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A Review of 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 value s 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 batter y 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, pulse shaping.

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. Huanget 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 to 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 Distrotion 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]-[14] for PTS-OFDM systems. In [15]-[17] many SI 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 Santhananthan 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 Seyedi 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 [23]. 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. Pulse Shaping

Each carrier in the OFDM spectrum is represented by main lobe with a number of side lobes having lower amplitudes. Since peak power is associated with main lobe and ICI power is associated with side lobes, so the motive of pulse shaping function is to increase the width of main lobe and/or reduce the amplitude of side lobes [9]. Proper pulse shaping techniques makes a digital communication system possible to transmit data within a limited BW with minimum ISI [11]. In this section some most commonly used pulse shaping functions have been introduced. These functions are REC, RC, BTRC, SP and ISP. Their Fourier transforms are given, respectively as [2,3,4,7,9].

In the previous section we assumed that the channel is ideal without any frequency offset. Therefore ICI can be made negligible and meanwhile ISI can be successfully removed by adding the cyclic prefix. The wireless channel, however, is far from ideal and a typical channel contains time and frequency dispersion that cause both ISI and ICI due to the lack of orthogonality between the perturbed synthesis basis functions and the analysis basis functions. Furthermore, the cyclic prefix is not for free: It costs increased power consumption and reduces spectral efficiency.

One way to solve this problem is to adopt a proper pulse shape prototype function which is well localized in time and frequency domain so that the combined ISI/ICI can be combated efficiently without utilizing any cyclic prefix. Unfortunately, in Gabor theory the Balian-Low theorem [9] states that, orthogonal basis formed by (2) based on a time and frequency well localized (compact support) prototype function g(t) does not exist for TF = 1. Therefore orthogonal basis and compactly supported pulses cannot be achieved simultaneously for OFDM/QAM systems without guard interval ($TF = \tau 0 \nu 0 = 1$). On the other hand, orthogonality which ensures simple demodulation complexity cannot be given up as it plays an important role in the cost calculation of system applications. This dilemma excludes pulse shaping OFDM/QAM from the candidate list and brings an alternative scheme OFDM/OQAM into sight.

For example, in indoor situations the time dispersion is usually small, see Fig 4, a vertically stretched time-frequency pulse is suitable and where the frequency dispersion is small, a horizontally stretched pulse is suitable. This enables a very efficient packing [17] of time-frequency symbols and hence maximizes e.g. the throughput or the interference robustness in the communication link. In the following part of this section, several different types of pulse shape functions are presented, namely the rectangular function, the half cosine function, the Gaussian function, the IOTA function and the EFG.

6. 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.

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