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Research paper

A novel method for joint- PAPR mitigation in OFDM-based massive MIMO downlink systems

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Abstract

Massive MIMO has gained much attention with the increase in the high speed data communication. The problem of peak-to-average power ratio (PAPR) is considered, the detrimental aspects in OFDM based massive multiple-input multiple-output (MIMO) downlink systems. The previous works done in reduction of PAPR problem using convex optimization are computationally inefficient. We considered Bayesian approach to mitigate PAPR by utilizing the redundant degrees of freedom (DOF) of the transmit array, which effectively reduced the level of PAPR. The performance or numerical results indicate the applied algorithm achieved a good improvement over the existing techniques in terms of the PAPR reduction.

Keywords: *PAPR reduction; Massive MIMO-OFDM; DOF; MIMO.*

1. Introduction

At present, there is a great deal of interest in Massive MIMO systems [2] with more number of antenna arrays at the base station (BS). Massive MIMO is a key technology that improves the data rate, spectral efficiency and energy efficiency over contemporary systems. It improves the spectral efficiency by the deployment of several numbers of antennas at the base station at a time, serving a much smaller number of single-antenna users sharing the same time-frequency bandwidth. These systems also substantially improve the energy efficiency which enables the use of less expensive and low-power components. In the future massive MIMO technology [1] brings substantial changes to upcoming wireless systems. Frequency-selective fading is a detrimental factor, and severely affects the Broadband wireless communications in practice. Orthogonal frequency-division multiplexing (OFDM), scheme can mitigate frequency selective fading by converting digital data on different sub-carrier frequencies to transport information from one user to other.OFDM signals[4,7] are characterized by noise like amplitude variations in time domain and have relatively large dynamic range leading to high peak to average power (PAPR) [9]. This high PAPR impacts severely affects the RF amplifier efficiency .To mitigate distortion and out-of-band radiation in signals, managing this high PAPR [3] signal necessitates a good-resolution digital-to-analog converter (DAC) and also a linear power amplifier (PA) at the transmitter side, which is costly and also power-inefficient. If number of antennas is more in number, makes such systems highly impractical to implement. So it is highly essential to mitigate the PAPR problem in massive MIMO-OFDM systems which minimizes price of hardware Implementations and also improves power efficiency level. To mitigate PAPR effect in single-input single-output (SISO) OFDM wireless systems, many techniques or methods are investigated. The most familiar techniques are clipping, tone reservation (TR) [5], active constellation extension (ACE) [11], selected mapping (SLM) [12], partial transmission sequence (PTS) [13] and others. These schemes can be conveniently extended for point-to-point MIMO systems easily, but extending to the multi-user (MU) MIMO downlink systems [12], [14] becomes very difficult and not straightforward, predominantly because the joint receiver-side signals processing becomes very difficult to deal in practice, because the users are distributed. Recently new schemes were developed to reduce PAPR in massive MIMO-OFDM systems [15]. One method is fast iterative truncation algorithm (FITRA) [6] which exhibits fairly low convergence rate. Another method is peak signal clipping scheme, although this scheme exhibits low computational complexity and attain only a slight PAPR mitigation and reserved antennas kept for compensation can produce massive PAPR effect.

Another method is peak signal clipping scheme, although this scheme exhibits low computational complexity and attain only a slight PAPR mitigation and reserved antennas kept for compensation can produce massive PAPR effect. Here we applied Bayesian approach [6,8] to deal the problem of the joint PAPR mitigation in downlink multi-user massive MIMO-OFDM systems [6]. In order to achieve low PAPR, a hierarchical truncated Gaussian mixture prior model is used and applied to the unknown signal. The above model has the potential to produce a quasi-constant magnitude solution with more number of entries as possible lying at the truncated boundaries, which effectively results in PAPR reduction [10]. To extract the estimates of hyper parameters obtained in the above model including signal, a variational expectation-maximization (EM) algorithm [17] is employed. A generalized approximate message passing (GAMP) technique [16] is used for expectation step helps in reduction of the computational complexity of the above algorithm. Simulation models indicate applying the above mentioned algorithm enables a good improvement in PAPR reduction over other algorithms.

