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SURVEY ARTICLE

An Efficient PAPR Reduction Technique for Mobile Terminals

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Abstract*— Orthogonal Frequency Division Multiplexing (OFDM) is an efficient method of data transmission for high speed communication systems. In the present era, it has been under intense research for broadband wireless transmission due to its robustness against multi-path fading. The main drawback of OFDM system is the high Peak to Average Power Ratio (PAPR) of the transmitted signals, which reduces the efficiency of transmit high power amplifier. In this paper, a novel scheme, in which a joint partial transmit sequence and clipping method is proposed for PAPR reduction. Simulation results show that the proposed scheme can give significant PAPR reduction while maintaining good performance in the BER.

Keywords*— Orthogonal Frequency Division Multiplexing (OFDM); Peak to Average Power Ratio (PAPR); Partial Transmit Sequence (PTS); Cumulative Complementary Distribution Function (CCDF); Inverse Fast Fourier Transform (IFFT); Bit Error Rate (BER); Phase Shift Keying (PSK); Clipping.

I. INTRODUCTION

In recent years, need for high speed data transmission has increased with the rapid growth in digital wireless communication. Multicarrier transmission, like Orthogonal Frequency Division Multiplexing (OFDM) is a technique with a long history [1]–[4] that has recently seen rising popularity in wireless communication. OFDM is used in many applications owing to its robustness to frequency selective fading or narrowband interference, high bandwidth efficiency and efficient implementation. International standards making use of OFDM for high-speed wireless communications are already established or being established by IEEE 802.11, IEEE 802.16, IEEE 802.20, and European Telecommunications Standards Institute (ETSI) Broadcast Radio Access Network (BRAN) committees. Moreover, it is expected to be the standard for the Fourth Generation (4G) cellular system. For wireless applications, an OFDM-based system can be of interest because it provides greater immunity to multipath fading and impulse noise, and eliminates the need for equalizers, while efficient hardware implementation can be realized using fast Fourier transform (FFT) techniques.

One of the major drawbacks of multicarrier transmission is the high peak-to-average power ratio (PAPR) of the transmit signal. A large PAPR brings disadvantages like increased complexity of the ADC and DAC and reduced efficiency of the RF power amplifier. Linear power amplifiers are used at the transmitter to amplify the data for transmission. The high PAPR will shift the operating point of the amplifier to the saturation region which leads to in-band distortion and out-band radiation. If the peak transmit power is limited by either regulatory or application constraints, the effect may reduce the average power allowed under multicarrier transmission. This in turn reduces the range of multicarrier transmission. Moreover, to prevent spectral growth of the multicarrier signal in the form of inter-modulation among subcarriers and out-of-band radiation, the transmit power amplifier must be operated in its linear region i.e., with a large input back off. This may have a detrimental effect on battery lifetime in mobile applications. In many low-cost applications, the drawback of high PAPR may outweigh all the potential benefits of multicarrier transmission systems.

Techniques used to reduce PAPR can be categorized into three: First, signal distortion techniques, such as clipping, peak windowing, and peak cancellation. Second, coding techniques that use a special code set that excludes OFDM symbols with a large PAPR ratio. In the third method, each OFDM symbol is scrambled with different scrambling sequences and the sequence that gives the smallest PAPR is selected. As an alternative approach, this paper proposed a technique which combines the methods of first and third categories to reduce the PAPR. The simulation results show that the proposed design has better performance compared with the individual techniques.

This paper is structured as follows. Characterization of the OFDM system with the proposed scheme is discussed in Section II. Section III describes the Clipping and Partial Transmit Sequence techniques and Section IV gives the simulation results and describes the corresponding theoretical analysis in terms of complementary cumulative density function (CCDF) and BER performance. Section V gives the conclusion.

II. PAPR AND REDUCTION SCHEMES

In OFDM system, multiple sub-carriers are superimposed to obtain the output. Hence some instantaneous power output might increase to a large extent and become far higher than the mean power of the system. If the peak power is too high, it could be out of the scope of the linear range of the power amplifier. This gives rise to non-linear distortion and resulting in performance degradation. If no measure is taken to reduce the high PAPR, OFDM systems could face serious restriction for practical applications. The PAPR of OFDM signal is defined as the ratio of the maximum instantaneous power to the average power, i.e.

$$PAPR_x = \frac{P_{PEAK}}{P_{AVERAGE}} = \frac{\max\limits_{0 \le n \le lN-1} \left\{ |x_n|^2 \right\}}{E\left\{ |x_n|^2 \right\}} \qquad (1)$$

where E{·} and max{·} denote the mathematical expectation and maximal element function, respectively.

