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Review on PAPR Reduction in OFDM Based System

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Abstract: ***In recent time, the demand for multimedia data services has grown up rapidly. One of the most promising multi-carrier system, Orthogonal Frequency Division Multiplexing (OFDM) forms basis for all 4G wireless communication systems due to its large capacity to allow the number of subcarriers, high data rate and ubiquitous coverage with high mobility. OFDM is significantly affected by peak-to-average-power ratio (PAPR). Unfortunately, the high PAPR inherent to OFDM signal envelopes will occasionally drive high power amplifiers (HPAs) to operate in the nonlinear region of their characteristic curve. The nonlinearity of the HPA exhibits amplitude and phase distortions, which cause loss of orthogonality among the subcarriers, and hence, inter-carrier interference (ICI) is introduced in the transmitted signal. Not only that, high PAPR also leads to in-band distortion and out-of-band radiation. Different techniques are used to reduce the Peak to Average Power Ratio (PAPR) to increase the efficiency of the OFDM system. In this paper some of these important techniques are reviewed.***

Keywords: PAPR OFDM

1. Introduction

Recently, the demand for multimedia data services has grown drastically which drive us in the age of 4th generation wireless communication system. This requirement of multimedia data service where user are in large numbers and with bounded spectrum, modern digital wireless communication system adopted technologies which are bandwidth efficient and robust to multipath channel environment known as multi-carrier communication system. The modern digital multicarrier wireless communication system provide high speed data rate at minimum cost for many users as well as with high reliability. In single carrier system, single carrier occupies the entire communication bandwidth but in multicarrier system the available communication bandwidth is divided by many sub-carriers. So that each sub-carrier has smaller bandwidth as compare to the bandwidth of the single carrier system. These tremendous features of multicarrier technique attract us to study Orthogonal Frequency Division Multiplexing (OFDM). OFDM forms basis for all 4G wireless communication systems due to its huge capacity in terms of number of subcarriers, high data rate in excess of 100 Mbps and ubiquitous coverage with high mobility. The introduction chapter consists of following parts:

Overview, Historical Development of OFDM, principle of orthogonality, advantages and disadvantages of OFDM technique, and the applications of OFDM technique.

High PAPR is one of the major issues occurring in OFDM modulation. When N number of sinusoidal signals gets added, the peak magnitude would have a value of N, where at some time instance, the average might be quite low due to the destructive interference between the sinusoids or it could be high due to the constructive interference between the sinusoids.

High PAPR signals are usually undesirable. Due to High PAPR signals, there would be requirement of a large range of dynamic linearity from the analog circuits which ultimately results in expensive devices and high power consumption resulting in lower efficiency (for e.g. Power amplifier will have to operate with larger back-off to maintain the linearity) [1].

In OFDM system, some of the input sequences which are needed to be transmitted would result in higher PAPR than others. So, an input sequence that requires all such carriers to transmit their maximum amplitudes would certainly result in a high output PAPR. Thus by restricting the possible input sequences to a smallest set of values, there might be possibility to obtain output signals with a guaranteed low output PAPR.

2. Related Work

The main issue of the OFDM system is high PAPR of transmitted signal in transmitter side which degrades the performance of the system when a non-linear HPA is used. So, it is necessary to use an appropriate PAPR reduction technique at the transmitter side. In this chapter, the detailed analysis of PAPR, its impact and definition, parameter to analysis PAPR and different methods of PAPR reduction are included. Simulation results are discussed and analyzed.

Many PAPR reduction techniques are proposed in the literature [2] [3] to reduce the PAPR of the OFDM signal. The PAPR reduction schemes are majorly divided into two categories

a) Distortion based Techniques
b) Non-distortion Techniques

The schemes that introduce spectral re-growth belong to distortion based category. These techniques are the most straightforward PAPR reduction methods. The clipping [2] is one of the simplest distortion based technique to reduce the PAPR of OFDM signal. It reduces the peak of the OFDM signal by clipping the signal to the desired level but it introduces both in-band distortion and out-of-band radiation.

To limit out-of-band radiation and PAPR, Jean Armstrong proposed iterative clipping and filtering scheme [4].