2. System model and proposed formulation

2.1. System model

We consider the OFDM based MIMO downlink system. The base station consists of M transmit antennas which is going to distribute to K single independent antenna users with N number of OFDM tones. Precoding signal vectors coming from information source is to be done at the base station to reduce multi-user interference. Zero-Forcing precoding scheme is considered, so that it mitigates multi-user interference.
The precoding matrix considered here is

$$F_n^{Lf} = H_n^H (H_n H_n^H)^{-1} \tag{1}$$

The precoded vector developed after precoding is

$$Wn=F_n s_n \tag{2}$$

W_n is the precoded vector, after the process of precoding all the precoded vectors are assigned to M antennas for OFDM scheme of modulation $[a_1, a_2, \ldots\ldots\ldots a_M]$.
The precoded signals are converted in time domain signals by application of inverse fast Fourier transform (IFFT) $[\hat{a}_{1,} \hat{a}_{2,} \ldots\ldots\ldots\ldots\ldots\ldots \hat{a}_M]$, and followed by a added cyclic prefix (CP) to M time domain samples in order to reduce the intersymbol interference (ISI).Lastly the samples are given to DAC which converts into analog signals .All the M signals are transmitted via frequency selective channel. In receiver section ADC coverts into digital samples followed by removal of the CP's of the received signals, N-point DFT is applied to retrieve the frequency domain signals of K users at the receiver.
At receiver the received vector comprises of K users signals can be given as

$$R_n = H_n W_n + E_n \tag{3}$$

Where E_n is the receiver noise mean value of zero and N_0 variance. So with the use of ZF precoding scheme the received vector is $R_n = S_n + E_n$ which indicates MUI is removed.

2.2. Peak to average power ratio (PAPR)

OFDM modulated signals are characterized by noise like amplitude variations in time domain and typically exhibit a large dynamic range due to independent phases of the sub carriers could be added in destructive or constructive manner via IFFT operation. This severely impacts the RF amplifier efficiency because the amplifiers need to be linear to allow the large amplitude swings and these factors indicate the amplifier cannot be used with a good efficiency level.
PAPR is the one of the detrimental aspects in OFDM systems, as it impacts SNR of ADC and DAC while degrading the amplifier efficiency level at the transmitter. It is measured mathematically as maximum power to average power of the complex pass band signal s (t).

$$PAPRofs(t) = \frac{\max|s(t)|^2}{Expectation\{|s(t)|^2\}} \tag{4}$$

Assuming number of transmit antennas at the base station is more than receiving antennas at the receiver terminal, then applying Zero Forcing precoding produces infinite count of precoded vector signals

$$W = [w_1^T, w_2^T, \ldots\ldots\ldots\ldots\ldots w_N^T] \tag{5}$$

To achieve the MUI cancellation. In this precoding we directly search for the signal with low PAPR among the signals instead of developing precoding matrix.

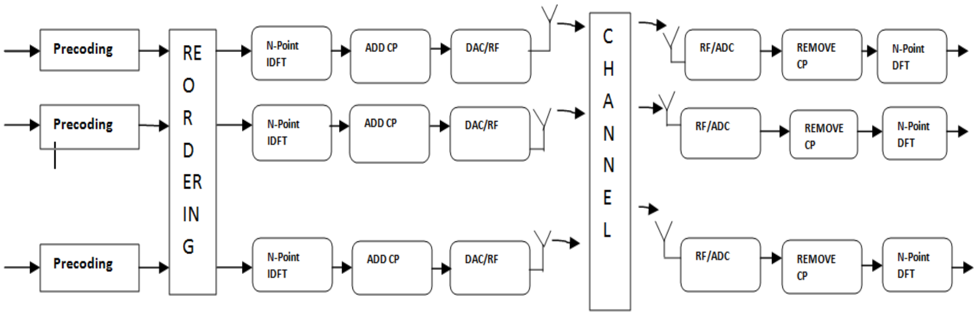


Fig. 1: Downlink System Model for OFDM based Massive MIMO Systems.

The precoded vector must be of the form $W_n=F_nS_n$.
Minimizing the largest magnitude PAPR corresponding with each transmit antenna can be effectively.

