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PAPR reduction of space-frequency coded OFDM systems using Active Constellation Extension

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ABSTRACT

Active Constellation Extension (ACE) is one of the techniques introduced for Peak to Average Power Ratio (PAPR) reduction of OFDM systems. In this technique, the constellation points are extended such that the PAPR is minimized but the minimum distance of the constellation points does not decrease. In this paper, an iterative ACE method is proposed for the PAPR reduction of OFDM systems with spatial diversity of Space Frequency Block Coding (SFBC). The proposed method is such that the PAPR is reduced simultaneously at all antennas, while the spatial encoding relationship still holds. In this method, at each iteration, the antenna with maximum PAPR is selected and the ACE algorithm is applied; then the signal of the other antennas are constructed from the resultant signal using SFBC relationship. Simulation results show that the algorithm converges and its performance is very close to the performance of the ACE in single antenna systems and it outperforms the alternative methods for PAPR reduction of SFBC–OFDM systems when the number of subcarriers increases.

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a well-known technique for transmission of high data rate over broadband frequency selective channels [1,2]. In this technique, several narrowband orthogonal subcarriers are used to transmit information instead of a single wideband carrier. One of the drawbacks of OFDM systems is high PAPR, which leads to the saturation of the high power amplifiers. Thus, a high dynamic range amplifier is needed, which increases the cost of the system. Some techniques have been proposed to reduce the PAPR in single antenna OFDM systems [3–14]. Some of these methods need Side Information (SI) to be transmitted to the receiver, such as Partial Transmit Sequences (PTS) [3,4] and Selected Mapping (SLM) [5–7]. Some other methods do not need SI, such as clipping and filtering [8–10], tone reservation [11], block coding [12,13], and ACE [14] methods.

In the ACE method, the constellation points are moved such that the PAPR is minimized without any increase in the Symbol Error Rate (SER). To find the proper extension of the symbols in single antenna OFDM systems, an iterative method based on Projection Onto Convex Sets (POCS) has been proposed in [14]. In this method, at each iteration, the time domain signal is clipped and filtered. The clipping and filtering noise moves the constellation points. The extended symbols must remain within the allowable regions; otherwise, the point is moved to its original position. These procedures are performed iteratively to achieve the target PAPR.

The data rate or SER of wireless systems can be improved using several transmitter antennas. In spatial multiplexing systems, independent symbols are transmitted from several antennas and this leads to the increase of data rate [15]. In comparison to spatial multiplexing systems, in spatial diversity systems different representations of the same data symbols are transmitted from transmitter antennas such that full diversity is achieved at the receiver and the SER is reduced. The space-time codes to achieve the full transmission diversity have been introduced in [16,17]. Through the combination of multiple transmission antenna and OFDM techniques, a higher capacity can be achieved over broadband multipath fading wireless channels. Multiple antenna OFDM system also can be used in spatial multiplexing [18] and spatial diversity structures [19,20] for improvement of data rate or SER performances, respectively. Space Time Block Coding (STBC) and Space Frequency Block Coding (SFBC) techniques can be used to achieve diversity in OFDM systems. Multiple antenna OFDM systems also suffer from high PAPR problem. The ACE and the SLM methods have been extended to spatial multiplexing OFDM systems in [21] and [22], respectively. In [23], Polyphase Interleaving and Inversion (PII) which is a derivation of SLM method has been proposed for PAPR reduction of SFBC–OFDM systems. A modified version of the SLM method has been introduced in [24] for SFBC–OFDM systems. In [25], the PTS method has been used for

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PAPR reduction of STBC and SFBC–OFDM systems. These methods need SI to be transmitted to the receiver. In [26], the clipping and filtering method has been extended to SFBC–OFDM system and a complex iterative method has been proposed to compensate for the clipping noise at the receiver side.

