ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2016

Analysis of OFDM System by Comparing Different PAPR Reduction Schemes

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ABSTRACT: Orthogonal Frequency Division Multiplexing (OFDM) is an efficient method of data transmission for high speed, high spectral efficiency and robustness to multipath fading channel in communication systems. However, the dominating drawbacks of OFDM system are due to high Peak to Average Power Ratio (PAPR) and Interchannel interference (ICI).High PAPR of the transmitted signals consist of large number of independent subcarriers, as a result of which the amplitude of such a signal can have high peak values which requires a highly linear power amplifier (PA) and because of nonlinear operation there is inter-modulation between the different carriers and introduce additional interference into the system. This additional interference leads to an increase in the bit error rate (BER) of the system. One way to avoid such non-linear distortion and keep low BER is to force the amplifier to work in its linear region. Unfortunately such solution is not power efficient and thus is not suitable for wireless communication because Power amplifiers with large linear range are bulky, costly and difficult to manufacture. Hence a high PAPR in the system design should be restricted. And with ICI the signal degrades heavily which is because of change in frequency known as frequency offset. There are two main reasons for frequencies offset which are frequency mismatch between transmitter & receiver and Doppler Effect. The high PAPR and undesired ICI degrade the performance of OFDM system therefore several methods have been proposed for the reduction of high PAPR and ICI. This paper analyses different PAPR reduction methods and makes a comparison among them using CCDF curves and MATLAB coding.

KEYWORDS: Orthogonal frequency division multiplexing (OFDM), peak-to-average power ratio (PAPR), bit error rate (BER), MATLAB, interchannel interference (ICI), complementary cumulative distribution function (CCDF).

1. INTRODUCTION TO OFDM

Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation (MCM) technique which seems to be an attractive candidate for fourth generation (4G) wireless communication systems. OFDM offer high spectral efficiency, immune to the multipath delay, low inter-symbol interference (ISI), immunity to frequency selective fading and high power efficiency. Due to these merits OFDM is chosen as high data rate communication systems such as Digital Video Broadcasting (DVB) and based mobile worldwide interoperability for microwave access (mobile Wi-MAX). However OFDM system suffers from serious problem of high PAPR. In OFDM system output is superposition of multiple sub-carriers. In this case some instantaneous power output might increase greatly and become far higher than the mean power of system. To transmit signals with such high PAPR, it requires power amplifiers with very high power scope. These kinds of amplifiers are very expensive and have low efficiency-cost. If the peak power is too high, it could be out of the scope of the linear power amplifier. This gives rise to non-linear distortion which changes the superposition of the signal spectrum resulting in performance degradation. If no measure is taken to reduce the high PAPR, MIMO-OFDM system could face serious restriction for practical applications [1], [5], [8], [11]-[13]. The techniques [5] for reduction of PAPR have been categorized into three main methods broadly classified into signal distortion technique, multiple signalling and probabilistic techniques, and coding techniques. Most widely used methods are clipping [3] and peak windowing [4], [6], [11]. These methods distort the OFDM signal and increase the bit error probability. Partial Transmit Sequences [7], [2] and Selected Mapping [9] 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 is also adopted reduce the PAPR.

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II. OFDM MODEL

The binary information bits are mapped to complex-valued MQAM symbols in a 2-dimensional signal constellation. The output of the mapper is serial-to parallel converted and processed using an N -point complex inverse fast Fourier transform (IFFT). The N complex-valued time domain signals are then followed by a guard interval (GI), which contains the number of last L −1 samples (N > L). The GI consists of a partial repetition of an OFDM symbol so it does not affect the PAPR. Therefore, we sometime do not take the GI into consideration.