Companding is another popular distortion based scheme for PAPR reduction in OFDM system. In [5], Wang *et al.* proposed a scheme based on μ-law companding to reduce the PAPR of OFDM signal. In μ-law companding scheme the peak value of the OFDM signal before and after companding remains same, which keeps peak power of the OFDM signal unchanged but the average power of the OFDM signal after companding increases and therefore the PAPR of the OFDM signal gets decreased. But due to increase in the average power of the OFDM signal the error performance of μ-law companding scheme degrades.

Jiang *et al.* proposed exponential companding (EC) function [6] to transform Rayleigh distributed magnitude of OFDM signal to a uniformly distributed OFDM signal using an exponential function and this scheme is known as "Exponential Companding" scheme. Exponential companding scheme can effectively reduce the PAPR of the OFDM signal but its BER performance also degrades with PAPR reduction. Huang *et al.* proposed four companding transformation functions [7] to reduce the PAPR of the OFDM signal, which includes: linear symmetrical transform (LST), linear non symmetrical transform (LNST), non-linear symmetrical transform (NLST) and non-linear non-symmetrical transform (NLNST). It has been shown that LNST performs the best among four companding function [7]. In LNST an inflexion point is introduced to treat large and small signals on different scale to achieve better BER and PAPR performance. Linear companding transform (LCT) [8] has been proposed by Aburakhia *et al.* to reduce the PAPR of the OFDM signal. LCT also treats large and small signals on different scale but has two inflexion points to achieve more flexibility in designing the companding function. The abrupt change in the transformed signal at inflexion point degrades the power spectral density (PSD).

Trapezoidal companding (TC) [9] proposed by Hou *et al.* is an efficient method to reduce the PAPR of OFDM signal with low BER. TC [10] transforms the Rayleigh distributed magnitude of original OFDM signal to a trapezoidal distribution and called "Trapezoidal Companding". Trapezoidal companding utilizes a piecewise function defined in three intervals of OFDM signal magnitude. Jeng et al. proposed [11] trapezium distribution based companding (TDBC) to transform the Rayleigh distribution of original OFDM signal to biased linear distribution called "Trapezium distribution".

All the companding schemes [5] [11] distort the shape of the original OFDM signal and PAPR reduction capability is achieved at the cost of BER performance degradation.

Non-distortion PAPR reduction schemes do not distort the shape of the OFDM signal and therefore no spectral re-growth takes place. Coding technique [2] is one of the simplest non-distortion PAPR reduction schemes, which can be applied for reducing the PAPR of OFDM signal. But these type of schemes result in significant loss of data rate in OFDM system.

Two more distortion-less PAPR reduction techniques namely partial transmit sequence (PTS) [12] and selective mapping (SLM) are also proposed in the literature. In PTS scheme all the subcarriers are partitioned into multiple disjoint sub blocks and then each of the sub blocks is multiplied by a set of rotating phase factors and combined to achieve a signal with lowest PAPR. In SLM, parallel data signal of length N is multiplied by a predetermined set of U phase vectors of length N and generates U alternative signals. Out of U alternative signals, one of them with the least PAPR is selected for transmission. In both of the schemes the information about the phase factors by which these sub blocks/data symbols are multiplied, needs to be conveyed to the receiver and it is known as side information (SI). The SI has the highest importance because it is used to recover the original data signal. If SI gets corrupted then entire OFDM symbol block can be damaged and error performance of SLMand PTS-OFDM system degrades severely. In PTS technique, if the number of sub blocks increases then it not only increases computational complexity for selecting the optimum set(provide least possible PAPR) of phase sequence but also increases the amount of SI to be conveyed to the receiver. The SI results loss of data rate in OFDM system. Similarly in SLMOFDM systems as the number of alternative OFDM signal increases, the number of bits required to encode the side information also gets increased, which results in data rate loss. The SI bits are extremely important for data recovery and it may be necessary to allocate few redundant bits to ensure accurate recovery of SI, but this operation will further increases the loss of data rate in OFDM system.