In this paper, the ACE method is extended to SFBC–OFDM systems. The main problem in the extension of the ACE method to the spatially encoded OFDM systems is the simultaneous PAPR reduction at all antennas while the spatial encoding relationships remain constant. In the SFBC–OFDM systems, the spatial encoding is done between the adjacent subcarriers of OFDM frame [19]. In the proposed method, at each iteration, the antenna with the maximum PAPR is selected and the clipping, filtering and movement of the constellation points are applied. Subsequently, the signals of the other antennas are produced using SFBC relationships. This procedure is done iteratively until it achieves the target PAPR or is stopped after a number of iterations. The main advantage of the ACE method compared to clipping and filtering method is that the transmitted symbols can be detected at the receiver side without any additional complexity and degradation on the SER performance. Also its advantage in comparison to PTS and SLM methods is that the receiver does not need SI for detection of transmitted symbols.

The remainder of this paper is organized as follows: In Section 2, the single antenna OFDM systems are modeled and the iterative ACE method for PAPR reduction in these systems is discussed briefly. Then, in Section 3, SFBC–OFDM systems are investigated and the ACE optimization problem is introduced. The proposed method is introduced in Section 3.1, and its convergence behavior and complexity are discussed in Sections 3.2 and 3.3, respectively. Section 4 is devoted to the simulation results and performance evaluation of the proposed method.

2. Single antenna OFDM systems and the ACE method

In single antenna OFDM systems, the input bit stream is interleaved and encoded by a channel encoder. Then, the coded bits are mapped onto complex symbols using digital modulation techniques. The sequential symbols are converted to blocks of N_c complex symbols, where $\mathbf{S}_m = [S_m(0), S_m(1), \ldots, S_m(N_c-1)]^T$ is the m th block and N_c is the number of OFDM subcarriers. Then, $N-N_c$ zeros are added at the end of $\mathbf{S}_m$ (N/N_c is the oversampling ratio) before the IFFT block to yield the oversampled time domain vector $\mathbf{s}_m = [s_m(0), s_m(1), \ldots, s_m(N-1)]^T$:

$$s_m(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N_c-1} S_m(k) e^{j(2\pi nk/N)}, \quad n = 0, 1, \ldots, N-1. \tag{1}$$

If $\mathbf{F}$ is defined as the $N \times N_c$ IFFT matrix with entries $f_{n,k} = e^{j(2\pi nk/N)}/\sqrt{N}$, then the above equation can be written in the matrix form of $\mathbf{s}_m = \mathbf{F}\mathbf{s}_m$. A Cyclic Prefix (CP) is added to the end of frame $\mathbf{s}_m$ before transmission to avoid Inter-Symbol Interference (ISI). The PAPR of the m th OFDM frame is defined as the ratio of the maximum to average power of the time domain samples:

$$\zeta_m = \frac{\max_n\{|s_m(n)|^2\}}{E\{|s_m(n)|^2\}} \tag{2}$$

where $E\{.\}$ is the mathematical expectation. Based on (1), the time domain samples are the sum of N_c independent terms. Thus, the maximum possible amplitude of the time domain samples is N_c.

To reduce the PAPR by the ACE method [14], the complex symbols $S_m(k)$ are extended such that the PAPR of the time domain signal is reduced while the minimum distance of the constellation points does not decrease. Thus, at the receiver side the Bit Error Rate (BER) does not increase. Fig. 1 shows the regions in which the symbols $S_m(k)$ can be moved such that the minimum distance of the constellation points does not decrease. If the symbol $S_m(k)$ is extended to the point $S_m(k)+C_m(k)$ and $\mathbf{C}_m = [C_m(0), C_m(1), \ldots, C_m(N_c-1)]^T$, then the following optimization problem must be solved:

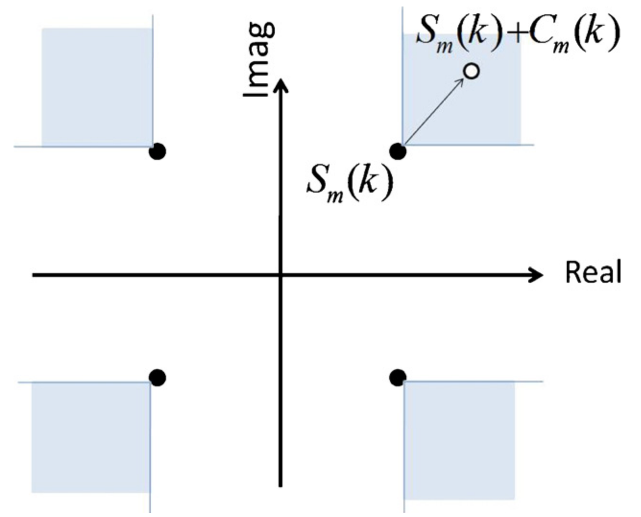

Fig. 1. The acceptable regions for the extension of the QPSK symbols in ACE method.

$$\begin{aligned} &\min_{\mathbf{C}_m} \left\{ \max_n\{|s_m(n) + (\mathbf{F})_n \mathbf{C}_m|^2\} \right\} \\ &\text{Subject to} \quad \forall k \quad S_m(k) + C_m(k) \in \mathcal{D} \quad \text{and} \quad \|\mathbf{C}_m\|^2 \le \Delta P \end{aligned} \tag{3}$$

where $(\mathbf{F})_n$ is the n th row of the matrix $\mathbf{F}$, $\mathcal{D}$ is the acceptable regions for the movement of the constellation points and ΔP limits the power increase. In [14] an iterative algorithm for finding the sub-optimum solution of (3) has been proposed. In this method, the time domain samples $s_m(n)$ are clipped as follows:

$$\hat{s}_m(n) = \begin{cases} s_m(n) & \text{if} |s_m(n)| \le A \\ \dfrac{A s_m(n)}{|s_m(n)|} & \text{if} |s_m(n)| > A \end{cases}, \tag{4}$$

where A is the clipping threshold. The nonlinear clipping operation creates in-band and out-of-band distortions. The out-of-band components must be removed. Therefore the samples are converted again to the frequency domain using the FFT operation and $N-N_c$ out-of-band components are removed. It is noteworthy that the in-band components $S_m(k)$, $k = 0, 1, \ldots, N_c-1$ have been moved from their initial position in the constellation. The new points denoted by $\hat{S}_m(k)$ must be mapped to the regions shown in Fig. 1. To achieve this, the points in acceptable regions are kept unchanged and the other points are mapped to these regions. Subsequently, the time domain samples are generated again form the extended symbols and the procedures of clipping, removing the out-of-band components and mapping to the acceptable regions are performed iteratively to achieve the target PAPR.

3. SFBC–OFDM systems and modified ACE method for PAPR reduction

In SFBC–OFDM systems with M_t transmitter antennas, the symbol transmitted from the k th subcarrier of the p th antenna, denoted by $S_m^{(p)}(k)$, represents the combination of the frequency domain symbols $S_m(k)$, $k = 0, 1, \ldots, N_c-1$ and their conjugates. If the time domain samples transmitted from the p th antenna is denoted by $\mathbf{s}_m^{(p)} = [s_m^{(p)}(0), s_m^{(i)}(1), \ldots, s_m^{(p)}(N-1)]^T$, then it can be written as

$$\begin{aligned} \mathbf{s}_m^{(p)} &= \mathbf{F}\mathbf{P}^{(p)} \left[\boldsymbol{\Gamma}^{(p)} \mathbf{S}_m + \boldsymbol{\Lambda}^{(p)} \mathbf{S}_m^* \right] \\ &= \mathbf{F}\mathbf{P}^{(p)} \boldsymbol{\Gamma}^{(p)} \mathbf{S}_m + \mathbf{F}\mathbf{P}^{(p)} \boldsymbol{\Lambda}^{(p)} \mathbf{S}_m^* \\ &= \boldsymbol{\Theta}^{(p)} \mathbf{S}_m + \boldsymbol{\Omega}^{(p)} \mathbf{S}_m^*. \end{aligned} \tag{5}$$