EFFICIENT PAPR REDUCTION METHOD FOR OFDM BASED MIMO SYSTEMS

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***Abstract:** The problem of peak-to-average power ratio(PAPR) reduction in orthogonal frequency-division multiplexing based massive multiple-input multiple-output downlink systems is considered. The problem is to find an OFDM-modulated signal that has a low PAPR and meanwhile enables multiuser interference cancelation from a set of symbol vectors to be transmitted to K users. It take a Bayesian approach and develop an efficient PAPR reduction method by exploiting the redundant degrees-of-freedom of the transmit array unlike previous works that tackled the problem using convex optimization. The sought-after signal is treated as a random vector with a hierarchical truncated Gaussian mixture prior, which has the potential to encourage a low PAPR signal with most of its samples concentrated on the boundaries. A variational expectation-maximization strategy is developed to obtain estimates of the hyperparameters associated with the prior model, along with the signal. In addition, the generalized approximate message passing is embedded into the variational EM framework, which results in a significant reduction in computational complexity of the proposed algorithm.*
***Key words:** PAPR, OFDM, expectation-maximization*

I. INTRODUCTION

Massive multiple-input multiple-output also known as large-scale or very-large MIMO, is a promising technology to meet the ever growing demands for higher throughput and better quality-of-service of next-generation wireless communication systems. MIMO is a method for multiplying the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation. MIMO is fundamentally different from smart antenna techniques developed to enhance the performance of a single data signal, such as beamforming and diversity. Massive MIMO systems are those that are equipped with a large number of antennas at the base station simultaneously serving am much smaller number of single-antenna users sharing the same time-frequency bandwidth. In addition to higher throughput, massive MIMO systems also have the potential to improve the energy efficiency and enable the use of inexpensive, low-power components. Hence, it is expected that massive MIMO will bring radical changes to future wireless communication systems. In practice, broadband wireless communications may suffer from frequency-selective fading. Orthogonal frequency division multiplexing (OFDM), a scheme of encoding digital data on multiple carrier frequencies, has been widely used to deal with frequency-selective fading. Orthogonal Frequency Division Multiplexing or OFDM is a modulation format that is being used for many of the latest wireless and telecommunications standards. OFDM is a form of multicarrier modulation. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period. However, a major problem associated with the OFDM is that it is subject to a high peak-to-average power ratio owing to the independent phases of the sub-carriers. To avoid out-of-band radiation and signal distortion, handling this high PAPR requires a high-resolution digital-to-analog converter and a linear power amplifier (PA) at the transmitter, which is not only expensive but also power-inefficient. The situation deteriorates when the number of antennas is large leaving such systems impractical. Therefore, it is of crucial importance to reduce the PAPR of massive MIMO-OFDM systems to facilitate low-cost and power-efficient hardware implementations. Many techniques have been developed for PAPR reduction in single-input single-output (SISO) OFDM wireless systems. The most prominent are clipping, tone reservation (TR), active constellation extension (ACE), partial transmission sequence (PTS) and others Although these PAPR-reduction schemes can be extended to point-to point MIMO systems easily, extension to the multi-user (MU) MIMO downlink is not straightforward, mainly because joint receiver-side signal processing is almost impossible in practice as the users are distributed. Recently, a new PAPR reduction method was developed for massive MIMO-OFDM systems. The proposed scheme utilizes the redundant degrees-of-freedom (DoFs) resulting from the large number of antennas at the BS to achieve joint multiuser interference (MUI) cancelation and PAPR reduction. Specifically, the problem was formulated as a linear constrained $l\infty$ optimization problem and a fast iterative truncation algorithm (FITRA) was developed. However, the FITRA algorithm shows to have a fairly low convergence rate. Also, the algorithm employs a regularization parameter to achieve balance between the PAPR reduction and the MUI cancelation (i.e. data fitting error). The choice of the regularization parameter may be tricky in practice. On the other hand, the regularization parameter may be seen instead as an additional degree of freedom that allows to regulate the operation of the algorithm. , a peak signal clipping scheme was employed to reduce the PAPR and some of the antennas at the BS are reserved to compensate for peak-clipping signals. This method has a lower computational complexity. But it achieves only a mild PAPR reduction and those antennas reserved for compensation may incur large PAPRs. In this paper, we develop a novel Bayesian approach to address the joint PAPR reduction and MUI cancelation problem for downlink multi-user massive MIMO-OFDM systems. Specifically, MUI cancelation can be formulated as an underdetermined linear inverse problem which admits numerous solutions. To search for a low PAPR solution, a hierarchical truncated Gaussian mixture prior model is proposed and assigned to the unknown signal (i.e. solution). This hierarchical prior has the potential to encourage a quasi-constant magnitude solution with as many entries as possible lying on the truncated boundaries, thus resulting in a low PAPR. A variational expectation-maximization (EM) algorithm is developed to obtain estimates of the hyperparameters associated with the prior model, along with the signal. In addition, the generalized approximate message passing (GAMP) technique is employed to facilitate the algorithm development in the expectation step. This GAMP technique also helps significantly reduce the computational complexity of the proposed algorithm.