Many schemes for embedding the SI have been proposed in [13] for PTS-OFDM systems. In [14] many SI embedding schemes have been proposed for SLM-OFDM system. These schemes [13] embed SI in the OFDM signal without using any extra bit. At the receiver, SI is extracted from the received OFDM signal, and decoded to obtain the information about the phase factor used at the transmitter to minimize PAPR. The demodulated signal is multiplied by the reciprocal of recovered phase factors, due to which the computational complexity at the receiving end gets increased. In many of the SI embedding schemes, the SI detection at lower values of SNR is very poor, due to which error performance of the OFDM system degrades severely.

Existing SI embedding schemes [13] eliminates the requirement of SI transmission but these suffer from one drawback or the other, whether in terms of computational complexity, poor PAPR reduction capability or incorrect SI detection.

In [15], Zhou *et al.* proposed MPSM-PTS scheme which extends the QPSK constellation points to disjoint points of 16-QAM constellation and eliminates the requirement of side information. The MPSM-PTS scheme [15] is completely free from SI, i.e. extraction of SI from the received signal is not required. Hence the receiver structure of the scheme proposed in [15] is computationally less complex.

In wireless standards like LTE, OFDM is used in downlink, where mobile station acts as receiver. The mobile stations have limited computational resources; therefore, a PAPR reduction scheme with less computational complexity at receiving end will be more beneficial. As discussed above, the schemes proposed in [13] have computationally complex receiver in comparison to the schemes proposed in [13]. Hence, MPSM-PTS scheme is a viable choice for PTS-OFDM system.

As discussed earlier, OFDM system is very sensitive to small carrier frequency offset; a small carrier frequency offset in between transmitter and receiver carrier frequencies can disturb the orthogonality of the subcarriers and causes ICI. The ICI interference degrades the overall performance of the OFDM system. It is generally characterized by carrier to interference ratio (CIR).

Various ICI cancellation techniques have been proposed in the literature to eliminate the effect of ICI, these include ICI self-cancellation, New ICI self-cancellation, General ICI self-cancellation scheme, ICI conjugate cancellation scheme, General phase rotated conjugate transmission ICI cancellation scheme etc.

In [16] Zhao and Haggman proposed an ICI cancellation scheme called "ICI self cancellation" to combat the effect of ICI. In this scheme the data symbols are repeated on multiple adjacent subcarriers using polynomial coding but it results in PAPR performance degradation. The CIR performance of ICI self cancellation can be further improved by the scheme [17] proposed by Santhananthan *et al.* and called "New ICI self-cancellation scheme". In this scheme [17] data symbols are repeated symmetrically using polynomial coding, which achieves frequency diversity effect of multipath fading channel. The CIR and the BER performance of ICI cancellation schemes [16], [17] are claimed to be further improved by General ICI cancellation scheme, proposed by Seyedi *et al.*, which is based on windowing technique used at the transmitter and receiver of OFDM system.

3. PAPR Reduction Techniques

Different techniques are developed to reduce the PAPR value from the transmitter medium to improve the efficiency of the system and remove the noise from the transmission line. Some of the important techniques are review in this paper.

1. Partial Transmit Sequence

Partial Transmit Sequence (PTS) is one of the most efficient techniques to diminish PAPR. In this scheme original OFDM signal is divided into number of sub-blocks. Then phase rotation is added to develop number of candidate signal and choose one with lowest PAPR [18].

In the PTS Technique, the input symbol sequence is partitioned into a number of disjoint symbol subsequences. IFFT is then applied to each symbol subsequence and the resulting signal subsequences are summed after being multiplied by a set of distinct rotating vectors.
Let input data blocks X = $\{X_K\}$, where (k = 1, 2…N -1), N is number of sub-carriers. Make M is the frequency domain (FD) data sequences, X^{ε} $(\varepsilon = 1,2, \dots M)$, by multiplying phase sequences

$$X^{\varepsilon} = \{P_K^{\varepsilon}\}(K = 0,1,2, \dots N-1)$$

With X elements provide following results

$$X^{\varepsilon} = [P_0^{\varepsilon} X_0, P_1^{\varepsilon} X_1 \dots \dots P_{N-1}^{\varepsilon} X_{N-1}]$$

$$\varepsilon = (1,2, \dots, M)$$

Where $P_K^{\varepsilon} = \exp(j\varphi_K^{\varepsilon})$, φ_K^{ε} is uniformly distributed in [0, 2π].

