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PAPR ANALYSIS BY ADAPTIVE ACTIVE CONSTELLATION EXTENSION FOR STBC MIMO-OFDM SYSTEMS

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ABSTRACT

In this paper Adaptive Active Constellation (A-ACE) is implemented for Peak to Average Power Ratio (PAPR) reduction of OFDM Systems with spectral diversity of Space time Block Coding (STBC). The Adaptive Active Constellation Extension (A-ACE) is more simple and attractive for practical downlink implementation purpose. With the combination of MIMO and OFDM, grater channel capacities could be realized with robustness to channel impairments like ISI and multipath fading through cyclic prefix (CP). To overcome the disadvantage of normal constellation method i.e. minimum PAR value cannot be achieved if the target clipping level is much below than the initial optimum value, we envisaged ACE algorithm with adaptive clipping control to STBC MIMO-OFDM systems. Simulation results demonstrate that the algorithm can reach the minimum PAPR for severely low clipping ratios is superior to the performance of the ACE method in the single antenna OFDM system.

Keywords:
PAPR, CCDF, STBC, MIMO-OFDM, Clipping based-Active Constellation Extension, Adaptive Active Constellation Extension.

INTRODUCTION

OFDM is a well-known method for transmitting high data rate signals in the frequency selective channels. In OFDM systems, a wide frequency selective radio channel is divided into several narrowband, low-rate and, frequency nonselective sub channels so that multiple symbols can be transmitted in parallel and, the equalization also becomes much simpler [1-3]. The utilization of multiple antennas at both transmitter and the receiver, known as multiple_input multiple_output (MIMO) techniques constitutes a cost effective approach to high-throughput wireless broadband communication systems. Space-time-frequency (STF) block coding schemes take advantage of diversity at a transmitting station often without requiring any channel-state information (CSI); at the same time, when using orthogonal block codes, they allow simple decoding at the receiver station. In recent years, OFDM combined with MIMO, known as MIMO-OFDM has shown lot of promise in high-data rate wireless broad band applications. Spatial domain increased the diversity gain and/or the system capacity [4, 5], and supports large capacity with robustness to multipath fading. Some of the applications of MIMO-OFDM are Digital subcarrier line (DSL), IEEE 802.11, IEEE 802.16, IEEE 802.15.3a and it is increasingly held that OFDM results in improved downlink performance for fourth generation (4G).

However as a result of superposition of many individual subcarriers, OFDM signals have a large peak-to-average power ratio (PAPR). The high PAPR leads to the saturation of the high power amplifiers, which requires high power amplifiers backoff and results in low efficiency. MIMO-OFDM also suffers from the drawback of high PAPR on each antenna.

A number of techniques were proposed to control the PAPR of the transmitted signals in MIMO-OFDM systems, such as clipping [8], modified PTS, SLM, Active Constellation Extension schemes [9-11], and cross-antenna rotation and inversions [12]. An effective technique for PAPR reduction is clipping. However, clipping is a non-linear process and may cause significant in-band distortion, which degrades the BER performance and out-of-band noise, and thus reduces the spectral efficiency. PTS and SLM are probabilistic methods which achieve significant PAPR reduction with only a small data rate loss. In these methods the receiver requires the Side Information (SI) to receive data without any performance degradation. Among various PAPR reduction techniques, the active constellation extension (ACE) technique is attractive for use in the down-link. The reason is that in the ACE method, the constellation points are moved i.e., phase of the symbols are changed such that the PAPR is reduced, but the minimum distance between the constellation points remains same, thus the BER at the receiver does not increase. This advantage, however, comes at the cost of a slight power penalty. For practical implementation, low complexity ACE algorithms based on clipping were proposed in [13, 14].

The basic idea of the CB-ACE algorithm is to generate the anti-peak signal for PAPR reduction by projecting the clipping in-band noise into feasible extension area while removing the out-of-band

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distortion with filtering. Filtering and applying the ACE constraint in the frequency domain, after clipping in the time domain, both require iterative processing to suppress the subsequent regrowth of the peak power. This method has the low clipping ratio problem in that it cannot achieve the minimum PAPR when clipping level at the initial PAPR stages. To solve the low clipping ratio problem, a new method of ACE for PAPR reduction has been introduced by combing a clipping-based algorithm with an adaptive clipping control, which allows us to find the optimal clipping level [16].