3. Bayesian model

To felicitate the algorithm we make some assumptions, let us take received vector mismatch due to Gaussian noise 'n' as $y = Bx + n$, 'n' is a Gaussian R.V. with zero mean and e^{-1} unknown variance. We utilize Bayesian process model automatically finds unknown parameters with a good balance between desired solution and data fitting error. In order to mitigate PAPR we utilize quasi-constant magnitude solution for the above system with restricted boundaries [-a, a], followed by truncated Gaussian mixture model with mean value of v and variance value of α_i^{-1} with probability function , the term $\pi\varepsilon$ [0,1] mixing coefficient with η_i as normalization coefficient.

$$p(x_i) = \{\pi N(x_i; v, \alpha_{i1}^{-1}) \frac{\pi N(x_i; v, \alpha_{i1}^{-1})}{\eta_{i1}} + \frac{(1-\pi) N(x_i; -v, \alpha_{i2}^{-1})}{\eta_{i2}} if x_i \varepsilon [-a, a] els \tag{6}$$

$$\hat{p}(y / x, v)$$

3.1. Bayesian Inference methodology

We apply Bayesian inference along with EM strategy for the above Gaussian model .GAMP technique is mixed with variational EM frame work for the estimates of deterministic parameters and hidden variables. GAMP is very less complex approach used for approximation of posterior functions. To get better estimates of mean values and covariance expectation and maximization steps are used.
Implementation of Algorithm:

1) Calculate approximate distribution function

$\hat{p}(y/x,v)$ with the help of GAMP approximation.

2) Applying step1 update the posterior of hidden variables using E-step.
3) Compute the new estimate of e and a using M- Step.
4) Return to step 1.

ALGORITHM:
Approximating with the help of GAMP
Inputs Applied: Mean values and variance values of posterior of density function

$q(x_i):\hat{x}_i = \langle x_i \rangle_{q(x_i)}, \tau_i^x = \langle x_i \rangle^V_{q(x_i)}$, i = 1,……., I, where $\langle . \rangle^V_{q(.)}$

Indicates variance of q (.), and the inverse noise variance β. Assume $\hat{s}_j$ as 0, j= 1…, J.

Output Estimates: Approximate likelihoods $N(x_i/\hat{\tau}_i, \tau_i^\gamma)$ with values of i = 1… I, and posteriors of u_j : $N(x_i/\hat{\tau}_i, \tau_i^\gamma)$ with values of

j = 1… J.

1) For each value of j:

$$\mathcal{T}_j^p = \sum_i A_{ji}^2 \mathcal{T}_i^x$$

$$\hat{p}_j = \sum_i A_{ji}\hat{x}_i - \tau_j^p \hat{s}_j$$

2) For each value of j:

$$\hat{u}_j = \langle u_j \rangle_{p\left(u_j | y_j, \hat{p}_j, \tau_j^p\right)}$$

$$\tau_j^u = \langle u_j \rangle^{\mathbb{V}}_{p\left(u_j | y_j, \hat{p}_j, \tau_j^p\right)}$$

$$\hat{s}_j = \frac{\hat{u}_j - \hat{p}_j}{\tau_j^p}$$

$$\tau_j^s = \frac{1}{\tau_j^p}\left(1 - \frac{\tau_j^u}{\tau_j^p}\right)$$

3) For each value of i:

$$\tau_i^r = \left(\sum_j A_{ji}^2 \tau_j^s\right)^{-1}$$

$$\hat{r}_i = \hat{x}_i + \tau_i^r \sum_j A_{ji}\hat{s}_j$$

Gamp technique estimates the likelihood and marginal posterior probabilities of the noiseless output u and given as

$$p\left(\frac{u_j}{y}, \beta\right) \cong p\left(\frac{\hat{u}_j}{y}, \beta\right) \alpha\, p\left(\frac{y_j}{u_j}, \beta\right) N\left(\frac{u_j}{\hat{p}_j}, \tau_j^p\right)$$

Where $\hat{p}_j, \tau_j^p$ are the terms estimated from GAMP technique.

Where E-step is Expectation of the approximation function and M-step is the maximization of the approximated probability function. E step and M-step are repeated for 200 numbers of iterations to develop the best estimate of approximation function values.

4. Result analysis

In simulation work we have taken a MIMO system we utilized the simulation parameters as shown in the table.

