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Hybrid PTS-Clipping Scheme for PAPR Reduction in MIMO-OFDM Systems

Beena A O[1], Sakuntala S Pillai[2], N. Vijayakumar[3]

[1]*Department of Electronics & Communication Engineering, SAINTGITS College of Engineering, Kottayam, India.*

[2]*Department of Electronics & Communication Engineering, Mar Baselios College of Engg. & Tech., Trivandrum, India.*

[3]*Department of Electronics & Communication Engineering, Govt. College of Engineering, Bartonhill, Trivandrum, India.*

Abstract:

Multi input multi output (MIMO) technique combined with Orthogonal Frequency Division Multiplexing (OFDM) is the proficient air interface for upcoming generations of high data rate and high speed wireless communication. Major disadvantage of systems with multi carrier modulation technique like OFDM is its high peak to average power ratio (PAPR) which outweighs all the potential advantages of the systems with OFDM. In this paper for the reduction of PAPR a hybrid technique which combines partial transmit sequence and clipping method is proposed. Results from simulations confirm that the proposed method provides considerable performance in PAPR reduction as well as maintaining fine overall performance in terms of BER.

Keywords*:* Orthogonal space time block codes (OSTBC), Multi-Input Multi-Output (MIMO), Peak to Average Power Ratio (PAPR), Partial Transmit Sequence (PTS), Clipping.

INTRODUCTION

The demand for high speed data transmission has been rapidly rising in this age of digital wireless communication. The emerging demands and challenges of multimedia services and applications can be fulfilled with the multiple-input multiple-output techniques combined with a multi carrier modulation scheme named orthogonal frequency division multiplexing (MIMO-OFDM) [1], [2]. MIMO-OFDM provides increased spectral efficiency and improved link reliability through orthogonality of subcarriers, spatial multiplexing gain and antenna diversity gain [3]-[5]. Also this will significantly increase the information capacity and data rate by efficient space-time coding methods. In 4G systems space-time coding techniques in conjunction with OFDM is employed to achieve very high data rate up to 1Gbps, attractive transmit diversity and coding gains in multipath fading channels [6], [7]. Especially, when the orthogonal space time block codes (OSTBC) joined with OFDM the utmost transmit diversity can be achieved and can simplify the receiver with a simple maximum likelihood (ML) receiver [8].

Eventhough there are enormous advantages with OFDM there is a disadvantage of high PAPR for the signal to be transmitted. , which outweighs all the potential advantages of the systems with OFDM. High PAPR will push the DAC and RF high power amplifier (HPA) into its nonlinear region of operation. This leads to in-band distortions and out-of-band radiation [9]. To avoid spectral expansion and out-of-band radiation the HPA should be in its linear region. Also PAPR is detrimental for battery lifetime in mobile applications. Hence it is essential to find techniques to diminish the problem of large PAPR.

There are a number of methods available in literature for PAPR reduction and can be generally classified as: methods which cause signal distortion, multiple signalling and probabilistic methods and coding schemes [10], [11]. Signal distortion methods decrease the PAPR by creating some distortions in the OFDM signal to be transmitted prior to the HPA. Clipping and filtering [12], peak windowing [13] and peak cancellation [14] are some of the schemes under this category. For the second methods the reduction in PAPR can be achieved by either selecting a signal with least PAPR from a set of multiple permutations of the OFDM signal called selected mapping (SLM) [15] or by introducing phase shifts, partial transmit sequence (PTS) [16] or adding peak reduction carriers (tone reservation and tone injection) [17] or changing constellation points [18]. In coding techniques OFDM symbols with a large PAPR are excluded by using a special code set [19].

In this paper a hybrid technique which combines clipping and filtering technique with partial transmit sequence is proposed as an alternative approach for PAPR reduction. Simulation and its results showed that the hybrid scheme proposed in this paper had better reduction in PAPR and bit error rate compared to that of the corresponding individual methods.