This paper is organized as follows: PAPR properties of OFDM signal with CB-ACE method are described in Section II. In Section III, we describe the STBC MIMO-OFDM systems. Section IV is devoted to describe and analyze the A-ACE and is compared with the original CB-ACE method for reducing PAPR. In Section V, we present simulation results. Conclusions are given in Section VI.

PAPR PROPERTIES OF OFDM SIGNALS WITH CB-ACE

OFDM is performed by taking the inverse discrete Fourier transform (IDFT) of a block of N QAM-modulated data symbols $X = [X_0, X_1, X_2,\ldots, X_{N-1}]^T$, with each symbol modulating the subcarrier from a set of subcarriers. The 'N' subcarriers are chosen to be orthogonal, that is, T is the original data symbol period, and $fo = 1/T$, is the frequency spacing between adjacent subcarriers. The resulting baseband OFDM signal x(t) for N subcarriers can be written as

$$x_n = \frac{1}{\sqrt{lN}} \sum_{k=0}^{N-1} X_k \exp\left(j\frac{2\pi nk}{lN}\right),\ n = 0,1,2,\ldots,lN-1. \quad (1)$$

Where l is the over-sampled factor, $l >= 4$, which is large enough to accurately approximate the peaks.

The PAPR of OFDM signal in a given block is defined as the maximum instantaneous power to the average power, i.e,

$$PAPR = \frac{\max_{0 \le n \le lN-1}\{|x_n|^2\}}{E\{|x_n|^2\}} \quad (2)$$

Where $E\{.\}$ and $\max\{.\}$ denote the mathematical expectation and maximal element function, respectively. Note that PAPR (3) does not include the power of the anti peak signal added by the PAR reduction.

The CB-ACE formulation is considered as a repeated-clipping-and-filtering (RCF) process with ACE constraint as follows;

$$S^{(i+1)} = S^{(i)} + \mu\tilde{c}^{(i)} \quad (3)$$

Where $\tilde{c}^{(i)}$ is Anti-peak signal at the i^{th} iteration,

μ is Convergence factor (i.e., is a positive real step size that determines the convergence speed)

μ can be estimated by using the expression below

$$\mu = \frac{Re[\langle c^{(i)},\tilde{c}^{(i)}\rangle]}{\langle c^{(i)},\tilde{c}^{(i)}\rangle} \quad (4)$$

Where Re defines the real part

$C^{(i)}$ is peak signal above the pre-determined level

$\langle , \rangle$ - Complex inner part.

The anti-peak signal $\tilde{c}^{(i)}$ generated for the PAPR reduction at the i^{th} iteration is given by

$$\tilde{c}^{(i)} = T^{(i)}C^{(i)} \quad (5)$$

$$T^{(i)} = Q^{\wedge *(i)}Q^{\wedge(i)} \quad (6)$$

Where $T^{(i)}$ Transfer matrix of size jN X jN at the i^{th} iteration

$C^{(i)}$ peak signal above the pre-determined level.

$Q^{\wedge(i)}$ = Constellation order.

$Q^{\wedge *(i)}$ = conjugative of Constellation order.

The clipping signal is given by

$$C_n^{(i)} = \left(|S_n^{(i)}| - A\right)e^{j\theta_n},\quad S_n^{(i)} > A$$
$$= 0 \qquad ,\quad S_n^{(i)} \le A \quad (7)$$

Where $Cn^{(i)}$ = clipping sample

$\theta_n = \arg(-S_n^{(i)})$

This clipping level A is related to the clipping ratio $\gamma = \frac{A^2}{E\{|S_n|^2\}}$. In general, we expect more PAR reduction gain with a lower target clipping level. The existing CB-ACE algorithm cannot achieve the minimum PAR for low target clipping ratios, because the reduced power by low clipping reduces the PAR reduction gain.