II. LITERATURE SURVEY

A. PAPR Reduction Techniques for OFDM Signals

As an attractive technology for wireless communications, Orthogonal Frequency Division Multiplexing which is one of multi-carrier modulation techniques, offers a considerable high spectral efficiency, multipath delay spread tolerance, immunity to the frequency selective fading channels and power efficiency. One of the challenging issues for Orthogonal Frequency Division Multiplexing system is its high Peak-to-Average Power Ratio. In this paper, it reviews and analysis different OFDM PAPR reduction techniques, based on computational complexity, bandwidth expansion, spectral spillage and performance. They are clipping, filterng, coding schemes and partial transmit sequences. The simplest and most widely used technique of PAPR reduction is to basically clip the parts of the signals that are outside the allowed region. Generally, clipping is performed at the transmitter. However the receiver need to estimate the clipping that has occurred and to compensate the received OFDM symbol accordingly. Therefore, clipping method introduces both in band distortion and out of band radiation into OFDM signals, which degrades the system performance including BER and spectral efficiency. Filtering can reduce out of band radiation after clipping although it cannot reduce in-band distortion. However, clipping may cause some peak regrowth so that the signal after clipping and filtering will exceed the clipping level at some points. . A simple block coding scheme was introduced and its basic idea is that mapping 3 bits data into 4 bits codeword by adding a Simple Odd Parity Code at the last bit across the channels. The main disadvantage of SOBC method is that it can reduce PAPR for a 4-bit codeword. Later, Wulich applied the Cyclic Coding to reduce the PAPR Fragiacomo proposed an efficient Simple Block Code to reduce the PAPR of OFDM signals. However, it is concluded that SBC is not effective when the frame size is large. In a typical OFDM system with PTS approach to reduce the PAPR, the input data block in is partitioned into disjoint subblocks. In general, for PTS scheme, the known subblock partitioning methods can be classified into three categories: adjacent partition, interleaved partition and pseudo random partition. Then, the subblocks are transformed into time-domain partial transmit sequences. The objective is to optimally combine the subblocks to obtain the time domain OFDM signals with the lowest PAPR.