In the remaining parts of the paper the system model was described in Section II and an insight into the PAPR schemes used for hybridization was given in Section III. The proposed system was detailed in Section IV. Section V described the simulation parameters and results and Section VI includes the conclusion.

SYSTEM MODEL

An OSTBC encoded MIMO structure having N_t antennas at transmitter and N_r antennas at receiver was combined with an OFDM scheme having N subcarriers was considered for simulation in this paper. The simplified block schematic of the 4G MIMO-OFDM system with above mentioned features was as shown in figure 1.

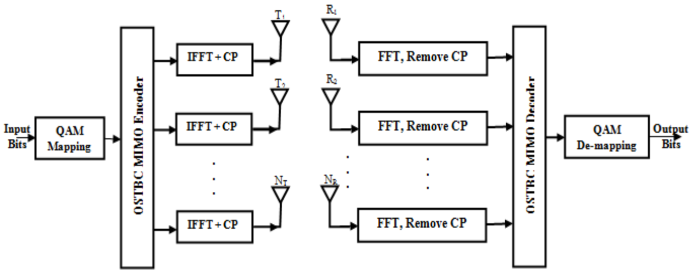

Figure 1. Block Schematic of OSTBC MIMO-OFDM system

The input message bits are QAM mapped into symbol vector, $X_k = [X_0, X_1, \dots, X_{N-1}]$. OSTBC codec for a 2X2 system was used to implement MIMO. The mapped symbols were encoded by using a code matrix, S which is orthogonal. The code matrix for a 2X2 system is:

$$S = \begin{bmatrix} s_1 & s_2 \\ -s_2{}^* & s_1{}^* \end{bmatrix} \quad (1)$$

Output of OSTBC encoder is transformed into parallel streams and each stream was given to IFFT block for the OFDM modulation. The resultant discrete time complex base band of the MIMO-OFDM signal was:

$$x_i(n) = \frac{1}{\sqrt{Nl}} \sum_{k=0}^{Nl-1} X_k e^{\frac{j2\pi nk}{Nl}}; 0 \le n \le Nl - 1 \quad (2)$$

where $i = 1, 2, \dots, N_t$ and $l = 4$, the oversampling factor. The number of subcarriers, N includes both data carriers and pilot carriers and X_k is the mapped symbol vector. After inserting the cyclic prefix the signal is transmitted via multipath Rayleigh fading channel and the entire process was reversed at the receiver.

Since multiple sub-carriers are superimposed in an OFDM signal sometimes the instantaneous power output is higher than the average power of the system. Large peak power affect the linear operation region of the HPA and causes non-linear distortion and hence to performance degradation.

PAPR can be described as the ratio of the instantaneous peak power to the average power of the OFDM signal.

$$\mathrm{PAPR_x} = \frac{\mathrm{P_{Peak}}}{\mathrm{P_{Average}}} = \frac{\max_{0 \le n \le lN-1} \{|x_n|^2\}}{E\{|x_n|^2\}} \quad (3)$$

where $E\{.\}$ is mathematical expectation and $max\{.\}$ is the maximal element function.

Also, $\quad \mathrm{PAPR\ (dB)} = 10\log_{10}(\mathrm{PAPR_x}) \quad (4)$

The metric used to analyze PAPR is complementary cumulative distribution function (CCDF). It is the probability of the signal which exceeds a given specified threshold, γ.

$$CCDF = 1 - Pr\{PAPR \le \gamma\} = 1 - (1 - e^{\gamma})^N \quad (5)$$

PAPR REDUCTION

From various PAPR reduction schemes presented in literature a hybrid technique which combines a signal distortion scheme and a multiple signalling scheme have been proposed to reduce PAPR. This section focuses more closely on the PAPR reduction techniques which are used to combine the proposed hybrid technique.