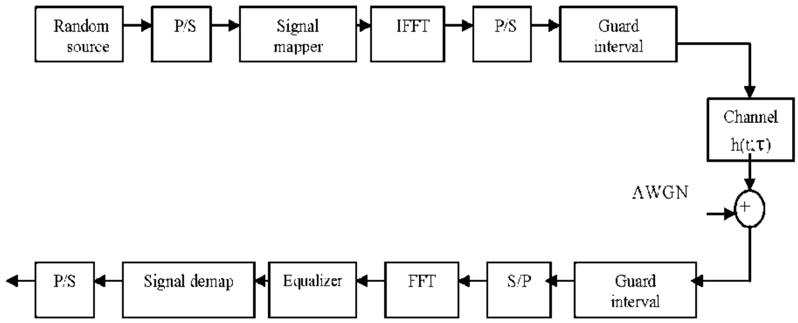

Fig.1 Block diagram of OFDM system

III. PAPR AND SYSTEM PERFORMANCE IN OFDM SIYSTEM

A. *PEAK AMPLITUDE TO POWER RATIO (PAPR)*

In general, the PAPR [3] of OFDM signals x(t) is defined as the ratio between the maximum instantaneous power and its average power.

$$\mathrm{PAPR}[x(t)] = \frac{P_{PEAK}}{P_{AVERAGE}} = 10\log_{10}\frac{\max[|X(n)|^2]}{E[|x_n|^2]}$$

Where PPEAK represents peak output power, PAVERAGE means average output power. E[·] denotes the expected value, xn represents the transmitted OFDM signals which are obtained by taking IFFT operation on modulated input symbols Wk. [7]. Xn is expressed as:

$$x_n = \frac{1}{\sqrt{N}}\sum_{K=0}^{N-1} X_k W_N{}^{nk}$$

The instantaneous output of an OFDM system often has large fluctuations compared to traditional single-carrier systems. This requires that system devices, such as power amplifiers, A/D converters and D/A converters, must havelarge linear dynamic ranges. If this is not satisfied, a series of undesirable interference is encountered when the peak signal goes into the non-linear region of devices at the transmitter, such as high out of band radiation and inter-modulation distortion. PAPR reduction techniques are therefore of great importance for OFDM systems. Also due to the large fluctuations in power output the HPA (high power amplifier) should have large dynamic range. This results in poor power efficiency.

B. FACTORS 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:

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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.

C. 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:

$$P(PAPR>Z) = 1-P(PAPR\ Z) \quad (3)$$

Where Z is the threshold power level.

IV. PROPOSED TECHNIQUES

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.

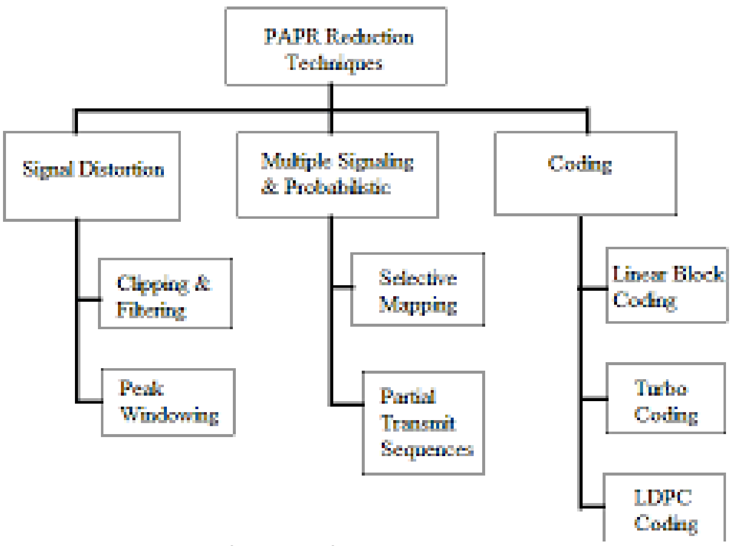

Fig. 2: Classification of PAPR reduction techniques

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A. CLIPPING AND FILTERING

Amplitude clipping is considered as the simplest technique which may be under taken for PAPR reduction in an OFDM system. A threshold value of the amplitude is set in this case to limit the peak envelope of the input signal. Signal having values higher than this pre-determined value are clipped and the rest are allowed to pass through un-disturbed [3].

$$B(x) = \begin{cases} x, & |x| \le A \\ Ae^{j\emptyset(x)}, & |x| > A \end{cases}$$

where,

B(x) = the amplitude value after clipping.

x = the initial signal value.

A = the threshold set by the user for clipping the signal.

