A Review on PAPR Reduction Technique in OFDM

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Abstract: Orthogonal frequency division multiplexing (OFDM) is becoming the chosen modulation technique for wireless communications. OFDM can provide large data rates with sufficient robustness to radio channel impairments. Many research centers in the world have specialized teams working in the optimization of OFDM for countless applications. The transmit signals in an OFDM system can have high peak values in the time domain since many subcarrier components are added via an IFFT operation. Therefore, OFDM systems are known to have a high PAPR (Peak-to-Average Power Ratio), compared with single-carrier systems. In fact, the high PAPR is one of the most detrimental aspects in the OFDM system, as it decreases the SQNR (Signal-to-Quantization Noise Ratio) of ADC (Analog-to-Digital Converter) and DAC (Digital-to-Analog Converter) while degrading the efficiency of the power amplifier in the transmitter. The PAPR problem is more important in the uplink since the efficiency of power amplifier is critical due to the limited battery power in a mobile terminal. This research paper discusses several techniques that are being used to reduce the PAPR in an OFDM system.

Keywords: OFDM, PAPR, SQNR, clipping, PTS, DFT

1. Introduction to PAPR

Large envelope fluctuation in OFDM signal is one of the major drawbacks of OFDM. Such fluctuations create difficulties because practical communication systems are peak power limited. Thus, envelope peaks require a system to accommodate an instantaneous signal power that is larger than the signal average power, necessitating either low operating power efficiencies or power amplifier (PA) saturation. In order to amplify the OFDM signal with large envelope fluctuations, PAs with large linear range are required, which makes it very expensive. If PA has limited linear range then its operation in non-linear mode introduces out of band radiation and in band distortion. It is also necessary to have D/A and A/D converters with large dynamic range to convert discrete time OFDM signal to analog signal and vice versa. PAPR is generally used to characterize the envelope fluctuation of the OFDM signal and it is defined as the ratio of the maximum instantaneous power to its average power. In addition to this, OFDM system requires tight frequency synchronization in comparison to single carrier systems, because in OFDM, the subcarriers are narrowband. Therefore, it is sensitive to a small frequency offset between the transmitted and the received signal. The frequency offset may arise due to Doppler Effect or due to mismatch between transmitter and receiver local oscillator frequencies. The carrier frequency offset (CFO) disturbs the orthogonality between the subcarriers, and therefore the signal on any particular subcarrier will not remain independent of the remaining subcarriers. This phenomenon is known as inter-carrier interference (ICI), which is a big challenge for error-free demodulation and detection of OFDM symbols.

2. Distortion Based PAPR Reduction Techniques

The schemes that introduce spectral re-growth belong to distortion based category. These techniques are the most straightforward PAPR reduction methods. This is one of the most simplest way to reduce PAPR in an OFDM system, but as we will see below that the simplicity in the approach brings an advantage along with several disadvantages.

2.1 Clipping

The clipping [3] 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].

2.2 Companding

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.

2.3 Exponential Companding

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.

2.4 Linear Companding Transform

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 [9] transforms the 
Rayleigh distributed magnitude of original OFDM signal 
with a trapezoidal distribution and called “Trapezoidal 
Companding”. Trapezoidal companding utilizes a piecewise 
function defined in three intervals of OFDM signal magnitude.

2.5 Trapezium Distribution

Jeng et al. proposed [10] 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]- 
[10] distort the shape of the original OFDM signal and 
PAPR reduction capability is achieved at the cost of BER 
performance degradation.

3. Non Distortion Based PAPR Reduction 
Techniques

Non-distortion PAPR reduction schemes do not distort the 
shape of the OFDM signal and therefore no spectral re-
growth takes place.

3.1 Coding Technique

Coding technique [3] 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 and hence as 
such are very popular and very seldom used.

3.2 PTS (Partial Transmit Sequence) & Selective 
Mapping (SLM) Scheme

Two more distortion-less PAPR reduction techniques 
namely partial transmit sequence (PTS) [11] and selective 
mapping (SLM) [12] 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 SLM- and 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 SLM-OFDM 
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]-
embedding schemes have been proposed for SLM-OFDM 
system. These schemes [13]-[17] 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]-[17] 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 [18], 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 
[18] 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 [18] 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]-[17] have computationally 
complex receiver in comparison to the schemes proposed in 
[13], [14]. Hence, MPSM-PTS scheme is a viable choice for 
PTS-OFDM system.

4. Inter Carrier Interference Cancellation

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 [19], New ICI self-cancellation [20], General ICI self-cancellation scheme [21], ICI conjugate cancellation scheme [22], General phase rotated conjugate transmission ICI cancellation scheme [23] etc.

4.1 ICI Self-Cancellation

In [19] 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.

4.2 New ICI Self Cancellation Scheme

The CIR performance of ICI self-cancellation can be further improved by the scheme [20] proposed by Santhanathan et al. and called “New ICI self-cancellation scheme”. In this scheme [20] 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 [19], [20] are claimed to be further improved by General ICI cancellation scheme [21], proposed by Seyed et al., which is based on windowing technique used at the transmitter and receiver of OFDM system.

4.3 ICI Conjugate Cancellation

In [22] ICI cancellation schemes called “ICI conjugate cancellation” have been proposed. In these schemes time domain OFDM signal and its conjugate signal are transmitted over two parallel paths. It has been shown that ICI conjugate cancellation scheme [14] in presence of small frequency offset provides better CIR performance and BER performance in fading channels as compared to ICI self-cancellation schemes [19], [20]. The CIR and BER performance of [19]-[22] are further improved by the scheme proposed by Wang et al. [23] called “General phase rotated conjugate transmission ICI cancellation scheme”. It [23] is a combination of carrier frequency estimation technique and ICI conjugate cancellation scheme [22]. It has been shown that ICI conjugate cancellation scheme [22] is a special case general phase rotated conjugate cancellation [23]. But one of the main disadvantages of this scheme is that it requires knowledge of CFO to perform the operation.

5. Conclusion

The current implementations of OFDM do not fully exploit the capabilities of OFDM. There are still several avenues which can be explored to reduce the peak-to-power ratio (PAPR) of OFDM signal. The PAPR performance of existing ICI cancellation schemes is either same or worse than normal OFDM signal. Therefore, the necessity to reduce the PAPR of normal OFDM signal and OFDM signal obtained from ICI cancellation schemes has been a prime motivating factor for this paper. The paper aims at exploring and arriving at the schemes for PAPR reduction in OFDM based systems (with and without ICI cancellation scheme) of practical use.

References