A. Partial Transmit Sequence (PTS)

The PTS scheme is under the category of multiple signalling and probabilistic schemes. In this method input data stream of length N was split into a set of *M* sub-blocks. Then each sub-block is weighted by a selected phase factor after taking the IFFT. The phase factors were selected as when the weighted signals are combined together the PAPR is minimized [20]-[22].

The first step in performing PTS is the partitioning of the mapped data stream, X into M number of sub-blocks. ie. $\sum_{m=1}^{M} X_m = X$, where $X_m = [X_{m,1}, X_{m,2}, \dots, X_{m,N-1}]^T$, $m = 1, 2, \dots, M$.

After taking IFFT each block was weighted by a complex phase factor, $b_m = e^{j\emptyset_m}, m = 1, 2, \dots, M$. The weighted sub-blocks are then combined to get a signal with minimized PAPR. It can be expressed as:

$$x'(b) = \sum_{m=1}^{M} b_m x_m \quad (6)$$

where $x'(b) = [x'_0(b), x'_1(b), \dots, x'_{Nl-1}(b)]^T$.

The key issue at this point is to locate the phase factors which provide the PAPR minimization. PAPR minimization is associated with minimizing the value $\max_{0 \le k \le Nl-1} |x'_k(b)|$.

The amount of reduction in PAPR is depending up on the sub-blocks and number of phase factors, *M*. But the complexity in searching increases exponentially with this. This can be reduced by limiting the set of phase factors to a finite number. Sub-block partitioning is also a major thing that influence the PAPR reduction. Among the three types of partitioning schemes, adjacent, interleaved, and pseudo-random partitioning schemes the third one has been found to be the best option [23].

B. Clipping

Clipping is under the class of signal distortion type PAPR reduction technique. Even though it produces some distortions to the received signal, it is the simplest method to reduce the PAPR [10]-[12]. In this method the peak of the OFDM signal envelope signal is limited by clipping the high amplitude peaks to a preset threshold. Since clipping is performed on the original information, there will be a trade-off between the clipping level and the BER performance.

For an OFDM pass band signal $x[n]$, the clipping can be performed as:

$$x_c[n] = \begin{cases} A & ; \ |x[n]| \ge A \\ x[n] & ; \ |x[n]| < A \\ -A & ; \ |x[n]| \le -A \end{cases} \quad (7)$$

where *A* was the fixed threshold called clipping level and $x_c[n]$ was the clipped version of the OFDM signal to be transmitted. The out-of-band radiation introduced due to the clipping process can be alleviated by filtering.

PROPOSED SYSTEM

A 2X2 OSTBC MIMO-OFDM system with the hybrid scheme which was proposed for PAPR reduction in this paper was implemented. The hybrid scheme combines the principles of PTS and clipping techniques to diminish the PAPR of transmitted OFDM signal.

Figure 2 illustrated the block schematic of the proposed hybrid technique applied in OSTBC MIMO-OFDM system to reduce the PAPR. For simplicity in the figure represents only one branch of the entire system. Each stream of the OSTBC encoder output will repeat the structure in its actual implementation.

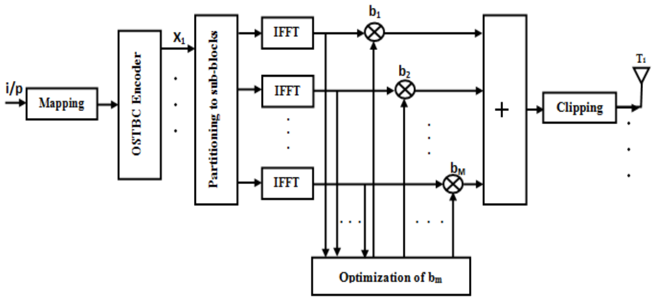

Figure 2. OSTBC MIMO-OFDM system with proposed scheme

After QAM symbol mapping each OSTBC encoded data stream was separated into M disjoint sub-blocks. Then each sub-block was weighted by a selected set of phase factors and combined them to produce a signal with minimized PAPR. Then a clipping action was performed to the combined signal for further reduction of PAPR.