Various techniques have been proposed to reduce PAPR [4], which can be categorized into three: First, signal distortion techniques, such as clipping [5], peak windowing, and peak cancellation. Second, coding techniques that use a special code set that excludes OFDM symbols with a large PAPR ratio. Third, scrambles each OFDM symbol with different scrambling sequences and selecting the sequence that gives the smallest PAPR ratio. Partial transmit sequence (PTS) [6], selected mapping (SLM) [9], interleaving etc. are under this category. As an alternative approach, the combined effect of clipping and PTS techniques are utilised to reduce PAPR with less compromise in the bit error rate performance is proposed. The simulation results show that the proposed design has better performance compared with the individual techniques. This section focuses more closely on the considered PAPR reduction techniques.

A. Partial Transmit Sequence

In the PTS technique, an input data block of N symbols is partitioned into disjoint subblocks [6], [7], [8]. The subcarriers in each subblock are weighted by a phase factor for that subblock. The phase factors are selected such that the PAPR of the combined signal is minimized. In the ordinary PTS technique input data block X is partitioned into M disjoint subblocks $X_m = [X_{m,0}, X_{m,1}, \ldots, X_{m,N-1}]^T$, m = 1, 2, …, M, such that $\sum_{m=1}^{M} X_m = X$ and the subblocks are combined to minimize the PAPR in the time domain. Complex phase factors, $b_m = e^{j\phi_m}$, m = 1, 2, …, M, are introduced to combine the PTSs. The set of phase factors is denoted as a vector $b = [b_1, b_2, \ldots, b_M]^T$. The time domain signal after combining is given by:

$$x'(b) = \sum_{m=1}^{M} b_m x_m \tag{2}$$

where $x'(b) = [x_0'(b), x_1'(b), \ldots, x_{Nl-1}'(b)]^T$. The objective is to find the set of phase factors that minimizes the PAPR. Minimization of PAPR is related to the minimization of $\max_{0 \le k \le Nl-1} \left| x_k'(b) \right|$. The selection of the phase factors is limited to a set with a finite number of elements to reduce the search complexity. Also the search complexity may increases exponentially with the number of subblocks M. The amount of PAPR reduction depends on the number of subblocks M and the number of allowed phase factors. Another factor that may affect the PAPR reduction performance in PTS is the subblock partitioning, which is the method of division of the subcarriers into multiple disjoint subblocks. There are three kinds of subblock partitioning schemes: adjacent, interleaved, and pseudo-random partitioning. Among them, pseudo-random partitioning has been found to be the best choice. The PTS technique works with an arbitrary number of subcarriers and any modulation scheme.

B. Clipping

Clipping is the PAPR reduction technique that comes under the distortion based category. But it is the simplest approach for reducing the PAPR of OFDM signals [10]-[12]. In this technique, to limit the peak envelope of the input signal, the high amplitude peaks of the signal are clipped to a predetermined threshold value. Since the clipping is done on the actual information itself, there is a possibility to lose the data. So there will be a trade-off between the clipping and the BER performance. For an OFDM passband signal *x[n]*, the clipped version $x_c[n]$ can be expressed as:

$$x_c[n] = \begin{cases} A; \left|x[n]\right| \ge A \\ x[n]; \left|x[n]\right| < A \\ -A; \left|x(n)\right| \le -A \end{cases} \tag{3}$$

where *A* is the pre-specified clipping level. This technique has some drawbacks which causes in band signal distortion, resulting in Bit Error Rate performance degradation. It also causes out-of-band radiation, which imposes out-of-band interference signals to adjacent channels. This out-of-band radiation can be reduced by filtering. But this filtering of the clipped signal leads to the peak regrowth [10]. That means the signal after filtering operation may exceed the clipping level specified for the clipping operation. An improvement in operation can also be made by repeating the above procedures.

III. Proposed Scheme In OFDM System

An OFDM system has been implemented with the hybrid scheme of partial transmit sequence and clipping as the Peak-to-average power ratio reduction technique. In the PTS technique, an input data block is partitioned into M disjoint subblocks. The subcarriers in each subblock are weighted by a phase factor such that the PAPR of the combined signal is minimized for that subblock. Then a clipping block is has appended for further reduction of PAPR. The proposed design can be depicted as shown below. Fig. 1 shows the block diagram of a baseband OFDM system using the proposed technique for PAPR reduction. An OFDM symbol is made of sub-carriers modulated by constellations mapping. This mapping can be achieved from Binary Phase-Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). For an OFDM system with N sub-carriers, the complex value symbol vector $X = [X_0, X_1, \ldots, X_{N-1}]T$, is obtained from the input bit stream by mapping into BPSK or QPSK. The input data block is partitioned into M disjoint subblocks. The l-times oversampled time domain signal of X_m, m = 1, 2, …, M, is denoted $x_m = [x_{m,0}, x_{m,1}, \ldots, x_{m,Nl-1}]^T$, m = 1, 2, 3,…, M, is obtained by taking an IFFT of length Nl on X_m concatenated with $(l - 1)N$ zeros. These are the partial transmit sequences.