Table1: Input Parameters

S. NO	Simulation Parameters	Values
1	Modulation	16-QAM
2	No of antennas at the base station(M)	96
3	No of receiving users(k)	10
4	No of OFDM tones utilized	128
5	No of delay taps	8
6	No of iterations	200

We demonstrate the effectiveness of the proposed algorithm with input parameters mentioned above in the table. Comparing the developed results with previously used techniques like FITRA technique, ZF precoding technique and the amplitude clipping scheme, our results achieved better improvement in reducing PAPR problem.

The plots were developed between CCDF and PAPR The complementary cumulative distribution function (CCDF) is considered as a parameter as a measure for evaluation of PAPR problem. The CCDF shows the probability that the PAPR of the signal estimated exceeds a given threshold PAPR₁ mathematically represented as

CCDF (PAPR₁) = Pᵣ (PAPR > PAPR₁).

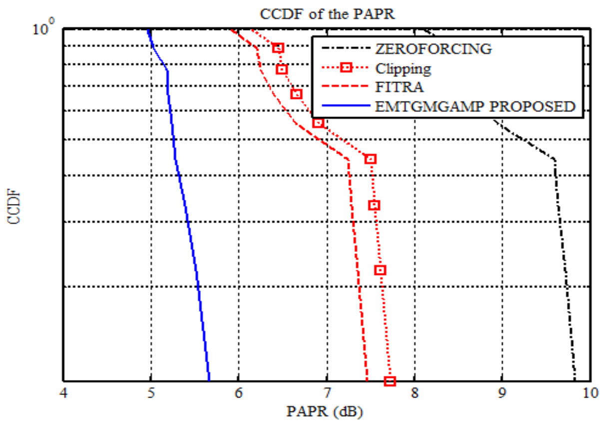
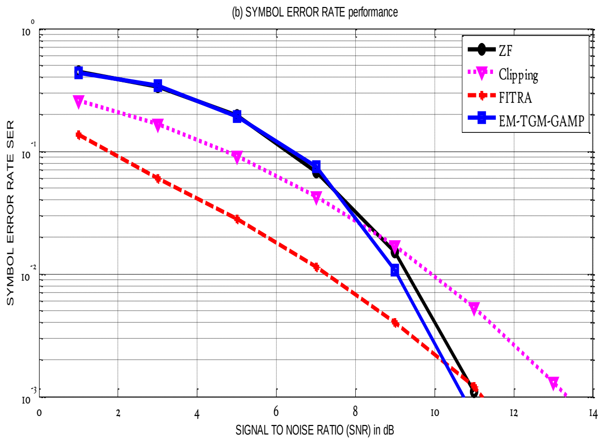


Fig. 2: PAPR Performance for Various Schemes.

For better evaluation of PAPR reduction, we plotted the CCDF of the PAPR for the above techniques. Clearly it shows that it reduces PAPR by 6 dB compared to ZF scheme, 3dB compared to FITRA algorithm and by about 4dB compared to clipping scheme. There is significant reduction in PAPR with proposed algorithm compared with rest of the algorithms, particularly for Massive MIMO downlink system.

Table 2: Comparison of Algorithms

Parameter	Zero Forcing[6]	Clipping[5]	FITRA[6]	Proposed EM-TGM-GAMP
PAPR (dB)	10.11	8.01	7.67	5.33



Symbol error rate performance of different schemes is plotted graphically for SER vs. SNR (dB).We observed the SER of all the schemes our algorithm suffers a SNR loss of 2.3dB and 1.4dB at SER of 10^-3compared to Zero Forcing and FITRA algorithm schemes respectively The SNR loss may be due to high normalization, in order to maintain same SNR strong normalization is required.

Graphical results shows that our proposed algorithm produces lowest PAPR of 0.75 dB ,the FITRA algorithm exhibits PAPR of 2.34dB and clipping scheme exhibits PAPR's 4.23dB ,where as the Zero Forcing scheme have highest PAPR of 10.5 dB.

5. Conclusion

Joint PAPR reduction in OFDM based massive mimo downlink systems is being considered. Applying Bayesian approach which models the PAPR problem into truncated Gaussian mixture prior model, which utilizes a variational EM algorithm and GAMP technique and produces low PAPR solution compared with other techniques. This model utilized DOF resulting from more number of antennas at the base station to reduce PAPR in the signal. MATLAB simulated results indicates that the applied algorithm mentioned above achieves significant improvement in reduction of PAPR compared to FITRA algorithm.

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