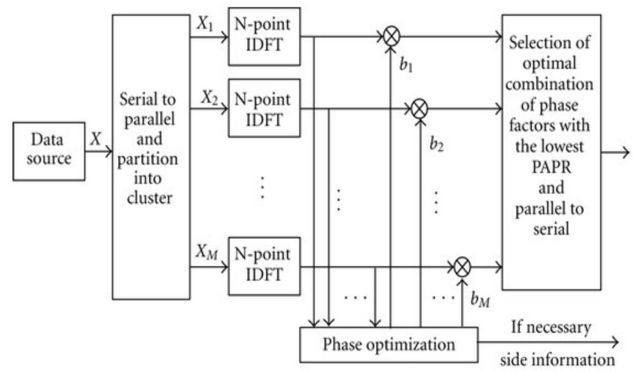


Figure 1: Block diagram of conventional PTS scheme [19].

To get M candidates' time domains using IDFT
$$X^{\varepsilon} = IDFT\{X^{\varepsilon}\}, \varepsilon = (1,2, \dots, M)$$
All the candidates have same information x provide different PAPRs. One with smallest PAPR in X^{ε} is selected for transmission [18].

2. Selective Mapping

Selective Mapping is promising technique to mitigate PAPR in OFDM system. Fundamental idea behind scheme is phase rotation. Signal with low PAPR is selected from different independent phase sequences that have same information at transmitter [20].

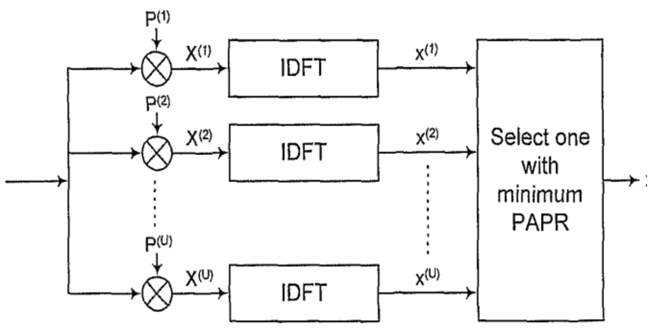


Figure 2: block diagram of SLM technique [20]

Let input data blocks be

$$X = [X_0, X_1, X_2, \dots X_{N-1}]^T$$

When multiply with independent phase sequence results

$$P^u = [P_0^u, P_1^u \dots X_{N-1}^u]^T, u = (1,2, \dots, U-1)$$

U= number of phase sequence

Keep length of input data and phase sequence same. Then get time domain signal by applying IFFT we get data block with different PAPR value and phase sequence [8].

$$X^u = [X_0^u + X_1^u + \dots X_{N-1}^u]^T$$

Select one with low PAPR and transmit. CCDF is used to measure the probability that the PAPR of a certain data block exceeds the given threshold [19]. CCDF of PAPR in SLM will be

$$P(PAPR > PAPR0) = (1 - (1 - e^{-PAPR0})^{\alpha N})^U$$

N= no. of sub-carrier
N_{IIFT} =N-point IFFT operation
U=independent phase sequence
PAPR0= threshold value
α = oversampling factor

3. Tone Reservation

This is an accurate method for PAPR mitigation. Amount of PAPR mitigation relies on some factor such as number of reserved tones, location of reserved tones, and amount of complexity and allow power on reserved tones.

Method shows that reserving a small fraction of tones leads to large mitigation of PAPR with simple operation at transmitter and no complexity at receiver end. There is no need for additional operation and no side information to receiver. It based on summing a data block and time domain signal. A data block is dependent block signal to the original multicarrier signal to minimize high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at receiver [21]. This scheme takes an edge as no need of side information to send along with message, less complexity. BER is improved to a little extent with tone reservation. One of the advantages with this technique is reduction in complexity.

4. Clipping And Filtering

The technique simply clips the part of signal which is above the selected average region. Advantage of this technique is less complexity and disadvantage is distortion and BER degradation [22]. Clipping is expressed as

$$C(X) = \begin{Bmatrix} x\,, & |x| \le A \\ A\,, & |x| > A \end{Bmatrix}$$

A = Positive real number represent clip level

It is a non-linear process which causes in-band noise, which degrades performance of BER and out of band noise which further reduces the spectral efficiency. Out of band radiation can be reduced by Filtering after clipping but cause peak re-growth which may exceed clip level. This peak re-growth is avoided by iterative clipping and frequency domain filtering.