The frequency domain complex symbol vector, $X_k = [X_0, X_1, \dots, X_{N-1}]^T$ was obtained from the input bit stream by mapping into 64-QAM. To perform MIMO transmission the symbol vector was encoded by OSTBC encoder then each stream was split into M disjoint sub-blocks such as: $\mathrm{X_m} = [\mathrm{X_{m,1}}, \mathrm{X_{m,2}}, \dots, \mathrm{X_{m,N-1}}]^{\mathrm{T}}, \mathrm{m} = 1,2, \dots \mathrm{M}$. The time domain signal corresponding to each block $\mathrm{X_m}$, can be obtained from the IFFT of length Nl by concatenating $(l-1)N$ zeros to $\mathrm{X_m}$. l is the oversampling factor. The corresponding OFDM signal is:

$\mathrm{x_m} = [\mathrm{x_{m,1}}, \mathrm{x_{m,2}}, \dots, \mathrm{x_{m,N\mathit{l}-1}}]^{\mathrm{T}}, \mathrm{m} = 1,2, \dots \mathrm{M}$. Each partial transmit sequence, $\mathrm{x_m}$ was weighted by a selected set of phase factors, $b = [b_1, b_2, \dots, b_M]^T$. The phase factors were optimized in such a way that the signal should produce minimum PAPR. This can be performed as minimization of $\max_{0 \le k \le Nl-1} \left|\sum_{m=1}^{M} b_m \, x_{m,k}\right|$.

Then the weighted signals were combined together to get a single signal with reduced PAPR.

Now the clipping action was performed to the resultant signal according to the equation (7) for further reduction in PAPR.

SIMULATION RESULTS

Performance of the proposed hybrid scheme for PAPR reduction was evaluated by the Matlab simulation of an IEEE 802.16 (WiMAX) system which is a technique used in 4G. For simulation purpose WiMAX system with 2 antennas at transmitter and 2 antennas at receiver was considered.

OSTBC coding for a 2X2 system was used for MIMO encoding. Each OSTBC coded data stream was divided into 8 sub-blocks. OFDM system with 256 subcarriers was considered and 64-QAM modulation was used for symbol mapping to frequency domain. The MIMO-OFDM signal was transmitted through the multipath Rayleigh fading channel and assumed that the channel was known at the receiver for simplicity in evaluation. Performance of the hybrid scheme proposed in this paper was evaluated by using CCDF curves of PAPR of the transmitted OFDM signal, which is the measure of efficiency and PAPR of a communication system. The overall performance of the system was also evaluated from the bit error rate performance.

Table I described the various simulation parameters used for evaluation.

Table I. Simulation Parameters

Simulation Parameters	Values
Antennas at transmitter, N_T	2
Antennas at receiver, N_R	2
No. of subcarriers, N	256
Modulation scheme	64-QAM
Oversampling factor, l	4
No. of sub-blocks, M	8
Set of phase factors, M	8
Channel	Multipath Rayleigh

The performance of the system in PAPR reduction in terms of the metric, CCDF for the proposed hybrid scheme and the corresponding individual methods were plotted in figure 3.

It was evident from the simulation curves that the PAPR generated by the system with proposed hybrid scheme was less compared to that of the individual. At CCDF of 10^{-3}, PAPR of the actual OFDM signal was greater than 10.6dB, by using the clipping technique alone the PAPR obtained was 7.3dB and when PTS technique alone was applied the PAPR achieved was 6.6dB. For the proposed hybrid system which combined both PTS and clipping schemes, the PAPR was decreased to 5.1dB. ie. the proposed method has nearly 5.5dB improvement in PAPR reduction performance at a CCDF of 10^{-3}.

