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Low Complexity Iterative Piece-Wise Companding Transform for Reduction of PAPR in MIMO OFDM Systems

T. Ramaswamy^{1*} and K. Chennakesava Reddy²

¹Department of ECE, Malla Reddy Engineering College (A), Hyderabad - 500100, Telangana, India; dani.swamy@gmail.com

²JNTUH, Hyderabad - 500085, Telangana, India; kesavary@yahoo.com

Abstract

Objectives: This paper presents one of the solutions to minimize the problem of PAPR (Peak Average to Power Ratio) in OFDM systems. This work mainly focuses on introducing iterative companding approach along with the available standard reduction methods. **Methods/Statistical Analysis:** This paper includes Iterative Linear Transform Approach (ILST), Iterative Two Piecewise Companding Transform (ITPWC) and Iterative Piecewise Companding Transform (IPCT). A performance evaluation was performed and found that IPCT attained very low BER and PAPR in all the above mentioned approaches. Apart from this it also consumes low computations there by proving the best of its class at the earliest. **Findings:** BER performance of the proposed IPCT approach under different channel environment depicts that the proposed approach provides less BER against ILST and ITPWC with 3-3.5 db improvement. **Application/Improvement:** The developed Iterative Piecewise Companding Transform (IPCT) is more suitable for MIMO systems which make it to be widely used for 4G, WLAN and Wimax applications.

Keywords: Companding, Low complexity, MIMO-OFDM, PAPR

1. Introduction

Modern Multiple Input Multiple Output (MIMO) systems require capability of transmitting large data with high data rate extensively¹. To improve spectrum efficiency and achieve higher rates at more than 100 Mbps more advanced techniques need to be implemented. Hence, the upcoming generation mobile communication needs more sophisticated modulation scheme and information transmission structure.

MIMOandOrthogonalFrequencyDivisionMultiplexing (OFDM) are adopted due to their superior performance. They promise to provide high-speed data transfer in wireless communication technologies and combining them can provide wireless industry evolution like 4G systems.

In MIMO-OFDM systems multiple sub carriers are superimposed that require higher power than the mean power of the system. However, the phases of these carriers are same. High PAPR is one of the serious problems in MIMO-OFDM systems. In order to transmit these high PAPR OFDM signals requires insertion of high power amplifiers with very high power scope. These kinds of amplifiers are very expensive and gives rise to non-linear distortions which changes the phase offset leading to the interference of the side by side signal spectrum resulting in performance degradation.

To mitigate this performance degradation many PAPR reducing approaches are proposed so far like Clipping and Filtering², Selective mapping technique³, Partial Transmit sequence⁴, Tone reservation method⁵ and companding transforms⁶.

In⁶, Wang et al. introduced μ -law companding method for the applications in speech processing, but later this μ -law companding approach is used in OFDM systems to reduce PAPR with the aim of increasing the average signal power.

^{*}Author for correspondence

In², Jiang et al, proposed a benchmark approach called exponential companding scheme where the PAPR reduction is obtained by transforming symbols with the exponential distribution of OFDM symbols while maintaining the constant average signal power. Both these methods (μ -law and EC) have become a benchmark for the rest of the upcoming methods.

In⁸ Aburakhia et al. proposed a Linear Companding Transform (LCT) that transforms large and small amplitudes with different scales. The average power may not be constant at different levels of input and outputs of companding transform.

In², Yang et al. proposed Two Piecewise Companding Transform (TPWC) that tried to attain constant average signal power and achieve one to one mapping. The method represents the small amplitudes with scale and higher amplitudes with both scale and shift.

In¹⁰, proposed a piecewise companding transform neglecting unnecessary compression in the reduction of peak power. On the other hand companding distortion can be effectively mitigated by expanding larger signals with slight changes in amplitude. The designing of parameters have to be done very carefully in decreasing the PAPR.

In this paper an iterative companding transform employing the traditional companding transforms is proposed. The main intension of this approach is to mitigate the trade off between the BER and PAPR. As of this paper, it presents the iterative piece wise companding that transform the amplitudes of the signals above a given companded peak amplitude are clipped for peak power reduction. Similarly the signals with amplitudes close to the given companded peak amplitude are linearly scaled for power compensation.