The problem in this case is that due to amplitude clipping distortion is observed in the system which can be viewed as another source of noise. This distortion falls in both in – band and out – of – band. Filtering cannot be implemented to reduce the in – band distortion and an error performance degradation is observed here. On the other hand spectral efficiency is hampered by out – of – band radiation. Out – of – band radiation can be reduced by filtering after clipping but this may result in some peak re – growth. A repeated filtering and clipping operation can be implemented to solve this problem. The desired amplitude level is only achieved after several iteration of this process.

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 [6]. 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.

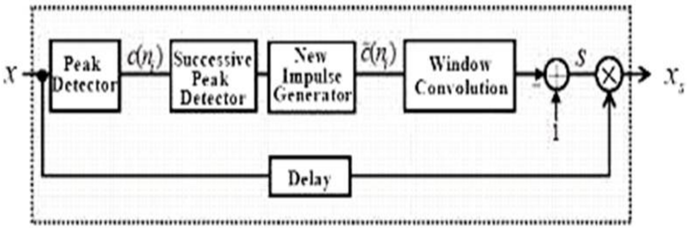

Fig 3: Peak windowing block in OFDM system

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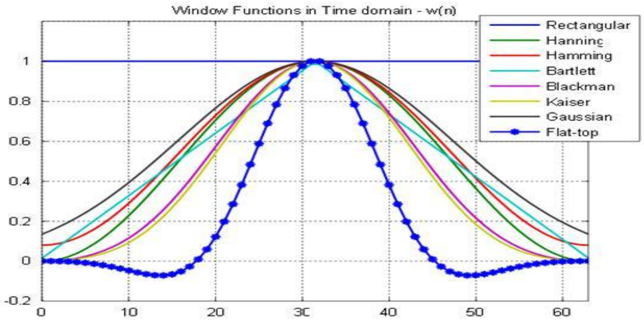

Fig 4: Different window functions in time domain

The comparison of Hamming and Kaiser Window in terms of the ripple ratio suggests that Kaiser Window gives lesser ripple ratio than hamming window, and the difference becomes larger as the normalized width increases. On the other hand it is observed that hamming window gives better roll-off ratio than Kaiser, and the difference becomes larger as the normalized width increases. By comparing Kaiser and the combinational windows including Hamming window for a fixed window length and main-lobe width, it can be observed that the maximum side-lobe amplitude for the ripple ratio occurs in the first side-lobe but that it lies in the third side-lobe for the combination of Kaiser and Hamming windows[14].

C. SELECTIVE MAPPING

Selective Mapping method (SLM) is a distortion less PAPR reduction method [9]. In this technique, the transmitter generates a set of sufficiently different candidate data blocks, all representing the same information as the original

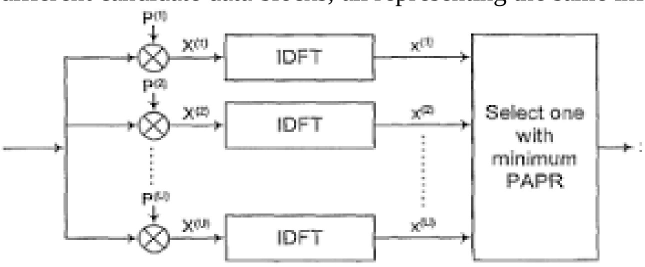

Fig 5: Block diagram of SLM technique [7]

data block each block is multiplied with u different phase vectors and selects the most favourable for transmission. 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 log2u bits as side information, where [y] 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 [7] is another method for PAPR without signal distortion. In this technique the input data block of N symbols is partitioned into disjoint sub blocks. The subcarriers in each sub block are weighted by a phase factor for that sub block. 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.

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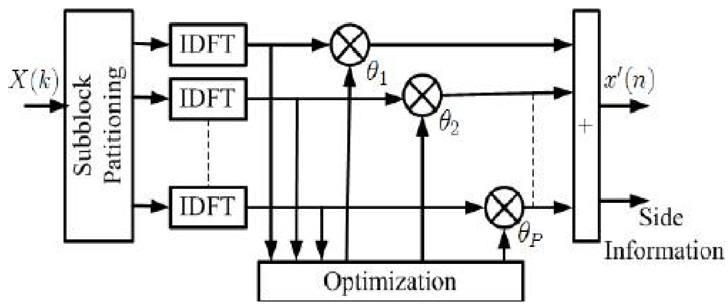

Fig. 6: Block Diagram of PTS Techniques [7]

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

V.SIMULATION RESULT

In the simulation, we assume that the OFDM system consists of 1024 subcarriers with 16-QAM. We also assume that the oversampling factor is four. We also assume that the guard interval is one by four. 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. In the window technique each window has its own characteristics, and different windows are used for different applications. To choose a spectral window, you must guess the signal frequency content. If the signal contains strong interfering frequency components distant from the frequency of interest, choose a window with a high side lobe roll-off rate. If there are strong interfering signals near the frequency of interest, choose a window with a low maximum side lobe level. In general, the Hanning window is satisfactory in almost all of cases because it has good frequency resolution and reduced spectral leakage. Partial Transmit Sequence and Selective Mapping techniques are distortion less PAPR reduction methods. Figure above shows the various CCDF curves during simulation of PAPR in OFDM system using several reduction techniques. Curves on the left shows the individual distribution of each scheme and curves on the wright shows the comparative distribution of each scheme.

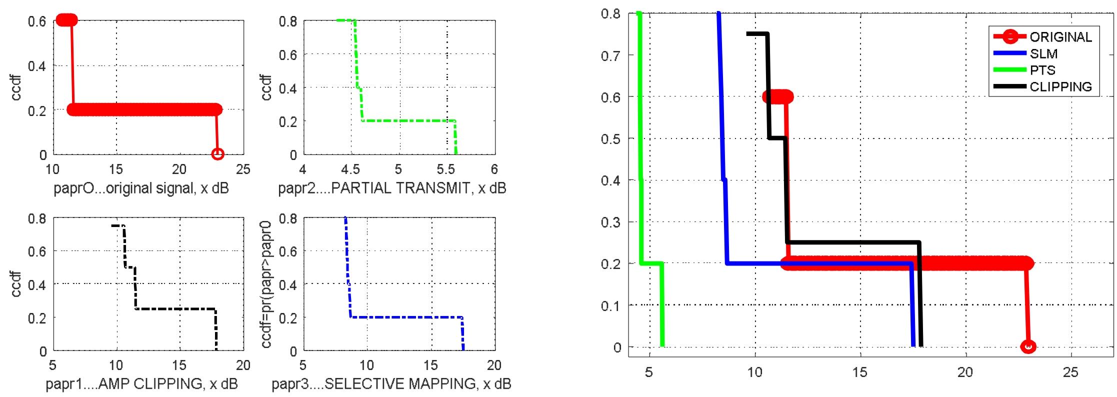

Fig.7: Various individual and combined CCDF curves.

Partial Transmit Sequence (PTS) and Clipping and Filltering (CF) methods have been applied into the system and the results have been studied. The results show better PAPR reduction in PTS method and less compared with SLM and CF methods.

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VI.CONCLUSION

PAPR reduction Technique	*decrease in data rate*	*power increase*	*distortion*	*complexity*
Amplitude clipping and lltering	No	No	Yes	Low
Coding	Yes	No	No	Medium
PTS	Yes	No	No	Very high
SLM	Yes	No	No	high

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. In this paper, the different properties of an OFDM System are analyzed and the advantages and disadvantages of this system are understood. It is concluded after investigating some of the techniques which are in common use to reduce the high PAPR of the system that among the three techniques that we took up for study, we found out that Windowing, Amplitude Clipping and Filtering results in Data Loss, whereas, Selected Mapping (SLM) and Partial Transmit Sequence (PTS) do not affect the data. Main drawback of these technique are searching complexity increases exponentially with the number of sub blocks and its need to transmit the phase factor information as side information to the receiver to extract the original signal. From the comparison curve of the clipping, SLM and PTS techniques, we could infer that PTS is more effective in PAPR reduction. However, no specific PAPR reduction technique is the best solution for the OFDM system. Various parameters like loss in data rate, transmit signal power increase, BER increase, computational complexity increase should be taken into consideration before choosing the appropriate PAPR technique.

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