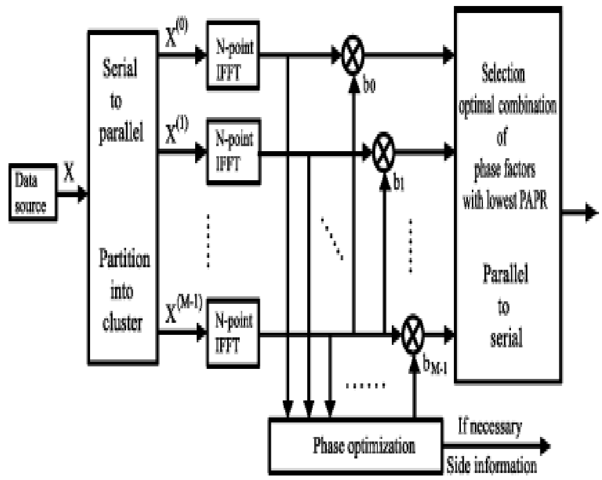

Fig. 1 Block diagram of PTS technique

B. Antenna Reservation scheme

An OFDM based MU-MIMO system is considered. The problem of high Peak-to-Average Ratio in OFDM based systems is well known and the large number of antennas (RF-chains) at the Base Station in massive MIMO systems aggravates this further, since large numbers of these Power Amplifiers are used. High PAR necessitates linear PAs, which have a high hardware cost and are typically power inefficient. In this paper we propose a low-complex approach to tackle the issue. The idea is to deliberately clip signals sent to one set of antennas, while compensating for this by transmitting correction signals on a set of reserved antennas (antenna-reservation). massive MIMO there is inherently a large degree-of-freedom (due to the large number of antennas at the BS), that can be utilized to reduce the PAR. In contrast, here propose an approach which does not deliver the same amount of PAR reduction, but is of much lower complexity and hardware cost. The idea is to reserve antennas (”antenna reservation” analogy to ”tone-reservation”), which will be used to compensate for a (deliberate) clipping of the signals on the remaining antennas. In terms of signal processing, an advantage is that even though there is a quite large number of antennas to be handled at the BS, most of the processing can be performed using simple linear methods. For example, low-complex precoding can be deployed which reduces the overall digital (signal processing) hardware cost. It is also important to look at the RF chains where, considering the large number of instances, it is very important to reduce both hardware cost and power consumption. It relies on reserving bandwidth (around 20% for 10 dB reduction in PAR), which, in-turn, reduces the spectral-efficiency significantly since it has a linear (pre-log-factor) relation to capacity. In massive MIMO there is inherently a large degree-of-freedom (due to the large number of antennas at the BS), that can be utilized to reduce the PAR The proposed antenna-reservation method has a low complexity overhead and can be implemented with existing hardware blocks, namely a DFT and a matrix inversion (pre-coder).

C. Active Constellation Extension

The high peak-to-average power ratio in Orthogonal Frequency Division Multiplexing modulation systems can significantly reduce power efficiency and performance. Methods exist which alter or introduce new signal constellations to combat large signal peaks. Here present a new PAR-reduction method that dynamically extends outer constellation points in active (data-carrying) channels, within margin-preserving constraints, in order to minimize the peak magnitude. This scheme simultaneously decreases the bit error rate slightly while substantially reducing the peak magnitude of an OFDM transmit block. Furthermore, there is no loss in data rate and unlike other methods, no side information is required. PAR reduction for an approximated analog signal is considered, Large PARs occur when symbol phases in the sub-channels line up in a fashion that results in constructively forming a peak in the time-domain signal. One class of methods reduce peak power by inserting signals in unused subchannels that partially cancel the time-domain peaks . Since the subchannels are orthogonal, these additional signals cause no distortion of the data-bearing subchannels. In the case of DMT in wireline systems, there are typically subchannels with SNRs too low for sending any information, so these subchannels must go unused and are available for PAR reduction. In wireless systems, however, there is typically no fast, reliable channel-state feedback to dictate whether some subchannels should go unused. Instead, a set of subchannels must be reserved regardless of the received SNRs, resulting in a bandwidth sacrifice. This may not be appropriate for some wireless systems. Here, a new nonbijective constellation technique called active constellation extension is introduced along with practical algorithms that show promising results for commercial use in OFDM systems.

III. PROPOSED SYSTEM

Here, a novel Bayesian approach to address the joint PAPR reduction and MUI cancelation problem for downlink multi-user massive MIMO-OFDM systems is developed. Specifically, MUI cancelation can be formulated as an underdetermined linear inverse problem which admits numerous solutions. The block diagram is shown in fig.2.