STBC MIMO-OFDM SYSTEM

Basic block diagram of the two antenna STBC MIMO-OFDM structure that employs the Alamouti method [6, 7] is shown in fig 1.

The information symbol vector $S = [S_0, S_1, \ldots, S_{N-1}]^T$ is coded into two vectors S_1 and S_2 by the space-time encoder as

$$S_1 = [S_0, -S_1^*, \ldots, S_{N-2}, -S_{N-1}^*]^T, \text{ and}$$
$$S_2 = [S_1, -S_0^*, \ldots, S_{N-1}, -S_{N-2}^*]^T \quad (8)$$

Where S^* is a complex conjugate of S. The above symbols after IDFT are transmitted concurrently from T_{X1} and T_{X2} antennas respectively. The subcarrier-1 transmits S_0 from T_{x1} and S_1 from T_{x2}, and the subcarrier-2 transmits $-S_1^*$ from T_{x1} and S_0^* from T_{x2}. The process of the STBC encoder and decoder can be explained in expressions of even and odd poly-phase components vectors [7].

Let $S_{even} = [S_0, S_2, \ldots, S_{N-4}, -S_{N-2}]^T$,

$$S_{odd} = [S_1, S_3, \ldots, S_{N-3}, S_{N-1}]^T \quad (9)$$

Where S_{even} and S_{odd} are lengths N/2 two vectors describing even and odd vectors components of S, the even and odd input components S_1 and S_2 can be described in form of the odd and even vector components as

$$S_{1,even} = S_{even} \qquad S_{1,odd} = -S_{odd}^*$$
$$S_{2,even} = S_{odd} \qquad S_{2,odd} = S_{even}^* \quad (10)$$

Hence, the equivalent STBC transmission matrix is written as

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$$G = \begin{bmatrix} S_{even} & S_{odd} \\ -S_{odd}^{*} & S_{even}^{*} \end{bmatrix} \qquad (11)$$

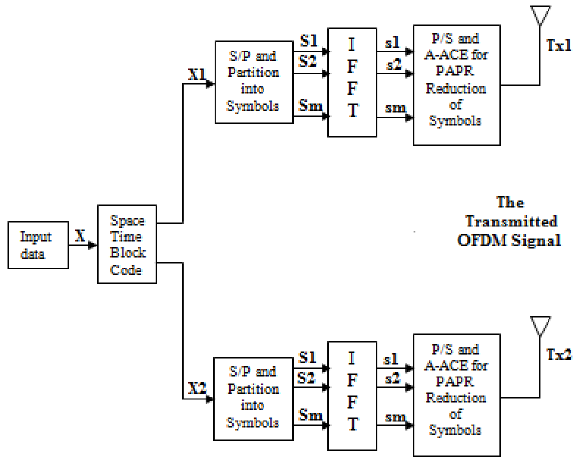

Fig1. Block diagram of STBC MIMO-OFDM with A-ACE PAPR reduction method

The STBC MIMO-OFDM communication provides two different gains of Spatial and Frequency [7], thus this communications is suitable to overcome the fading channels. However this system also suffers from large PAPR due to characteristics of multi-carrier communication OFDM employed on each antenna.

The CCDF of the PAPR of the MIMO-OFDM signals at each transmit antenna is written as

$$PAPR_{MIMO-OFDM} = \max_{0 \le i \le lN-1} PAPR_i \quad (12)$$

Where $PAPR_i$ denotes the PAPR at the i^{th} transmit antenna. This can be further derived as

$$PAPR\,(PAPR_{MIMO-OFDM} > PAPR_0) = 1 - (1 - e^{PAPR_0})^{M_t N} \quad (13)$$

From equation (16) the CCDF of the MIMO-OFDM is much lower than in equation (10). PAPR reduction method should be employed for OFDM signal on each antenna.

