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PAPR Reduction Techniques in OFDM System

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ABSTRACT
Orthogonal Frequency Division Multiplexing (OFDM) is one of the techniques against the multipath fading channel for wireless communications. However, the high Peak-to-Average Power Ratio (PAPR) problem of OFDM is a major drawback of multicarrier transmission system which leads to power inefficiency in RF section of the transmitter. This paper presents different PAPR reduction techniques with analysis. We also simulate the selected mapping technique (SLM) for different route number which is most efficient technique for PAPR reduction when the number of subcarrier is large.
Keywords — Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR) Techniques.

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) technology is one of the most attractive techniques for fourth generation (4G) wireless communication. It effectively combats the multipath fading channel and improves the bandwidth efficiency. At the same time, it also increases system capacity so as to provide a reliable transmission [1]. OFDM uses the principles of Frequency Division Multiplexing (FDM) [1] but in much more controlled manner, allowing an improved spectral efficiency [1].

OFDM whole procedure block diagram is shown in figure 1.The basic principle of OFDM is to split a high-rate data stream into a number of lower data rate streams that are transmitted simultaneously over a number of subcarriers. These subcarriers are overlapped with each other. Because the symbol duration increases for lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased.

Inter-symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. OFDM faces several challenges. The key challenges are ISI due to multipath-use guard interval, large peak to average ratio due to non linearity’s of amplifier; phase noise problems of oscillator, need frequency offset correction in the receiver. OFDM generates high Peak-to-Average Power Ratio (PAPR) which distorts the signal if the transmitter contains nonlinear components such as power amplifiers (PAs). The nonlinear effects on the transmitted OFDM symbols are spectral spreading, inter modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals. Therefore the PAs requires a back off which is approximately equal to the PAPR for distortion-less transmission. This decreases the efficiency for amplifiers. Therefore, reducing the PAPR is of practical interest.

Many PAPR reduction methods have been proposed. Some methods are designed based on employing redundancy, such as coding [3], [4], selective mapping with explicit or implicit side information [5], [2], [4], or tone reservation [9], [11]. An apparent effect of using redundancy for PAPR reduction is the reduced transmission rate. PAPR reduction may also be achieved by using extended signal constellation, such as tone injection [9], or multi-amplitude CPM. The associated drawback is the increased power and implementation complexity. A simple PAPR reduction method can be achieved by clipping the time-domain OFDM signal. In this work, we survey the PAPR reduction techniques for OFDM.

The remainder of this paper is organized as follows. In section II describe introduction about PAPR. Section III describes PAPR reduction techniques. In Section IV the analysis of different techniques is given. Conclusions are given in section V.

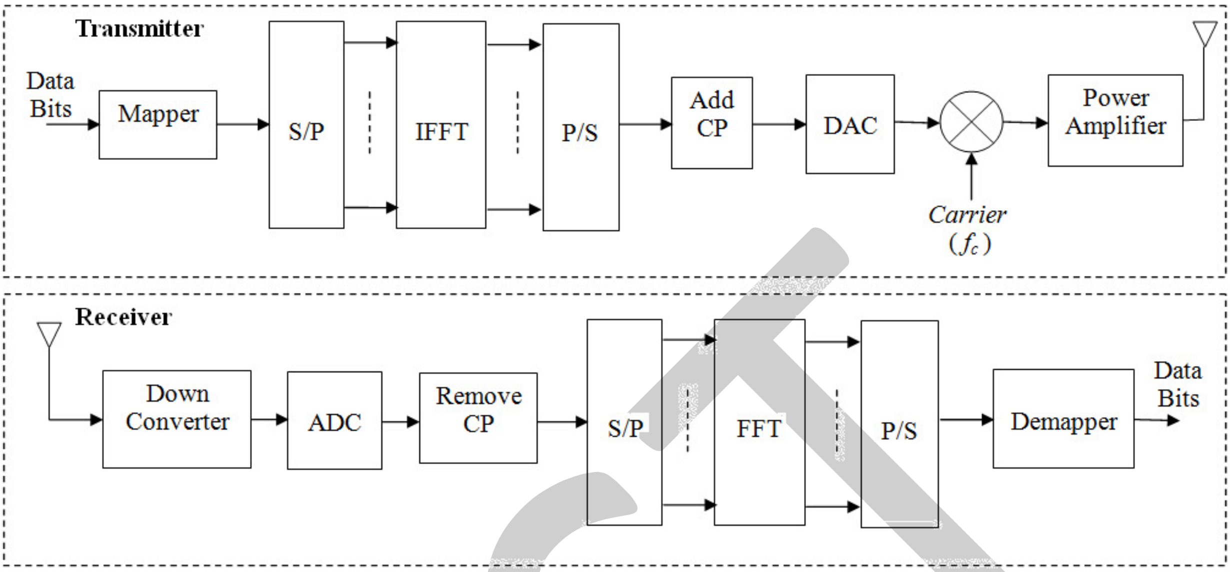

Fig. 1 Block diagram of OFDM System

II. PEAK TO AVERAGE POWER RATIO

A major disadvantage that arises in multicarrier systems like OFDM is the resulting non-constant envelope with high peaks [12]. When the independently modulated subcarriers are added coherently, the instantaneous power will be more than the average power. Consider the OFDM signal $x(t)$ defined in (1) where N subcarriers are added together.

