Design of Adaptive Active Constellation Extension (ACE) algorithm for PAPR reduction in MIMO Systems

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Abstract - One of the effective methods used for reducing Peak to Average Power Ratio (PAPR) in MIMO - OFDM systems is Adaptive Active Constellation Extension Algorithm. The proposed scheme is employed with Quadrature Phase shift keying (QPSK). One of the big advantages is that the side information does not need to be sent to the receiver. The Adaptive ACE method is the most attractive scheme due to its good system performance and simplicity, also effectively reduces Peak-to-Average Power Ratio (PAPR) for different modulation formats and subcarrier sizes without any complexity increase and bandwidth expansion.

Index Terms - peak to average power ratio (PAPR), orthogonal frequency division multiplexing (OFDM), multi input multi output (MIMO), Active constellation extension (ACE).

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is an attractive technique for wireless communications because it supports robust reliability and high data rate in the frequency selective fading channel environments. Moreover, multiple-input-multiple-output is another attractive technology to improve the wireless system capacity. Therefore, the combination of MIMO and OFDM could exploit the spatial dimension capability of a wireless communication system to improve the wireless link performance and system capacity by employing multiple antennas at both the transmitter and receiver ends. MIMO-OFDM has attracted increasing attention because it is robust to time selective fading channels.

However, MIMO-OFDM systems also inherit disadvantages from OFDM techniques, e.g., sensitivity to the time and frequency synchronization errors and high peak-to-average power ratio. Because in Multi Input Multi Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) wireless systems, independent OFDM signals are simultaneously transmitted from multiple-transmit antennas to multiple-receive antennas. Therefore, similar to OFDM systems, MIMO-OFDM systems still suffer an inherent drawback of a high peak-to-average power ratio (PAPR).

II. PAPR IN OFDM

Let \( X(0), X(1) \ldots , X(N-1) \) represents the data sequence to be transmitted in an OFDM symbol with subcarriers. The baseband representation of the OFDM symbol is given by

\[
x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X(n) e^{-j \frac{2\pi n t}{N}}, 0 \leq t \leq T
\]

where \( x(t) \) is OFDM symbol at time \( t \), \( T \) is the duration of the OFDM symbol. The input information symbols are assumed to be statistically independent and identically distributed. According to the central limit theorem, when \( N \) is large, both the real and imaginary parts of \( x(t) \) becomes Gaussian distribution, each with zero mean and a variance of \( \frac{E[|x(t)|^2]}{2} \), the amplitude, or modulus, of OFDM signal is given by

\[
x_r = \sqrt{\text{Re}^2 \{x_r\} + \text{Im}^2 \{x_r\}}
\]

In OFDM modulation technique, a block of \( N \) data symbols, \( \{X_n, n = 0, 1, \ldots , N - 1\} \), is formed with each symbol modulating the corresponding subcarrier from a set \( \{f_n, n = 0, 1, \ldots , N - 1\} \). The \( N \) subcarriers are chosen to be orthogonal, i.e., \( f_n = n\Delta f \), where \( \Delta f = 1/NT \) and \( T \) represents the original data symbol period. The PAPR of the transmitted signal \( x(t) \) can be defined as

\[
PAPR(x(t)) = \max_{0 \leq t \leq NT} \frac{|x(t)|^2}{E[|x(t)|^2]} = \max_{0 \leq t \leq NT} \frac{|x(t)|^2}{\frac{1}{NT} \int_0^{NT} |x(t)|^2 dt}
\]

Since most practical systems deal with discrete-time signals, instead of reducing the continuous-time peak \( \max |x(t)| \), the maximum amplitude of LN samples of \( x(t) \) is reduced, where parameter \( L \) denotes the oversampling factor. To
evaluate the PAPR performance from statistical point of view of the OFDM signals, the complementary CDF (CCDF) is used to describe the probability of exceeding a given threshold \( \text{PAPR}_0 \), i.e.,

\[
\text{CCDF}(\text{PAPR}_0) = Pr(\text{PAPR} > \text{PAPR}_0).
\]

### III. PAPR REDUCTION TECHNIQUES

Several techniques have been proposed to mitigate the high PAPR of MIMO-OFDM signals. Clipping is used to reduce the peak power by clipping the OFDM signals to the threshold level. Selective mapping (SLM) techniques use the input data sequences to generate alternative input symbols sequences. Each of these alternative input data sequence is made the IFFT operation, and then the one with the lowest PAPR is selected for transmission. Partial transmit sequence (PTS) schemes generate several alternative signal sequences representing the same OFDM signal sequence and select the one with the minimum PAPR among them. Tone reservation (TR), tone injection (TI), and active constellation extension (ACE) change constellation points for some subcarriers to reduce the PAPR.

