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

K.SRINIVASARAO1, and Dr. B.PRABAKARARAO2
Electronics and Communications1,2, G. V. P. College of Engineering for Women', Visakhapatnam1, A.P., India1

ksrinivas.ece@gmail.com1
J. N. T University2.
Kakinada2, A.P., India2
dbpr@rediffmail.com2

ABSTRACT

In this paper Adaptive Active Constellation (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, greater 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
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 \(X = [X_0, X_1, X_2, ..., X_N]^T\), 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 \(f_0 = 1/T\), is the frequency spacing between adjacent subcarriers. The resulting baseband OFDM signal \(x(t)\) for N subcarriers can be written as

\[x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \exp(j2\pi nk/N), n = 0, 1, 2, ..., N-1.\]  

Where \(l\) is the oversampled 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.,

\[\text{PAPR} = \frac{\max_{x(t) \neq 0} |x(t)|^2}{E[|x(t)|^2]}\]  

Where \(E[\cdot]\) and \(\max\{\cdot\}\) 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:

\[S^{(i)} = \hat{S}^{(i)} + \mu \hat{\xi}^{(i)}\]  

Where \(\hat{\xi}^{(i)}\) is Anti-peak signal at the \(i\)th iteration,

\(\mu\) is Convergence factor (i.e., is a positive real step size that determines the convergence speed) \(\mu\) can be estimated by using the expression below

\[\mu = \frac{\text{Re}\{\xi^{(i)} \xi^{(i)}\}_{\text{C}}}{\text{C}^{(i)} \xi^{(i)}_{\text{C}}}\]  

Where Re defines the real part \(C^{(i)}\) is peak signal above the pre-determined level \(\{\cdot\\}\) - Complex inner part.

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

\[\hat{\xi}^{(i)} = T^{(i)} \hat{C}^{(i)}\]  

\[T^{(i)} = Q^{\lambda^{(i)}} Q^{\lambda^{(i)}}\]  

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

\[\hat{C}^{(i)}\] peak signal above the pre-determined level.

\[Q^{\lambda^{(i)}} = \text{Constellation order.}\]

\[Q^{\lambda^{(i)}} = \text{conjugative of Constellation order.}\]

The clipping signal is given by

\[C^{(i)}_{\text{th}} = \left| \left| S^{(i)} \right| - A \right| e^{j \theta_n}, \quad S^{(i)} > A\]  

\[0, \quad S^{(i)} \leq A\]  

Where \(C^{(i)}_{\text{th}}\) is clipping sample

\[\theta_n = \text{arg} \left( -S^{(i)} \right)\]

This clipping level \(A\) is related to the clipping ratio \(\gamma = \frac{A^2}{E[|S^{(i)}|^2]}\). 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 \(S = [S_0, S_1, ..., S_{N-1}]^T\) is coded into two vectors \(S_1\) and \(S_2\) by the space-time encoder as

\[S_1 = [S_0, -S_1^*, ..., S_{N-2}, -S_{N-1}^*]^T, \text{ and}\]  

\[S_2 = [S_1, S_0^*, ..., S_{N-1}, -S_{N-2}^*]^T\]  

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

\[S_{\text{even}} = [S_0, S_2, ..., S_{N-2}, S_{N-1}]^T, \]  

\[S_{\text{odd}} = [S_1, S_0^*, ..., S_{N-2}, S_{N-1}]^T\]  

Where \(S_{\text{even}}\) and \(S_{\text{odd}}\) 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

\[S_{1, \text{even}} = S_{\text{even}} \quad S_{1, \text{odd}} = -S_{\text{odd}}^*\]  

\[S_{2, \text{even}} = S_{\text{odd}} \quad S_{2, \text{odd}} = S_{\text{even}}^*\]  

Hence, the equivalent STBC transmission matrix is written as
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 ĉ(i).
   b) Removing the out-of-hand of ĉ(i) by projecting ĉ(i) onto the feasible region in ACE.
   c) By taking IDFT obtain c(i).
5. Update c(i) in (4) and minimizing (6).
   a) Computing the optimal step size µ,
   \[\mu = \frac{\text{Re}(\mathcal{C}^{(i)}\mathcal{C}^{(i)})}{|\mathcal{C}^{(i)}|} \]
   Where Re defines the real part.
   \[\mathcal{C}^{(i)}\text{ is peak signal above the pre-determined level}, \]
   \[\mathcal{C}^{(i)} - \text{Complex inner part.}\]
   b) Adjust the clipping level A
   c) \[A^{(i+1)} = A^{(i)} + v \nabla_A\]
   Where A(i+1) is next iteration level
   \[A^{(i)}\text{ is present iteration level} \]
   \[\mu\text{ is convergence factor} \]
   \[v\text{ is the step size with } 0 \leq v \leq 1 \]
   \[\nabla_A\text{ is Gradient with respect to } A\text{ given as} \]
   \[\nabla_A = \frac{\sum_{n}[c^{(i)}]}{N_p} \]
   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
scheme. We evaluated the PAPR statistically by using complementary cumulative Comanded 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 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 are 3.0dB, 4.4dB with respective to CB-ACE, A-ACE respectively 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 are 3.5 dB, 6.0dB with respective to CB-ACE, A-ACE respectively 64-QAM.

These results have more convergence in terms of different values of $\gamma$ 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 $\gamma$ 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.

**ACKNOWLEDGMENT**

I sincerely thank Prof.G.Tirumal Rao, E.C.E Department, G.V.P College of Engineering (Autonomous) for his immense support and valuable suggestions.

**REFERENCES**


Dr. B. Prabhakara Rao received his B.Tech degree in Electronics and Communications Engineering, M.Tech degree in Electronics and Communication Systems from SV University, Tirupati in 1979, 1981 respectively and received the Ph.D degree from IISc, Bangalore in 1995. Dr. B Prabhakara Rao has more than 32 years of experience in teaching and 25 years of R & D. He is an expert in Signal Processing & Communications. He produced 10 PhD’s and guiding 20 PhD scholars. He held different positions in his career like Head of the Department, Vice Principal, in JNTU College of Engineering, Director (Institute of Science & Technology) Director of Evaluation and Director (foreign Universities Relations); and Director of Admissions, currently he is Rector in the Newly Established JNT University. He published more than 175 technical papers in National and International journals and conferences. His interests are coding theory, information theory and signal processing with applications to wireless communications.

K. Srinivasa Rao received the B.Tech Degree in Electronics and Communication Engineering from Nagarjuna University, and M.Tech degree in Instrumentation and Control Systems from J.N.T University College of Engineering, Kakinada, he has 9 years of teaching experience and is Sr. Assistant Professor of Electronics and Communication Engineering, G.V.P. College of Engineering for Women, Visakhapatnam. His research interests include Wireless Communications, Signal processing. He is pursuing Ph.D. from J.N.T.U. Kakinada.