2. Peak to Average Power Ratio Formulation

Let $X = [x_0, x_1, \dots, x_{N-1}]$ represent the data sequence that is to be transmitted independently in OFDM system with N sub carriers. The signal is oversampled with a factor L (L = 4) and the OFDM symbols can be represented as:

$$\chi_n = \frac{1}{\sqrt{NL}} \sum_{k=0}^{NL-1} X_k e^{i\mathbf{2}\pi \frac{kn}{NL}} \, 0 \le n \le NL \tag{1}$$

Where
$$X = \left[x_0, x_1, \dots, x_{\frac{N}{2}-1}, 0, 0, \dots, x_{\frac{N}{2}}, \dots, x_N\right]$$
 is the input signal vector. The PAPR of this transmitted signal is given as:

$$PAPR = 10\log 10 \left(\left(\max(|x_{\perp}n|^{\dagger}2) \right) / \left(E(|x_{\perp}n|^{\dagger}2) \right) \right) \tag{2}$$

The PAPR reduction capability is measured by the Complementary Cumulative Distribution Function (CCDF), which is defined as the probability that the signal's PAPR exceeds a specific threshold value $\gamma_0 > 0$

$$CCDF(\gamma_0) = Prob\{PAPR > \gamma_0\} = 1 - (1 - e^{-\gamma_0})^N$$
 (3)

The principle of companding transform is to compress the high peaks symbols and to enhance the low amplitude symbols simultaneously, thereby decreasing the PAPR of the transmitted signal prior to the digital to analog convertor and HPA.

3. Companding Transforms

This section presents different companding transforms that are used in this paper.

3.1 Linear Symmetrical Transform (LST)

This is the simplest of the CT whose companding function is given as:

$$f(x) = (k \cdot |x| + b) \cdot san(x) \tag{4}$$

Where sgn (.) is the sign function. Two constant parameters 0 < k < 1 and b > 0 are here to specify the companding profile in order to maintain an unchanged power after companding transform. The inverse companding is given as:

$$f^{-1}(x) = \frac{|x| - b}{k} sgn(x) \tag{5}$$

3.2 Two Piecewise Companding (TPWC)

This is a Linear Non Symmetrical Transform (LNST) which is the best in terms of PAPR reduction and also provides a solution for abrupt jump issue during companding¹². Its function is given as:

$$f(x) \begin{cases} u\mathbf{1}|x|.sgn(x), & |x| \le v \\ (u\mathbf{2}|x|+s).sgn(x) & |x| > v \end{cases}$$
 (6)

Where u1 > 1, 0 < u2 <1 and s = (u1 - u2)v > 0 and 0 \le v \le V is the cut off point with $v = \max\{|x_n|\}$. The de-companding function is given as:

$$f^{-1}(x) = \begin{cases} \frac{1}{u} |x| \cdot sgn(x) & |x| \le u_1 v \\ \frac{1}{u_2} (|x| - s) \cdot sgn(x) & |x| > u_1 v \end{cases}$$
 (7)

The relation between three variables u1, u2, v is given with linear equation as:

$$u_1 \mathbf{1}^{\dagger} \mathbf{2} ((\mathbf{1} - \exp(-\partial^{\dagger} \mathbf{2})) + u_1 \mathbf{2}^{\dagger} \mathbf{2}. \exp(-\partial^{\dagger} \mathbf{2}) = 1$$

Please refer² for more info on this approach.

3.3 Piecewise Linear Companding (PLC)

When the original signal x_n is companded with a given peak amplitude A_n , the companding function is given as:

$$f(x) = \begin{cases} x & \text{ix } 1 \le A_i \\ kx + (1-k)A_c & \text{if } 1 \le A_c \\ sgn(x)A_c & \text{ix } 1 > A_c \end{cases}$$
 (8)

And its de-companding function is given as:

$$\left(x \mid x \mid \leq A_i @ \left(x - \frac{(1-k)A_c}{k} (1-k)A_c < |x| \leq A_c @ \right) \right)$$

$$sgn(x)A_c \mid x \mid > A_c$$

$$(9)$$

From the above analysis it is observed that the proposed companding transform is specified by constant parameters A_c , A_i , and k. However, the average power is maintained to be constant and according the Equation (2) the value of PAPR for the proposed approach that can be achieved is determined by A_c^{10} ,

4. Proposed Iterative Mechanism

The main objective of this approach is to obtain a significant PAPR reduction at the expense of a less amount of band distortion and spectral regrowth. The block diagram of the proposed approach is Figure 1.

The proposed approach is summarized as:

- Initialize the desired PAPR_{des} and the maximum number of iterations. Select companding parameters of the concerned companding transform.
- Convert the frequency domain symbols X to over sampled time domain OFDM signal x using L oversampling factor.
- At the first iteration m = 1 and k1 = 1 a new symbol enters the iterative loop, set k1 = k2 = 2.
- At first iteration $x_{out} = x$, otherwise $x_{out}^m = x^{m-1}$.
- χ^m is companded by the concerned CT to generate γ^m .

