Cell partitioned M-QAM for semi-blind uplink interference suppression on multicell massive MIMO systems

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Abstract: This letter adopts higher-order modulation scheme than 16QAM to our previously proposed semi-blind uplink interference suppression scheme for multicell multiuser massive MIMO systems. Our semi-blind approach is attained by the decision feedback channel estimation (DFCE) and the sample matrix inversion (SMI) spatial adaptive filtering. However, its efficiency depended on inter-cell interference (ICI), in particular for higher-order QAM. We propose to employ cell partitioning-based M-ary QAM to avoid ICI at the initial condition and verify overall spectral efficiency improvement.

Keywords: channel estimation, pilot contamination, massive MIMO, multicell, decision feedback, sample matrix inversion

Classification: Wireless Communication Technologies

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1 Introduction

The concept of massive multiple-input multiple-output (MIMO) has now been extensively applied to advanced wireless communication systems [1]. Its crucial issue is known as pilot contamination, caused by inter-cell interference (ICI) among pilot signals which must be reused in each cell due to the limits inherent in the orthogonal training sequence set [2]. Meanwhile, the massive antenna array of the base station (BS) has the potential to suppress any prominent interference thanks to its excessive degree of freedom (DoF). Taking full advantage of this feature, we have previously proposed a semi-blind uplink interference suppression scheme [3]. It is comprised of the blind adaptive array (BAA) initialized by the channel state information (CSI)-aided postcoding and decision feedback channel estimation (DFCE). It enables the suppression of both ICI and inter-user interference (IUI) by utilizing mutually independent data signals, even without inter-cell CSI knowledge. Our study so far clarified its effectiveness up to 16QAM with the aid of multi-modulus algorithm (MMA), sample matrix inversion (SMI) spatial filtering, and forward error correction (FEC) [4] under the stringent single frequency reuse condition. This letter expands its applicability to higher-order QAM signals for more general use. The key approach is the assignment of the modulation order based on the cell partition. The higher-order QAM is applied in the cell-center region to avoid ICI, which helps to further suppress it by SMI filtering and DFCE, even without BAA. This letter provides more extensive results than our conference publication [5], like the performance of spectral efficiency.

2 System model

Throughout the letter, normal letters, bold lowercase letters and uppercase letters indicate scalar quantities, vectors and matrices, respectively. $(\cdot)^T$ and $(\cdot)^H$ represent transpose and conjugate transpose, respectively. Let N_r , N_c , N_u , N_p and N_s denote the number of BS antenna elements, cells, user terminals (UTs), pilot symbols and data symbols, respectively. Here we assume that each UT has one antenna. $\mathbf{H}_{i,j} \in \mathbb{C}^{N_r \times N_u}$ represents an uplink channel matrix from UTs in the j -th cell to the BS antenna elements in the i -th cell. $\mathbf{T} = \rho_p \left[\mathbf{t}_1^T \cdots \mathbf{t}_u^T \cdots \mathbf{t}_{N_u}^T \right]^T \in \mathbb{C}^{N_u \times N_p}$ is the pilot signal vectors common in all cells. $\mathbf{S}_i = \rho_d \left[\mathbf{s}_{i,1}^T \cdots \mathbf{s}_{i,u}^T \cdots \mathbf{s}_{i,N_u}^T \right]^T \in \mathbb{C}^{N_u \times N_s}$ is the transmission signal vectors from UTs locating in the i -th cell. ρ_p and ρ_d represent transmission signal strength for pilot and data part, respectively. $\mathbf{R}_i = \sum_{j=1}^{N_c} \mathbf{H}_{i,j} \mathbf{T} + \mathbf{N}_i \in \mathbb{C}^{N_r \times N_p}$ and $\mathbf{X}_i = \sum_{j=1}^{N_c} \mathbf{H}_{i,j} \mathbf{S}_j + \mathbf{Z}_i \in \mathbb{C}^{N_r \times N_s}$ are received pilot and received data symbols where $\mathbf{N}_i \in \mathbb{C}^{N_r \times N_p}$ and $\mathbf{Z}_i \in \mathbb{C}^{N_r \times N_s}$ represent additive white Gaussian noise (AWGN) matrices with variance of σ_n^2 .

(a) Block diagram of the proposed receiver.

(b) Assignment of modulation order.

Fig. 1. Proposed concept.

3 Proposed scheme

Here we describe the proposed new scheme which has improved the previous ones. Original proposal exploited beamspace pre-processing, MMA with CSI-aided weight initialization, DFCE and SMI based minimum mean square error (MMSE) spatial filtering [4]. Here, MMA required more extensive conditions for adaptive weight derivation such as iterations, number of data symbols, and FEC capability affecting the initial weight. It causes difficulties in applying $M(>16)$ -ary QAM signals to the proposed scheme. The new advantage of this letter is given by the limitation of the application region of them to the cell-center region, which makes BAA and FEC of the previous scheme unnecessary. Figure 1(a) depicts a block diagram of the proposed receiver. The detailed procedure is presented as follows.

3.1 Beamspace pre-processing

First, the beamspace pre-processing, eigenvector beamspace adaptive array (EBAA), is applied. The principal signal components are extracted to establish well-balanced beamforming gain and interference suppression capability. Eigenvector decomposition (EVD) of the autocorrelation matrix of array input yields the eigenvectors;

$$(X_i X_i^H) U_i = U_i \Lambda_i. \quad (1)$$

Required beamforming weight matrix, $\hat{U}_i \in \mathbb{C}^{N_r \times N_b}$, can be obtained by extracting N_b column-wise eigenvectors whose eigenvalues are in descending order. Applying $\hat{U}_i$ to X_i provides degenerated received pilot and data signals.

3.2 Iterations of MMSE postcoding weight derivation and DFCE

Channel matrix in the i -th cell, $H_{i,i}$ is estimated using the orthogonal pilot sequence, i.e. $TT^H = I_{N_u}$ where I_{N_u} represents $N_u \times N_u$ identity matrix, and it is used to derive the MMSE postcoding weight, $\tilde{V}_i \in \mathbb{C}^{N_u \times N_r}$.

$$\begin{aligned}\tilde{H}_{i,i} &= R_i T^H = \sum_{j=1}^{N_c} H_{i,j} T T^H + N_i T^H \\ &= H_{i,i} + \sum_{j=1, j \neq i}^{N_c} H_{i,j} + N'_i,\end{aligned}\quad (2)$$

$$\tilde{V}_i = (\tilde{H}_{i,i}^H \tilde{H}_{i,i} + \sigma_n^2 I_{N_u})^{-1} \tilde{H}_{i,i}^H, \quad (3)$$

$$Y_i = \tilde{V}_i X_i. \quad (4)$$

Since the postcoding weight, $\tilde{V}_i$, is obtained solely using the CSI of the i -th cell, it cannot suppress ICI and IUI completely. It is reused for CSI estimation to obtain more accurate CSI through a decision result, $\tilde{S}_i$, which is derived from Y_i .

$$\begin{aligned}\tilde{H}_{i,i} &\leftarrow X_i \tilde{S}_i^H (\tilde{S}_i \tilde{S}_i^H)^{-1} = \sum_{j=1}^{N_c} H_{i,j} S_j \tilde{S}_i^H (\tilde{S}_i \tilde{S}_i^H)^{-1} + N_i \tilde{S}_i^H (\tilde{S}_i \tilde{S}_i^H)^{-1} \\ &= H_{i,i} + \sum_{j=1, j \neq i}^{N_c} H_{i,j} S_j \tilde{S}_i^H (\tilde{S}_i \tilde{S}_i^H)^{-1} + N''_i.\end{aligned}\quad (5)$$

If a sufficient number of symbols than the pilot is available, ICI and noise components can be mitigated. Refined CSI is then reused to derive postcoding weight in Eq. (3). The series of above signal processing Eqs. (3)–(5) can be performed iteratively. It gradually improves CSI estimation accuracy and interference suppression performances and can accurately capture the desired signal that satisfies the operating conditions of the subsequent MMSE-SMI.

3.3 Data-aided MMSE-SMI

The array output data part is exploited to SMI spatial filtering weight. After some iterations of MMSE postcoding weight derivation and DFCE, the accuracy of the received data is improved and its decision result is applied as the reference signal to distinguish the desired and interference signals properly. SMI-based MMSE weight is obtained as

$$W_{SMI} = (X_i X_i^H)^{-1} (X_i \tilde{S}_i^H). \quad (6)$$

Applying W_{SMI}^H to the array input, $Y_i = W_{SMI}^H X_i$, finally outputs the desired signals that interference components are suppressed.

3.4 Cell partitioning for QAM

The new proposal is to apply the M -ary QAM signals to the partitioned cell region, as illustrated in Fig. 1(b). In a multi-cell environment, UTs in the cell-edge region severely suffer from ICI impact. Since ICI is relatively reduced in the cell-center region, only iterations of MMSE postcoding weight derivation and DFCE in Fig. 1 can obtain a sufficient symbol detection accuracy. It allows the interference suppression of the subsequent MMSE-SMI to operate properly. Further, higher-order QAM also requires high SNR and hence its application in the cell-center region is quite reasonable from that perspective.

4 Computer simulation

4.1 Simulation parameters

The number of BS antennas, N_r , and the number of data symbols, N_s , are 256 and 200, respectively. The number of pilot symbols and UTs per cell are set to $N_p = N_u = 14$. Assuming a narrowband single carrier transmission, a fading channel is modeled as an independent and identically distributed (i.i.d) Rayleigh flat fading. UTs are assumed to be spatially uncorrelated. Other representative parameters are consistent with our previous studies [3, 4]. The cell range applied to each modulation scheme is expressed using a ratio α to the cell radius r ; when $\alpha = 1.0$, αr represents the entire cell. After $N_n = 3$ iterations of MMSE postcoding weight derivation and DFCE, MMSE-SMI is applied. $N_c = 7$ cells are deployed and we evaluate an uplink SINR per UT in the center cell.

4.2 Simulation results

Figure 2(a) plots cumulative distribution functions (CDFs) of output SINR when 64QAM is applied as the modulation scheme. Here, the characteristics of the previous scheme with MMA [4] are plotted as a comparison. When $\alpha = 0.3$ and 0.4, output SINR at the 1% CDF baseline of the proposed scheme is more than 25dB. The previous scheme cannot provide a satisfactory SINR; MMA cannot derive the optimal solution in the condition even though ICI is mitigated, and thus subsequent MMSE-SMI also does not work properly. On the other hand, in the proposed scheme without MMA, its simplification reaches successful interference suppression that obtains sufficiently accurate desired signals; subsequent MMSE-SMI can further suppress interference components. Similarly, when 256QAM is applied as the modulation scheme (Fig. 2(b)), it can be confirmed that the interference suppression works properly by limiting the application area.

Figure 2(c) shows the relationship between the output SINR at CDF = 1% with the ratio to cell radius, α , in the case of applying QPSK, 16QAM, 64QAM, and 256QAM, respectively. The figure compares the proposed scheme with competitive ones that only perform data-aided MMSE postcoding and DFCE. The optimal application area of each modulation scheme is determined based on Table I which shows the achievable spectral efficiency (SE) and corresponding SNR values for each combination of modulation and coding schemes [6]. The optimized 1st percentile SINR of the proposed scheme is much better than that of the comparative scheme.

Fig. 2. Simulation results.

Table I. Modulation and coding scheme parameters.

SNR [dB]	SE [bps/Hz]	Mod.	Code rate	SNR [dB]	SE [bps/Hz]	Mod.	Code rate
0	0.67	QPSK	1/3	13.0	3.20	16QAM	4/5
1.5	1.00	QPSK	1/2	15.0	4.00	64QAM	2/3
4.0	1.30	QPSK	2/3	17.0	4.50	64QAM	3/4
5.0	1.50	QPSK	3/4	18.5	4.80	64QAM	4/5
5.5	1.60	QPSK	4/5	20.0	5.33	256QAM	2/3
7.0	2.00	16QAM	1/2	22.0	6.00	256QAM	3/4
10.0	2.67	16QAM	2/3	24.0	6.40	256QAM	4/5
11.5	3.00	16QAM	3/4	27.0	7.00	256QAM	7/8

It indicates that the interference suppression works more strongly in the proposed scheme.

Figure 2(d) exhibits CDFs of SE at each modulation scheme in the optimized region. Each SE performance includes coding parameters as shown in Table I. From the figure, we can see that the proposed scheme improves the SE performance by 17.0%, 9.1%, 5.2%, and 3.7% for QPSK, 16QAM, 64QAM, and 256QAM, respectively, compared to the data-aided iterative MMSE. From the above results, introducing adaptive modulation to partitioned cell regions can successfully suppress ICI and IUI even when a higher modulation order is used.

5 Conclusion

This letter proposed a realistic solution for the application of multi-level modulation on multi-cell Massive MIMO with semi-blind uplink interference suppression. By limiting the application area of 16QAM or more to the partitioned cell region, sufficient interference suppression can be achieved even with a simplified receiver structure excluding BAA, which has highly constrained operating conditions. Computer simulation verified its efficiency in terms of spectral performance. In conclusion, the overall efficiency of our proposed scheme has been ensured as a solution for pilot contamination in massive MIMO systems.

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