Due to structure of orthogonal space-time block codes, the SISO A-ACE algorithm need only be applied for the first transmission period, since it can be proven that complex sequences S_i and $\pm S_i^*$ exhibit the same PAPR properties. Therefore, we only need to perform A-ACE processing on each SISO block independently, obtaining the minimum PAPR time-domain signal ready to transmit after adding the cyclic prefix for the first transmission period. To obtain the time-domain signals for the rest of the transmission periods, the scaling and conjugate DFT properties can be used to avoid the unnecessary IFFT operations for the remaining transmission periods across all transmit antennas:

$$s^*[(-n)_{mod\ N}] \overset{F}{\leftrightarrow} S^*[K] \qquad (14)$$

ADAPTIVE ACTIVE CONSTELLATION EXTENSION ALGORITHM

The key idea of the A-ACE for reducing PAPR value is to control the clipping level and the convergence factor together at each step and thus minimizing the peak power signal greater than the target clipping level.

The summary of the algorithm is given below.

1. *The A-ACE algorithm can be initialized by selecting the parameters namely the target clipping level and the number of iterations, denoted by i.*
2. *As a startup i = 2 and the initial target clipping level is assumed as A.*
3. *Compute the clipping level in (5); if there is no clipping signal, transmit signal,* $S^{(i)}$.
4. *Transfer the clipping signal into anti-peak signal subjected to ACE constraint;*
   - a) *Convert* $c^{(i)}$ *into* $\tilde{C}^{(i)}$.
   - b) *Removing the out-of-band of* $\tilde{C}^{(i)}$ *by projecting* $\tilde{C}^{(i)}$ *onto the feasible region in ACE.*
   - c) *By taking IDFT obtian* $c^{(i)}$.
5. *Update* $c^{(i)}$ *in (4) and minimizing (6).*
   - a) *Computing the optimal step size μ,*

     $$\mu = \frac{Re[\langle c^{(i)}, \tilde{c}^{(i)} \rangle]}{\langle c^{(i)}, \tilde{c}^{(i)} \rangle}$$

     Where Re defines the real part
     $C^{(i)}$ *is peak signal above the pre-determined level,*
     $\langle , \rangle$ *- Complex inner part.*
   - b) *Adjust the clipping level A*
   - c) $A^{(i+1)} = A^{(i)}\mu^{(i)} + v\nabla_A$

     Where $A^{(i+1)}$ *is next iteration level*
     $A^{(i)}$ *is present iteration level*
     μ is convergence factor
     v is the step size with $0 \le v \le 1$
     ∇_A *is Gradient with respect to A given as*

     $$\nabla_A = \frac{\sum_{n\epsilon i} |c_n^{(i+1)}|}{N_P} \qquad (15)$$

   Where N_P *is Number of peak samples larger than A*
6. *Increase the iteration counter i = i+1. If i < L, go step 3 and repeat; otherwise, transmit signal,* $S^{(i)}$.

Compared to the existing CB-ACE with complexity of order O (*ln* log *ln*), the complexity of proposed algorithm slightly increases whenever the adaptive control is calculated in (c). However this increase in complexity is negligible compared to that of order O (*ln* log *ln*).

SIMULATION RESULTS ANALYSIS

Extensive simulations in MATLAB have been carried out for the PAPR analysis of Adaptive-ACE STBC MIMO-OFDM systems with rectangular pulse shaping. Random generated data is modulated by QPSK, 16-QAM and 64-QAM to compare the PAPR performance of the proposed

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scheme. We evaluated the PAPR statistically by using complementary cumulative Companded STBC distribution function (CCDF).

Fig 2 shows that CCDF based comparison of PAPR of the A-ACE, CB-ACE STBC MIMO-OFDM and conventional STBC MIMO-OFDM systems, with N = 512 for QPSK modulation. At clip rate of 10^{-2}, the PAPR gains are 2.5dB, 2.7dB with respective to CB-ACE, A-ACE respectively for QPSK.