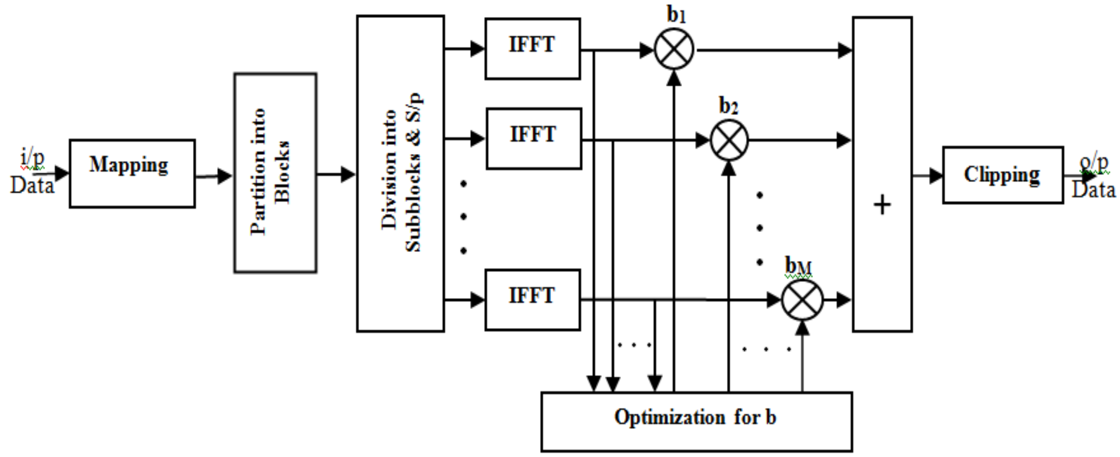

Fig. 1. Block diagram of a baseband OFDM system with proposed technique

In the discrete-time domain, the nth element can be expressed as:

$$x_n = \frac{1}{\sqrt{lN}} \sum_{k=0}^{N-1} X_k . e^{\frac{j2\pi nk}{lN}} , n = 0,1,\ldots,lN-1 \qquad (4)$$

where l is over-sampling factor. The PAPR does not increase significantly after $l = 4$. In order to avoid aliasing and to accurately describe the PAPR an oversampling factor $l \geq 4$ is required. The set of phase factors $b = [b_1, b_2, \ldots, b_M]^T$ are used to combine the PTSs. The clipping operation is done on this sequence to reduce the PAPR further. But we cannot clip the signal after a particular threshold value which will make the reconstruction more difficult.

The main idea for combining the two methods is relaying on the observation that the overall performance in PAPR reduction will increase by using these two different types of signal processing. By using this technique the PAPR can be reduced and the operating point of the linear amplifier which is used at the transmitter side can be kept in the linear dynamic range itself. This will avoid the shifting of the operating point to the saturation region by which the orthogonality can be maintained.

IV. SIMULATION RESULTS

Simulation results are used to evaluate the peak-to-average power ratio reduction capability and bit error rate of the proposed scheme. The Rayleigh fading channel is considered for simulation. In simulation, an OFDM system is considered with subcarrier N = 64 or 128 and QPSK modulation is used for encoding the information. The performance scheme can be evaluated by using cumulative distribution of PAPR of OFDM signal. The complementary cumulative distribution function (CCDF) is the parameter, which is used to measure the efficiency and PAPR of a communication system. The CCDF of the PAPR of the data block is desired to compare outputs of proposed scheme to various reduction techniques.

Table 1
SIMULATION PARAMETERS

Simulation Parameters	Values
Subcarriers	64
Modulation scheme	QPSK
Oversampling factor	4
Set of phase factors, M	4

The complementary cumulative distribution function (CCDF) of the PAPR for the proposed scheme and the individual techniques are plotted in Fig. 2. It is clear from the plot that the PAPR of the proposed system is reduced. From Fig. 2 it can see that with probability of 10^{-3}, PAPR of the original signal is more than 10.6dB, while for a system with PTS and clipping, the PAPR is reduced approximately to 5.1dB.