$$x(t) = \sum_{k=0}^{N-1} (a_k \exp(j2\pi (f_c + k\,\Delta f)\, t)) \\ = \exp(j2\pi f_c t)\, a(t), \qquad (1)$$

Where a_k, $0 \leq k \leq N-1$, are complex-valued constellation points representing data and $f_k = f_c + k\Delta f$, $0 \leq k \leq N-1$, is the k^{th} subcarrier, with f_c being the lowest subcarrier frequency. Δf is the frequency spacing between adjacent subcarriers, chosen to be 1/Ts to ensure that the subcarriers are orthogonal. If a(t) is sampled at rate R samples per second, where t is replaced by nT_s/N, n = 0, . . .,N−1, then a(t) is represented by the sampled function a[n] expressed as,

$$a[n] = \sum_{k=0}^{N-1} a_k \left(\exp \frac{j2\pi kn}{N}\right)$$

If N is large enough, then, based on *central-limit theorem* (CLT), the resulting signal $x(t)$ will be close to a complex Gaussian process [12]. This means that both of its real and imaginary parts are Gaussian distributed and its envelope and power follows Rayleigh and exponential distributions respectively. The PAPR for the continuous-time signal $x(t)$ is the ratio of the maximum instantaneous power to the average power. For the discrete-time version $x[n]$, PAPR is expressed as

$$PAPR(x[n]) = \max_{0 \leq n \leq N-1} \frac{|x[n]|^2}{E[|x[n]|^2]}$$

Where E[.] is the expectation operator. It is introduces that PAPR is evaluated per OFDM symbol. Figure 2 shows how a high peak is obtained by adding four sinusoidal signals with different frequencies and phase shifts coherently. The resulting signal’s envelope exhibits high peaks when the instantaneous amplitudes of the different signals have high peaks aligned at the same time.

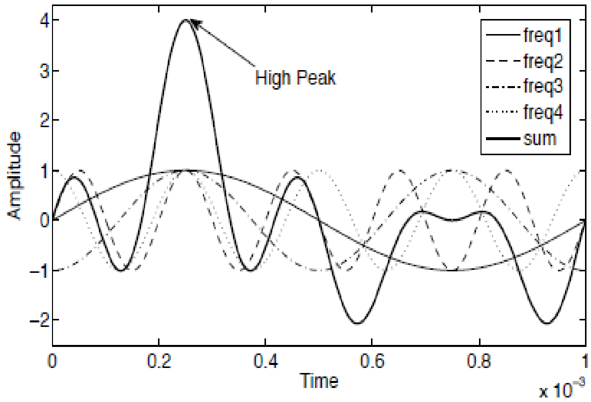

Fig. 2 High peaks in OFDM signal

III. PAPR REDUCTION TECHNIQUES

Several PAPR reduction techniques have been proposed in the literature. These techniques are divided into two groups. These are signal distortion techniques and signal scrambling techniques.

3.1 Signal Distortion Techniques

Signal distortion techniques are Peak Windowing [13], Envelope scaling [9], Peak Reduction Carrier [6], Clipping and Filtering [3].

3.1.1 Peak Windowing

The peak windowing method has been suggested by Sungkeun Cha, Sungeun Lee [13]. This method, proposes that it is possible to remove large peaks at the cost of a slight amount of self interference when large peaks arise infrequently. Peak windowing reduces PAPRs at the cost of increasing the BER and out-of-band radiation. Clipping is a one kind of simple introduces PAPR reduction technique which is self interference. The technique of peak windowing offers better PAPR reduction with better spectral properties. In peak windowing method we multiply large signal peak with a specific window, for example; Gaussian shaped window, cosine, Kaiser and Hamming window. In view of the fact that the OFDM signal is multiplied with several of these windows, consequential spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Thus, the window should be as narrow band as possible, conversely the window should not be too long in the time domain because various signal samples are affected, which results an increase in bit error rate (BER). Windowing method, PAPRs can be obtained to 4dB which from the number of independent subcarriers. The loss in signal-to-noise ratio (SNR) due to the signal distortion is limited to about 0.3dB. A back off relative to maximum output power of about 5.5dB is needed in spectra distortion at least 30dB below the in-band spectral density.