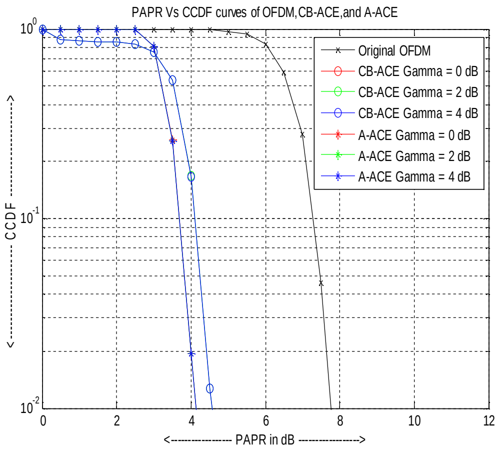

Fig 2 Plot between PAPR and CCDF for different clipping ratios (Gamma) using CB-ACE, A-ACE method for QPSK

Fig 3 shows that CCDF based comparison of PAPR of the A-ACE, CB-ACE STBC MIMO-OFDM and conventional STBC MIMO-OFDM systems, with N = 512 for QPSK modulation. At clip rate of 10^{-2}, the PAPR gains are3.0dB, 4.4dB with respective to CB-ACE, A-ACE respectively for 16-QAM.

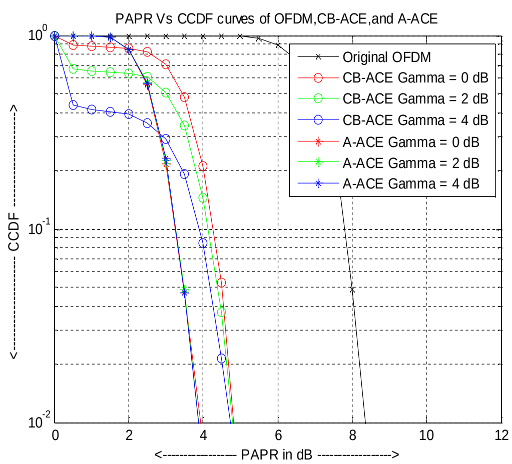

Fig 3 Plot between PAPR and CCDF for different clipping ratios (Gamma) using CB-ACE, A-ACE method for 16-QAM

Fig 4 shows that CCDF based comparison of PAPR of the A-ACE, CB-ACE STBC MIMO-OFDM and conventional STBC MIMO-OFDM systems, with N = 512 for QPSK modulation. At clip rate of 10^{-2}, the PAPR gains are3.5 dB, 6.0dB with respective to CB-ACE, A-ACE respectively 64-QAM.

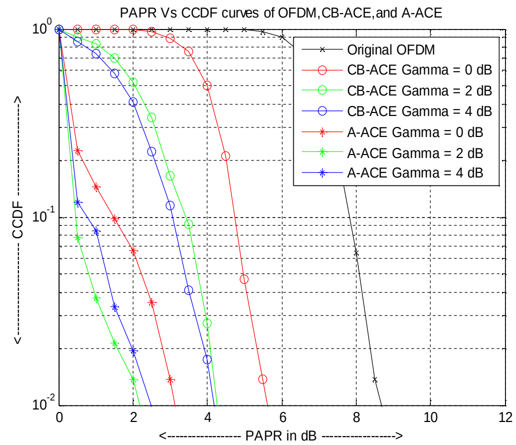

Fig 4 Plot between PAPR and CCDF for different clipping ratios (Gamma) using CB-ACE, A-ACE method for 64-QAM

These results have more convergence in terms of different values of γ converge faster except for the small difference in the initial phase near 0 dB. It can be seen that the slopes are almost similar to each of the γ values above this portion.

CONCLUSIONS

In this work we configured the A-ACE method for reducing PAPR to STBC MIMO-OFDM systems. By control of both the clipping level and convergence factor at each stage, peak power signal is minimized effectively with sufficient margin even at low clipping power levels. From simulation results, it is observed that PAPR gains 3.3dB and 4.3dB from OFDM, so A-ACE method is an efficient technique to reduce PAPR than clipping only based-ACE method. Although only two transmit/receive antennas are analyzed in this paper, this technique can be easily extended to other systems which use a large number of antennas with added complexity.

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