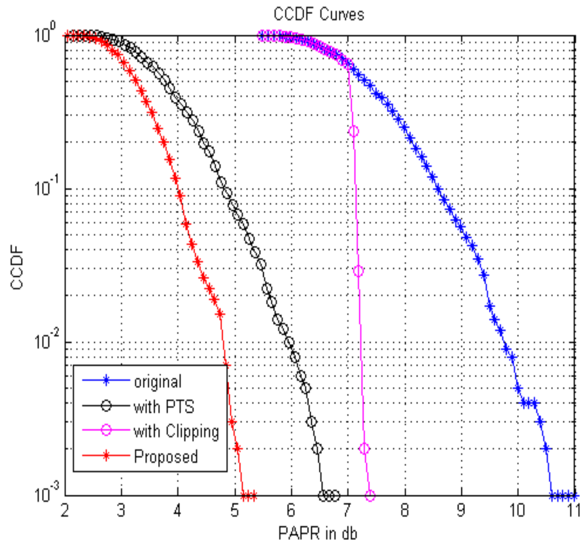

Figure 3. CCDF curves for Proposed and Individual Schemes

Since the PAPR was reduced by a significant amount the proposed hybrid technique for PAPR reduction can keep the linear dynamic range of the operating region of HPA at transmitter.

The overall system performance was also analysed in this paper by evaluating the bit error rate (BER) performance and the simulation curves were described in figure 4.

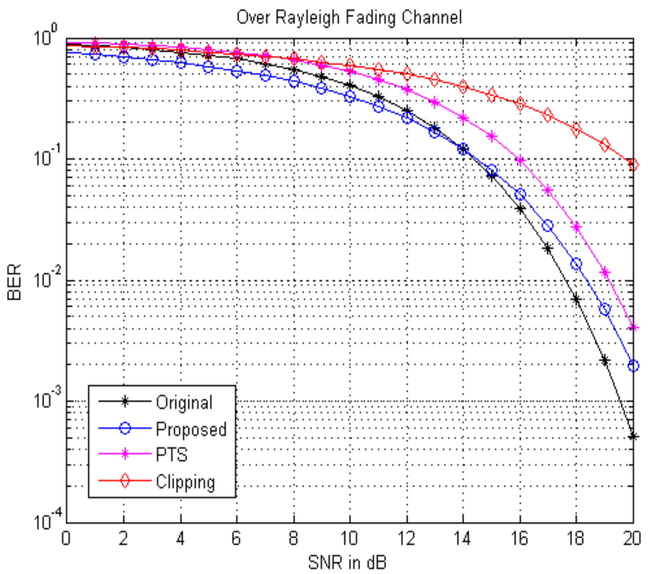

Figure 4. BER Performance Curves

It was evident from figure 4 that, the BER performance of the 2X2 MIMO-OFDM system with proposed hybrid scheme for PAPR reduction was close to the conventional MIMO-OFDM system. Hence the proposed hybrid scheme can attain an proficient tradeoff between reduction in PAPR and BER.

Table II summarizes the results of simulation of the proposed hybrid scheme for PAPR reduction and compare the same with individual schemes. The results were compared at an SNR of 20dB and at a CCDF of 10^{-3}.

Table II. Summary: Simulation Results

PAPR Reduction Scheme	**BER at SNR =20dB for 64- QAM, Rayleigh Channel**	**PAPR(dB) at CCDF = 10^{-3}**
Original OFDM	~10^{-4}	10.6
Clipping	10^{-1}	7.3
PTS	~10^{-3}	6.6
Hybrid scheme	10^{-3}	5.1

CONCLUSION

Hybrid PAPR reduction technique as the joint partial transmit sequence and clipping method was proposed in this paper. The base band model of 4G 2X2 MIMO-OFDM system was implemented first for the evaluation of the proposed scheme. In simulation, PTS technique was followed by the clipping operation. The simulation and its results confirm that the proposed hybrid scheme can provide PAPR reduction to a larger extent than the component methods at a reasonable BER. The improvement in performance can be obtained by optimizing the phase factors used in PTS scheme and filtering followed by clipping scheme.

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