5. Peak Cancellation

In this algorithm the amplitude and phase of peak is kept within constellation region which points to the data symbol to be transmitted. For example, to use this technique for QPSK constellation, it carries four regions to represent the four different value of QPSK symbol.

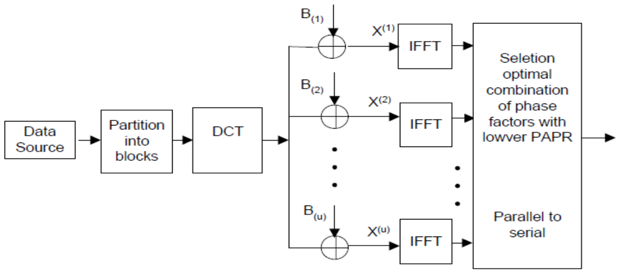
6. Peak Windowing

With this technique it is possible to remove larger peaks at the rate of a little amount of interference when large peaks arise infrequently. It mitigates PAPR at cost of increases BER (bit-error-rate) and out-of-bands radiation. In this method multiply large signal peak with a specific window such as Gaussian shaped window, Kaiser, cosine, and hamming window which results a spectrum of convolution of original OFDM spectrum with spectrum of window. The window size should be narrow otherwise it affects number of signal sample which cause increasing BER [22].

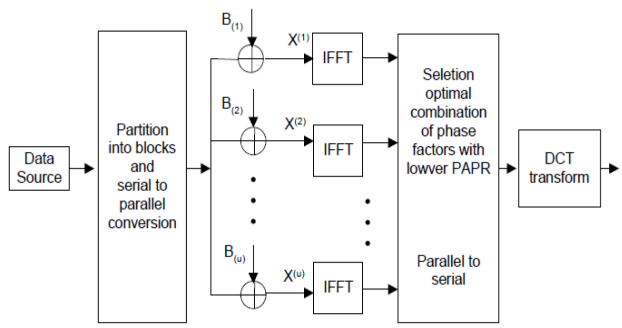
7. DCT-SLM

The main idea of the scheme is to use a combination of two appropriate methods. One is the DCT matrix transform technique and the other is the SLM technique. The transmitter block is showed in Figure 1. In the transmit end, the data stream is firstly transformed by DCT matrix, then the transformed data is processed by the SLM unit. If data block passed by DCT matrix before IFFT, the autocorrelation coefficients of IFFT input is reduced, then the PAPR of OFDM signal could be reduced.

In this DCT matrix use after SLM to further reduce the PAPR of signal. In his fashion, the autocorrelation of the signal, which has been processed by SLM, is reduced by DCT matrix transform. The PAPR of fine output signal is further reduced. The block of transmitter is showed in Figure 2.



(a)



(b)

Figure 3: Block Diagram of DCT-SLM scheme

4. Analysis of Different Techniques

Table 1 shows the comparative analysis of the different PAPR reduction technique which help to identify the best technique used to reduce the PAPR on the OFDM system.

Table 1: Comparison of PAPR reduction techniques [13]

Name Of Scheme	Name of Parameters			
	Distortion Less	Power Increase	Data Rate Loss	BER Improved
PTS	Yes	No	Yes	Yes
SLM	Yes	No	Yes	Yes
TI	Yes	Yes	No	Yes
Peak Cancellation	No	No	No	No
Companding	No	Yes	No	No
PW	No	Yes	No	No
DCT-SLM	Yes	Yes	Yes	Yes

5. Conclusion

This paper has attempted to review a significant number of papers to cover the recent development in the field of PAPR reduction in OFDM system. Present study reveals that techniques have been used PAPR reduction on OFDM system. This paper we review some of the main techniques used for PAPR reduction and analysis them with some reference outputs. From table 1 it is shown that DCT-SLM combination technique is give better results than other technique. The list of references to provide more detailed understanding of the approaches described is enlisted. Apologize to researchers whose important contributions may have been overlooked.

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