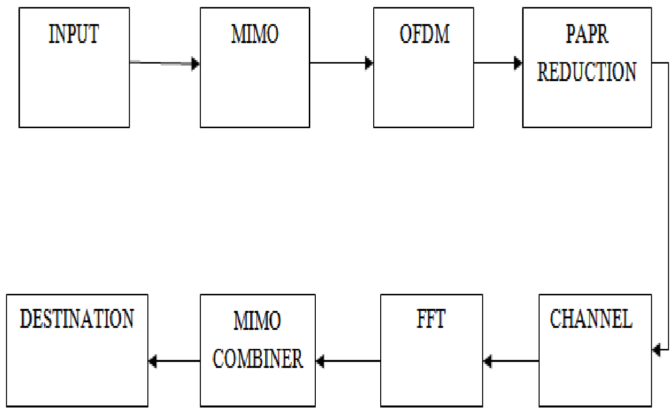

Fig. 2 System block diagram

To search for a low PAPR solution, a hierarchical truncated Gaussian mixture prior model is proposed and assigned to the unknown signal (i.e. solution). This hierarchical prior has the potential to encourage a quasi-constant magnitude solution with as many entries as possible lying on the truncated boundaries, thus resulting in a low PAPR. A variational expectation-maximization (EM) algorithm is developed to obtain estimates of the hyperparameters associated with the prior model, along with the signal. In addition, the generalized approximate message passing technique is employed to facilitate the algorithm development in the expectation step. This GAMP technique also helps significantly reduce the computational complexity of the algorithm. In this paper, instead of designing the precoding matrix, directly search for the signal w to achieve a joint PAPR reduction and MUI cancelation. Approximate message passing (GAMP) is a very-low-complexity Bayesian iterative technique recently developed for obtaining approximate marginal posteriors and likelihoods. It therefore can be naturally embedded within the EM framework to provide an approximate posterior distribution of x and reduce the computational complexity. Specifically, the EM-GAMP framework proceeds in a double loop manner: the outer loop (EM) computes the Q-function using the approximate posterior distribution of x, and maximizes the Q-function to update the model parameters the inner loop (GAMP) utilizes the newly estimated parameters to obtain a new approximation of the posterior distribution of x. However, this procedure is not suitable for our variational EM framework, because from the GAMP's point of view, the hyperparameters need to be known and fixed in order to compute an approximate posterior distribution of x, while the variational EM treats the model parameters) as latent variables. Therefore, instead of computing the approximate posterior distribution of x, in the variational EM framework, the GAMP is simply used to obtain an amiable approximation of the likelihood function and this approximation involves no latent variables. Besides, unlike the EM-GAMP framework where the inner loop (GAMP) is implemented in an iterative way, in the variational EM-GAMP framework,the GAMP only needs to go through one iteration to obtain an approximation of the likelihood function. In fact, the GAMP algorithm described here is a simplified version of the original GAMP algorithm by retaining only its first three steps and skipping its iterative procedure.

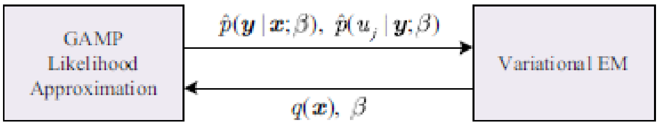

Fig. 3 Variational EM-GAMP framework

To facilitate the algorithm development, we introduce a noise term to model the mismatch between y and Ax. i.e.

$$y = Ax + \epsilon$$

where ϵ denotes the noise vector and its entries are assumed to be i.i.d. Gaussian random variables with zero-mean and unknown variance $\beta^{-1.}$ Here β is treated as an unknown parameter because the Bayesian framework allows an automatic determination of its model parameters and usually provides a reasonable balance between the data fitting error and the desired characteristics of the solution. To reduce the PAPR associated with each transmit antenna, aim is to find a quasi-constant magnitude solution to the above underdetermined linear system. To encourage a quasi-constant magnitude solution, a hierarchical truncated Gaussian mixture prior for the signal x is proposed. In the first layer, coefficients of x are assumed independent of each other and each entry x_i is assigned a truncated Gaussian mixture distribution. The second layer specifies Gamma distributions as hyperpriors over the precision parameters. In general, Bayesian inference requires computing the logarithm of the prior. To address this issue, here turn the prior into an exponential form by introducing a binary latent variable. A variational expectation maximization (EM) strategy is employed for the Bayesian inference. Consider a probabilistic model with observed data y, hidden variables z and unknown deterministic parameters θ. It is straightforward to show that the marginal probability of the observed data can be decomposed into two terms

$$\ln p(y;\theta)=F(q,\theta)+KL(q||p)$$

KL(q||p) is the Kullback-Leibler divergence between p(z|y; θ) and q(z). Since KL(q||p)≥ 0, it follows that F(q, θ) is a lower bound of lnp(y; θ), with the equality holds only when KL(q||p)= 0, which implies p(z|y; θ) = q(z). The EM algorithm can be viewed as an iterative algorithm which iteratively maximizes the lower bound F(q, θ) with respect to the distribution q(z) and the parameters θ.

IV. CONCLUSION

The problem of joint PAPR reduction and multiuser interference cancelation in OFDM based massive MIMO downlink systems is considered. A hierarchical truncated Gaussian mixture prior model was proposed to encourage a low PAPR solution/signal. A variational EM algorithm was developed to obtain estimates of the hyperparameters associated with the prior model, as well as the signal. Specifically, the GAMP technique was embedded into the variational EM framework to facilitate the algorithm development. The algorithm only involves simple matrix vector multiplications at each iteration, and thus has a low computational complexity. The algorithm achieves notable improvement in PAPR reduction as compared with the FITRA algorithm, and meanwhile renders better MUI cancelation and lower out-of band radiation. The algorithm also demonstrates a fast convergence rate, which makes it attractive for practical real-time systems.

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