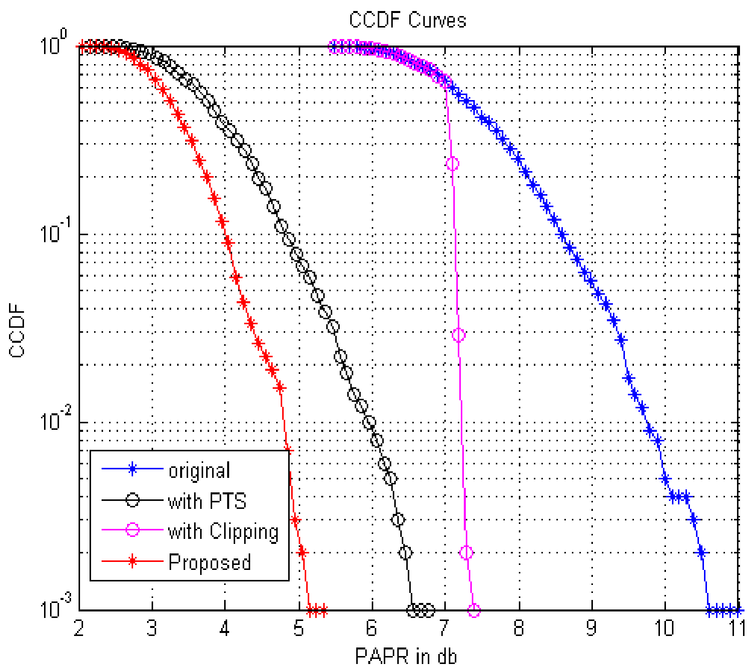

Fig. 2. CCDFcurves of PAPR for Proposed and Individual Schemes

The simulation results show that the CCDF curve for the proposed method has nearly 5.5dB improvement with a probability of 10^{-3}.

Table 2
COMPARISONS BETWEEN PAPR REDUCTION PERFORMANCE WITH QPSK

PAPR Reduction Schemes	PAPR(dB) At CCDF = 10^{-3}
Original OFDM	10.6
OFDM with clipping	7.3
OFDM with PTS	6.6
OFDM with proposed scheme	5.1

Table 1 list the simulation parameters and Table 2 summarizes the results of the PAPR reduction performance with different considered schemes. From the results, when compared with the individual methods, the proposed scheme provides better performance.

It is not possible to reduce the PAPR without looking into the Bit Error Rate performance. Hence the BER performance is also calculated for the proposed design and it is shown in Fig. 3.It is clear from this figure that, the proposed system maintains the BER performance so close to the conventional OFDM system. At the same time it reduces the PAPR considerably. Hence the proposed scheme can obtain an efficient tradeoff between PAPR reduction and BER.

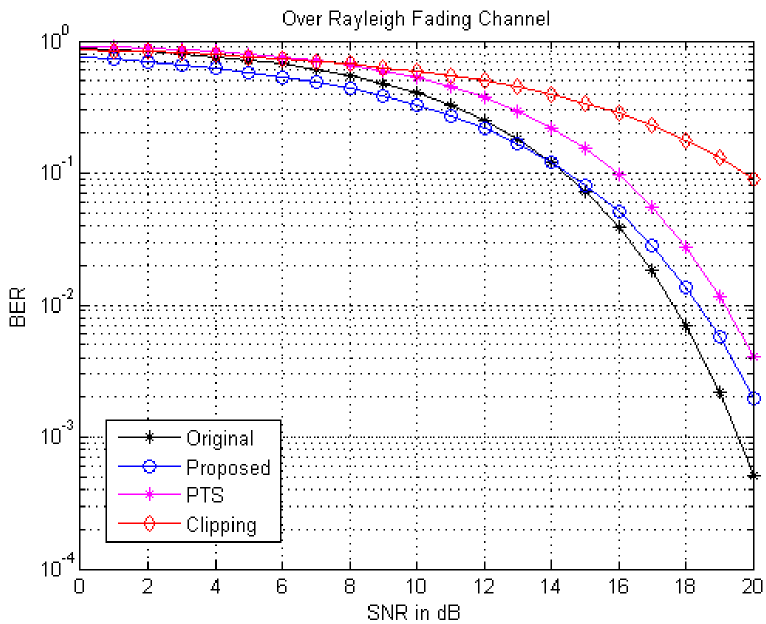

Fig. 3. BER Performance Curve

V. Conclusion

This paper proposes an alternative PAPR reduction technique based on a combination of a partial transmit sequence method with the clipping method. In the simulation, PTS technique is followed by the clipping operation. The simulation results show that this hybrid scheme gives higher PAPR reduction than the component methods and provides an affordable BER performance for the proposed design.

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