3.1.2 Envelope Scaling

They anticipated a new algorithm to reduce PAPR by scaling the input envelope for some subcarriers before they are sent to IFFT [5]. They used 256 subcarriers with QPSK modulation technique, so that envelopes of all the subcarriers are equal. The key idea of this scheme is that the input envelope in some sub carrier is scaled to achieve the smallest amount of PAPR at the output of the IFFT. Thus, the receiver of the system doesn't need any side information for decoding the receiver sequence. This scheme is appropriate for QPSK modulation; the envelopes of all subcarriers are equal. Results show that PAPR can be reduced significantly at around 4 dB.

3.1.3 Peak Reduction Carrier

Peak Reduction Carrier technique is proposed by Tan and Wassell. The technique is to use the data bearing peak reduction carriers (PRCs) to reduce the effective PAPR in the OFDM system [6]. It includes the use of a higher order modulation scheme to represent a lower order modulation symbol. The amplitude and phase of the PRC is positioned within the constellation region symbolizing the data symbol to be transmitted. This method is suitable for PSK modulation; where the envelopes of all subcarriers are the same. When the QAM modulation scheme will be implemented in the OFDM system, the carrier envelope scaling will result in the serious BER degradation. To limit the BER degradation, amount of the side information would also be excessive when the number of subcarriers is large.

3.1.4 Clipping And Filtering

One of the simple and effective PAPR reduction techniques is clipping, which cancels the signal components that exceed some unchanging amplitude called clip level. However, clipping yields distortion power, which called clipping noise, and expands the transmitted signal spectrum, which causes interfering. Clipping is nonlinear process and causes in-band noise distortion, which causes degradation in the performance of bit BER and out-of-band noise, which decreases the spectral efficiency [3].

Clipping and filtering technique is effective in removing components of the expanded spectrum. Although filtering can decrease the spectrum growth, filtering after clipping can reduce the out-of-band radiation, but may also cause some peak re-growth, which the peak signal exceeds in the clip level. The technique of iterative clipping and filtering reduces the PAPR without spectrum expansion. However, the iterative signal takes long time and it will increase the computational complexity of an OFDM transmitter. But without performing interpolation before clipping causes it out-of-band. To avoid out-of-band, signal should be clipped after interpolation. However, this causes significant peak re-growth. So, it can use iterative clipping and frequency domain filtering to avoid peak re-growth.

3.2 Signal Scrambling Techniques

Block Coding Techniques [5], Selected mapping (SLM) [7], Tone Reservation (TR)[12], Tone Injection (TI)[12] etc are Signal Scrambling Techniques.

3.2.1 Block Coding Techniques

The fundamental idea is that of all probable message symbols, only those which have law peak power will be chosen by coding as valid code words for transmission. No introduction of distortion to the signals. If there have N subcarriers, they are represented by 2N bits using QPSK modulation and thus 22N messages. Using the whole message space corresponds to zero bits of redundancy. Using only half of the messages corresponds to one bit of redundancy. The remaining message space is then divided in half again and this process continues until N bits of redundancy have been allocated which corresponds to a rate one-half code for N carriers. Large PAPR reduction can be achieved if the long information sequence is separated into different sub blocks, and all sub block encoded with System on a Programmable Chip (SOPC).

3.2.2 Selected Mapping

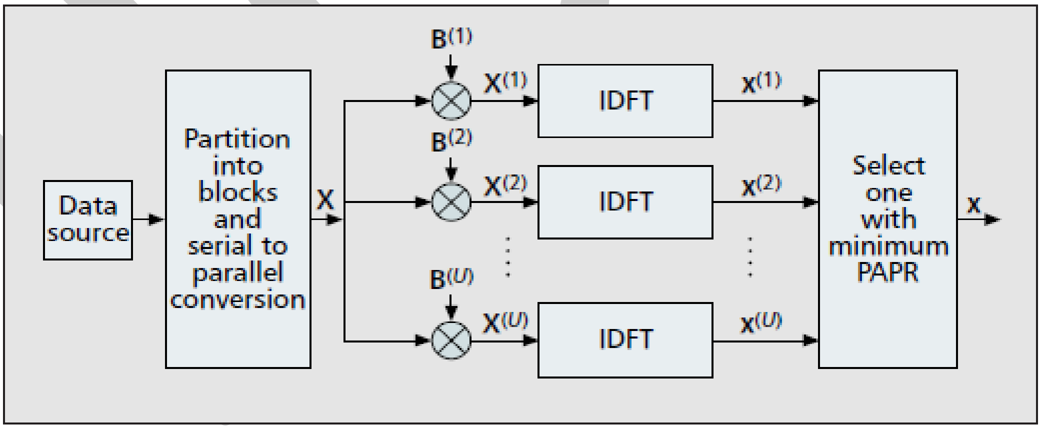

Fig. 3 Block diagram of SLM technique

Figure 3 shows the block diagram of Selected Level Mapping (SLM). The probability of PAPR larger than a threshold z can be written as $(PAPR > z)$ =1− (1−exp −z) N. Assume that M OFDM symbols carry the same information and that they are statistically independent of each other. In this case, the probability of PAPR greater than z is equals to the product of each independent candidate's probability. This process can be written:

$$P\{PAPR_{low} > z\} = (P\{PAPR > Z\})^M$$

$$=((1-\exp(-z))^N)^M$$

In selected mapping method, firstly *M* statistically independent sequences which represent the same information are generated and next the resulting *M* statistically independent data blocks $S_m = [S_{m,0}, S_{m,1}, \ldots\ldots, S_{m,N-1}]^T$, m = 1,2…..M are then forwarded into IFFT operation simultaneously. Finally, at the receiving end, OFDM symbols $x_m=[x_1,x_2\ldots,x_N]^T$ in discrete time-domain are acquired, and then the PAPR of these M vectors are calculated separately. Eventually, the sequences $\boldsymbol{xd}$ with the smallest PAPR will be elected for final serial transmission.

3.2.3 Tone Reservation

The main idea of this method is to keep a small set of tones for PAPR reduction. This can be originated as a convex problem and this problem can be solved accurately. Tone reservation method is based on adding a data block and time domain signal. A data block is dependent time domain signal to the original multicarrier signal to minimize the high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at the receiver. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones This method explains an additive scheme for minimizing PAPR in the multicarrier communication system. It shows that reserving a small fraction of tones leads to large minimization in PAPR ever using with simple algorithm at the transmitter of the system without any additional complexity at the receiver end. Here, N is the small number of tones, reserving tones for PAPR reduction may present a non–negligible fraction of the available bandwidth and resulting in a reduction in data rate. The advantage of TR method is that it is less complex, no side information and also no additional operation is required at the receiver of the system.

3.2.4 Tone Injection

Tone Injection (TI) method has been recommended by Muller, S.H., and Huber, J.B. [2]. This technique is based on general additive method for PAPR reduction. Using an additive method achieves PAPR reduction of multicarrier signal without any data rate loss. TI uses a set of equivalent constellation points for an original constellation points to reduce PAPR. The main idea behind this method is to increase the constellation size. Then, each point in the original basic constellation can be mapped into several equivalent points in the extended constellation, since all information elements can be mapped into several equivalent constellation points. These additional amounts of freedom can be utilized for PAPR reduction. The drawbacks of this method are; need to side information for decoding signal at the receiver side, and cause extra IFFT operation which is more complex.

VI. ANALYSIS OF DIFFERENT TECHNIQUES

The PAPR reduction technique should be chosen with awareness according to various system requirements. Table 1 shows the comparison of PAPR Reduction techniques.

VII. CONCLUSION

We describe and summarize several techniques of PAPR and simulate SLM technique which is the best solution for PAPR. The selected technique provides us with a good range in performance to reduce PAPR problem. SLM algorithm adapted to any length of route number that means it can be used for different OFDM systems with different number of carriers. It is particularly suitable for the OFDM system with a large number of sub-carriers (more than 128). This research will continue in directions Firstly, PAPR reduction concepts will be expanded for distortion less transmission and identifying the best alternatives in terms of performance increase. Secondly, PAPR reduction technique will be develop for low data rate loss and efficient use of channel. A study of the complexity issues of the PAPR reduction technique is required, especially looking at ways of further reducing the complexity of the sphere decoder.

TABLE -1: COMPARISON OF PAPR REDUCTION TECHNIQUES

Reduction Techniques	Parameters			Operation required at Transmitter (TX) / Receiver (RX)
	Bit Rate Loss	***Decrease distortion***	***Power raise***	
Clipping and Filtering	NO	NO	NO	TX: Clipping RX: None
Selective Mapping (SLM)	YES	NO	YES	TX: M times IDFTs operation RX: Side information extraction, inverse SLM
Partial Transmit Sequence (PTS)	YES	NO	YES	TX: V times IDFTs operation RX: Side information extraction, inverse PTS
Interleaving	YES	NO	YES	TX: D times IDFTs operation, D-1 times interleaving RX: Side information extraction, de-interleaving
Block Coding	YES	NO	YES	TX: Coding or table searching RX: Decoding or table searching
Tone Injection (TI)	NO	YES	NO	
Tone Reservation (TR)	YES	YES	YES	

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