- Convert y^m to frequency domain to generate c^m using NL-FFT points.
- Perform the frequency domain filtering by multiplying it with H_{rect} to get C^{mo}.
- Convert *c* ^{mo} to time domain using NL-IFFT points.
- Calculate PAPR denoted as PAPR^m, if
 PAPR^m ≤ PAPR_{des} or m>M iteration the set
 k2 = 1 and exit the loop if not return to step 3.

The filtering response is given as:

$$H_{rect} = \begin{cases} 1 & 1 < k \le N - 1 \\ 0 & N \le k \le LN - 1 \end{cases}$$
 (10)

The proposed approach is low complex than the traditional approaches for exponential companding it requires NL computation (N = 256, L = 4) while CT^{11} 2LN*log₂ (LN). However, the proposed approach requires (0.65*MNL) computations.

5. Simulation Results

The experiment is evaluated for MIMO systems with different antennas under different channels. This approach is also compared in terms of PAPR (Figure 2), OBI (Figure 3), BER (Figures 4, 5, 6) and complexity (Figure 7).

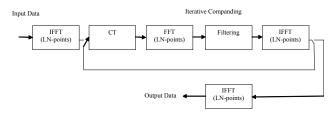


Figure 1. Block diagram of iterative companding.

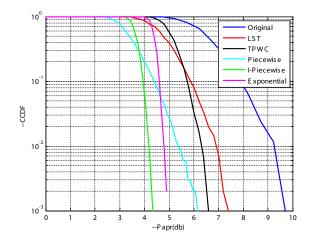


Figure 2. PAPR analysis with the proposed approach and comparison against others.

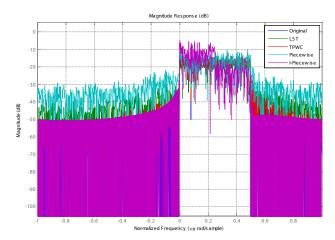


Figure 3. Power spectral density of companded signals showing decrease in distortion with proposed approach.

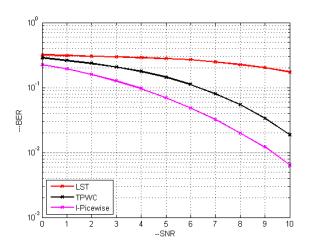


Figure 4. Performance analysis of the proposed approach for 2×2 antenna system under AWGN channel.

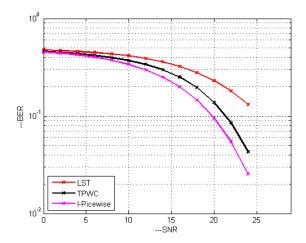


Figure 5. Performance analysis of the proposed approach for 2×2 antenna system under Rayleigh channel for Nsym = 1024 and Nsub = 64.

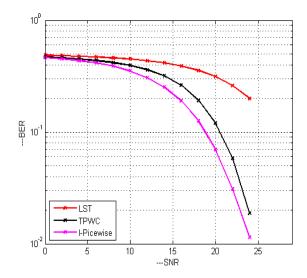


Figure 6. Performance analysis of the proposed approach for 2×2 antenna system under SUI channel Nsym = 1024 and Nsub = 64.

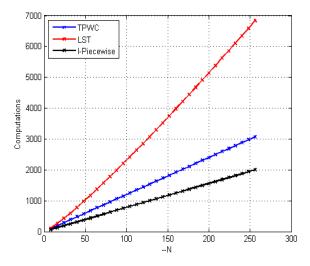


Figure 7. Computational analysis of the proposed approach with traditional approaches at M = 3 iterations and L = 4.

In Figure 2 the PAPR is decreased by 0.8 dB against exponential companding² and 1.5 dB against the traditional piecewise companding¹⁰, Figures 4, 5 and 6 shows the BER performance of the proposed approach under different channel environment. It clearly depicts that the proposed approach a less BER against ILCT (LCT⁸) and TPWC² with 3-3.5 db improvement. In Figure 7 the computational complexity is analysed against exponential and ILCT methods with L=4 and at M=3 iterations. It clearly depicts that the present approach is consuming very less computations with highest at N=256, the computation were 2000 which is very promising.

6. Conclusion

An iterative piecewise companding transform is proposed for MIMO-OFDM systems in this paper. The proposed approach is providing the promising results against the traditional approaches in terms of PAPR, BER and computations thus, providing a very low complex approach. The present research can be further extended with different antenna schemes and data rates.

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