame size. The proposed method even when the frame size is large has a lower complexity than the other scheme. The flexibility in coding rate choice and low complexity of this technique with large frame sizes and high coding rates can make it as a good candidate for OFDM system. Fig.9 [17] shows the structure of using CBC technique in OFDM system and the table 1 [17] is the table that shows the PAPR reduction for different coding technique. In this table, CBC stands for Complement Block coding, SBC stands for Simple Block Coding, MSBC stands for Modified SBC, SOPC stands for simple odd parity code and CC stands for Cyclic Coding.



N	n	r	PAPR (dB)				
			CBC	SBC	MSBC	SOPc	CC
4	1	3/4	3.56	3.56	3.56	3.56	3.56
8	1	7/8	2.59	2.52	2.52	2.52	3.66
8	2	3/4	2.67	3.72	2.67	1.18	3.66
16	1	15/16	2.74	1.16	1.16	1.18	3.742
16	2	7/8	2.74	2.52	2.49	1.18	3.742
16	3	13/16	2.74	——	——	1.18	3.742
16	4	3/4	2.74	2.98	3.12	1.18	3.742
32	1	31/32	2.74	0.55	0.55	0.58	——
32	2	15/16	1.16	1.16	1.16	0.58	——
32	3	29/32	1.16	——	——	0.58	——
32	4	7/8	2.5	2.51	2.51	0.58	——
32	5	27/32	2.75	——	——	0.58	——
32	8	3/4	2.75	3	3.69	0.58	——

Table 1: PAPR reduction comparison for CBC, SBC, MSBC, SOPC and CC [17]

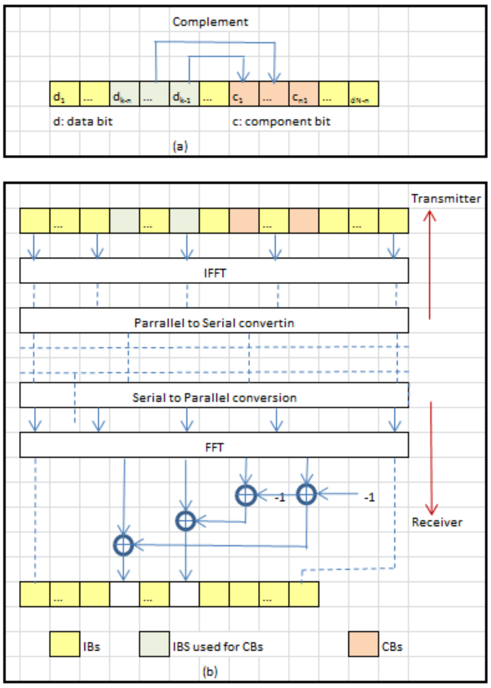


Fig.9 CBC technique: (a) code sequence with CBC; (b) using CBC in an OFDM System

T. Jiang and G. X. Zhu [18], proposed a new block coding scheme with low complexity which they called it, Sub-Block Complement Coding (SBCC). This is similar to the Fragiacomo’s method, with almost the same advantages. At the end of coding techniques we can conclude that simplicity and abilities of this technique makes it as a good candidate for using in OFDM systems. The only disadvantage that can be mentioned is: getting a worthy performance of PAPR reduction but at the price of coding rate loss. Table 2 illustrates the comparison for the three discussed major reduction techniques.

	Complexity implementation	BW Expansion	BET degradation	Power Increase
SML	High	Yes	No	No
CAF	Low	No	Yes	No
Coding	Low	Yes	No	No

Table 2: Comparison for reduction technique

3. Proposed algorithm for reducing PAPR

3.1 PAPR

PAPR is a historic issue in the development of the Wireless communication, the more PAPR of OFDM the more requirements and challenges for implementing.

However the PAPR is calculated from the peak- amplitude of the waveform divided by the average value of the waveform as follows:

$$PAPR = \frac{max_n\{|x[n]|^2\}}{E\{|x[n]|^2\}} \tag{7}$$

The amplitude of x[n] has a Rayleigh distribution, while the power has a central chi-square distribution with two degrees of freedom. The distribution of PAPR states in term of a Complementary Cumulative Distribution Function (CCDF) which can be given as follows [19]:

$$F_x(\propto) = Pr\left(\frac{|x[n]|^2}{E\{|x[n]|^2\}} < \propto\right) = 1 - e^{-\propto} \tag{8}$$

The probability that PAPR will be above a certain threshold point (PAPR$_0$) is [19]:

$$\Pr(PAPR > PAPR_0) = 1 - F(PAPR_0)^N$$
$$= 1 - (1 - e^{-PAPR_0})^N \tag{9}$$

The decibel form for Eq.9 is as follows:

$$PAPR_{dB} = 10log_{10}(PAPR) \tag{10}$$

Although the probability of happening the largest PAPR is not that high, but for sending the high PAPR of OFDM signal without any distortion, all the linearity in High Power Amplifier (HPA) and A/D converter should be met these requirement. Since the equipment that meets these necessities is costly. Consequently, it is very demanding and important to reduce PAPR in OFDM system.

3.2 OFDM

OFDM is a multiplexing technique that divides the bandwidth into multiple frequency sub-carriers. It uses multiple sub-carriers which they are closely spaced to each other without causing interference. As it illustrates in Fig.10, carrier centers are in orthogonal frequencies and there are orthogonality relationship between signals.

In this figure the peak of each signal coincides with trough of the other signals, and since there is $1/T_s$ space between the subcarriers (SCs), the subcarriers are orthogonal. Orthogonality between two signals let the multiple information signals to be transmitted and detected without a glitch and interference. An OFDM modulator can be implemented with an Inverse Discrete Fourier Transform (IDFT) followed by an Analog to Digital Converter (ADC).

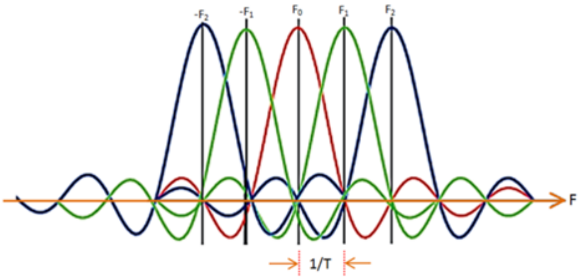


Fig.10 Space between subcarriers (1/Ts)

For designing OFDM system, it is very useful to be able to apply a mathematical expression for calculating PAPR distribution. On the other hand, by having PAPR distribution we can use it to calculate Bit Error Rate (BER). Depends on the type of model and technique which is used; we have different expression for PAPR. As it has been mentioned previously, there is $1/T_s$ space between the subcarriers, we know OFDM uses multiple sinusoidal for OFDM systems which can be defined as follows:

$$s(t) = a_0 g_0(t) + \dots\dots\dots\dots\dots\dots + a_{k-1} g_{k-1}(t) \tag{11}$$

$$= \sum_0^{k-1} a_k g_k\,(t)$$

$$s(t) = \sum_0^{k-1} a_k g_k\,(t) \tag{12}$$

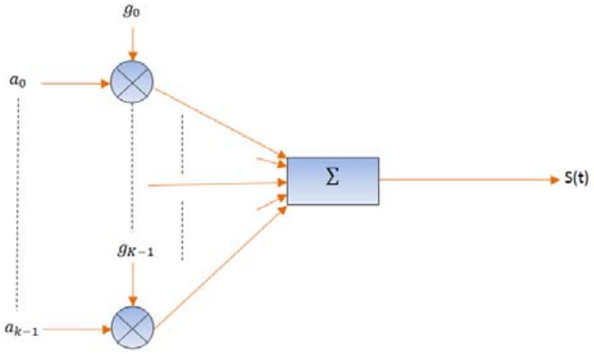


Fig.11 illustration for Eq.11

Where

$$g_k(t) = \frac{1}{\sqrt{T}} e^{\frac{2\pi k t j}{T}} \omega(t) \tag{13}$$

And $\omega(t) = u(t) - u(t - T), \qquad [0\ \ T)$

By substitute Eq.13 into Eq.12 we get:

$$s(t) = \frac{1}{\sqrt{T}} \sum_{0}^{K-1} a_k \, e^{\frac{2\pi k t j}{T}} \, \omega(t) \qquad (14)$$

Where the a_k is information signal and $g_K(t)$ is corresponding carrier signal.
As the Eq.14 shows each of the information signals times the related sinusoidal and then sum of them will be sent out as $s(t)$.
However, The OFDM signal can be represented as follows [20]:

$$\mathrm{S_{tx}(t) = \sum_{K=-\infty}^{\infty} \sum_{n=0}^{N-1} a_{n,k} g_n(t - Kt)} \qquad (15)$$

$$g_n(t) = \begin{cases} \frac{1}{\sqrt{T-T_{CP}}} e^{\frac{2\pi n t}{T-T_{CP}} j} & , \quad t \in [0,T] \\ 0 & , \quad t \notin [0,T] \end{cases} \qquad (16)$$

Where T is the period of each subcarrier, and 1/T is space between the subcarriers.
In our method in each OFDM symbol, only the first 1+N/4 sample will be sent, therefore the mathematical representation for our proposed scheme is as follows:

$$\mathrm{S_{tx}(t) = \sum_{K=-\infty}^{\infty} \sum_{n=0}^{N-1} a_{n,k} g_n(t - Kt)} \qquad (17)$$

$$g_n(t) = \begin{cases} \frac{1}{\sqrt{T-T_{CP}}} \left(e^{\frac{n\pi t}{2(T-T_{CP})} j} \right) & , \quad t \in [0,T] \\ 0 & , \quad t \notin [0,T] \end{cases} \qquad (18)$$

By using the Eq.18 and clipping and filtering Techniques we get a better performance comparing to [1] and [14]. Here the complete relation between PAPR, CCDF and BER are used to determine the performance of proposed method. The simulation results in figures 12, 13, and 14 show the reduction of PAPR.

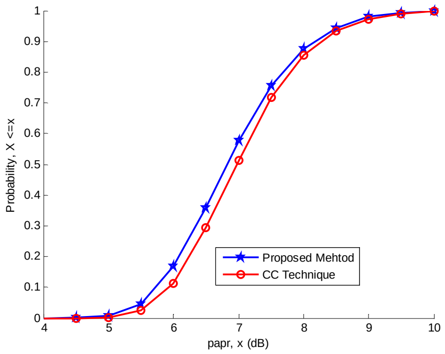


Fig.12 CDF Plot of PAPR

The simulation in fig.13 shows the reduction of PAPR about 0.2 dB therefore the performance of reducing PAPR, which is the advantage of this method.

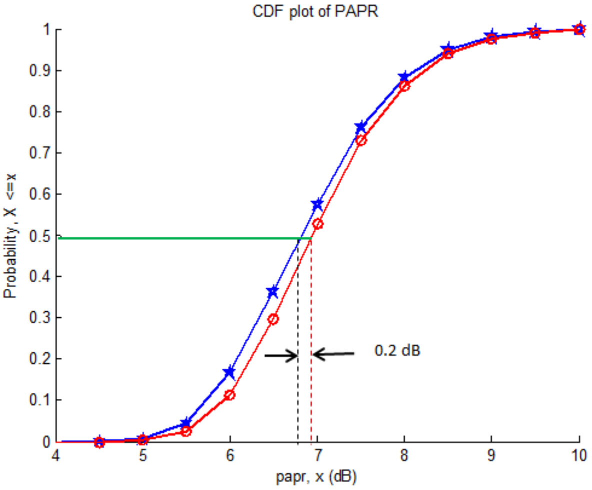


Fig.13 Reduction of PAPR is about 0.2 dB

A major drawback of OFDM systems is high PAPR which can cause degradation in Bit Error Rate (BER), fig.14 shows the result of simulation.

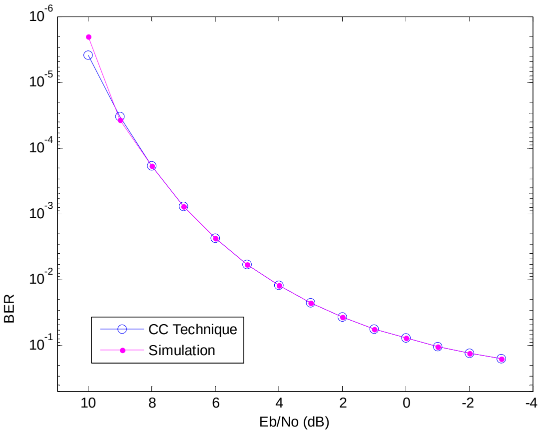


Fig.14 Simulation of BER

Based on the above simulation results, we can state there is some reduction in PAPR.

4. Conclusion

Reducing PAPR is meant to decrease the distortion that presented by nonlinearity and therefore as a result PAPR-reduction leads to reduce both out-of-band radiation and the BER degradation. However, in this paper, some important approaches focusing on PAPR-reduction are discussed and a simple and effective method is proposed. In our suggested method comparing with conventional OFDM, the separation of subcarriers (SCs) will be fourth.

Thus in each OFDM symbol, only the first $1+N/4$ samples will be sent while the rest will be ignored. As we know in order the receiver to be synchronized, the rest of samples by using the partial symmetry of Fourier transform with using the Eq.13 will be constructed. PAPR is not unsolvable; the key is the complexity and the cost associated with the proposed schemes. Considering the simulation results, we can state the proposed method can lead to reduce PAPR and gain better performance with lower complexity.

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