Among various peak-to-average power ratio (PAPR) reduction techniques, the active constellation extension (ACE) technique is attractive because ACE allows the reduction of high-peak signals by extending some modulation constellation points toward the outside of the constellation without any loss of data rate [3]. The basic principle of clipping-based ACE (CB-ACE) algorithms involves switching between the time domain and the frequency domain. Filtering and applying the ACE constraint in the frequency domain, after clipping in the time domain, both require iterative processing to suppress the subsequent re-growth of the peak power.

However, the CB-ACE algorithms have a low clipping ratio problem in that they cannot achieve the minimum PAPR when the target clipping level is set below an initially unknown optimum value. Our approach combines a clipping-based algorithm with an adaptive clipping control, which allows us to find the optimal clipping level. Simulation results show that our proposed algorithm can achieve the minimum PAPR regardless of the low target clipping level.

The clipping of the peak signal results to distortion of the original OFDM signal. The distortion of the original signal can be assumed as the noise, which results to an unreliable communication between the transmitter and the receiver.

### IV. PROPOSED PAPR TECHNIQUE

The main objective of the Adaptive Active Constellation Extension (Adaptive ACE) algorithm for reducing the Peak-to-Average Power Ratio (PAPR) is to control both the clipping level and the convergence factor at each step and thereby minimize the peak power signal whichever is greater than the initial target clipping level. The Adaptive Active Constellation Extension (Adaptive ACE) algorithm can be initialized by selecting the parameters namely the target clipping level, denoted by \( A \) and the number of iterations, denoted by \( i \). In the first step, the iteration is taken as two i.e., \( i = 2 \) and the initial target clipping level is to be taken as \( A \).

The predetermined clipping level, denoted by \( A \), is related to the target clipping ratio, \( \gamma \) and given as

\[
\gamma = \frac{A^2}{\mathbb{E}\{\left| x_n \right|^2\}}
\]

Where, \( \gamma \) – Target Clipping Ratio, \( A \) – Predetermined Clipping Level, \( x_n \) – Oversampled OFDM signal. The clipping of the peak signal results to distortion of the original OFDM signal.

The Peak-to-Average Power Ratio by the Adaptive Active Constellation Extension (Adaptive ACE) algorithm is to be calculated for the Orthogonal Frequency Division Multiplexing (OFDM) signal which is obtained after filtering the clipped signal. The clipped and filtered OFDM signal obtained by using Adaptive Active Constellation Extension (Adaptive ACE) algorithm is to be transmitted via an Additive White Gaussian Noise (AWGN) channel, in order to calculate the Signal-to-Noise Ratio (SNR) and Bit Error Rate (BER).

### V. SIMULATION RESULTS

The Peak-to-Average Power Ratio (PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) system is equal to 10 dB without using any algorithm i.e., by using the basic formula of PAPR for the original OFDM signal. The existing techniques for reducing the high Peak-to-Average Power Ratio (PAPR) of the OFDM systems are Partial transmit sequence (PTS) and Selected Mapping (SLM).

Then, the PAPR basic formula is used for different values of target clipping ratios (\( \gamma = 4, 2, 0 \)). The Peak-to-Average Power Ratios (PAPR) for the selected mapping is 6.5 dB. The Peak-to-Average Power Ratios (PAPR) for the Partial transmit sequence is 4.6 dB.

The Peak-to-Average Power Ratios (PAPR) for the target clipping ratios of 0 dB, 2 dB
and 4 dB are 4.5 dB, 3.9 dB and 3.8 dB respectively. From the PAPR values for different target clipping ratios, it is clear that the PAPR increases when the value of target clipping ratio increases.

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The low clipping ratio problem means minimum PAPR cannot be achieved for low target clipping ratios.

VI. CONCLUSIONS

The major drawback of the Orthogonal Frequency Division Multiplexing (OFDM) system is the high Peak-to-Average Power Ratio (PAPR). The high PAPR results to the increase in the complexity of Analog-to-Digital Convertors (ADCs) & Digital-to-Analog Convertors (DACs) and also reduces the efficiency of the power amplifiers.

The Active Constellation Extension (ACE) Algorithm provides the minimum Peak-to-Average Power Ratio (PAPR), even when the initial target clipping ratio is set below the unknown optimum clipping point. Hence, the proposed algorithm avoids the problem of low clipping ratio, which is caused in the process of reducing the PAPR by using the Clipping-Based Active Constellation Extension (CB-ACE) Algorithm.

Hence, by reducing the Peak-to-Average Power Ratio (PAPR), the complexity of the Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC) can be reduced. The reduced
Peak-to-Average Power Ratio (PAPR) also increases the efficiency of the Power Amplifiers.

References: