Multi-Stage Partial Parallel Interference Cancellation Algorithm for MUSA Systems

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Abstract

Multi-User Shared Access is a non-orthogonal multiple access scheme of 5G,which has a high computational complexity and a large time delay due to the usage of successive interference cancellation detection algorithm. This paper proposes a multi-stage partial parallel interference cancellation detection algorithm, which does not require repeated ordering and repeated matrix inversion. In the first stage of detection, the bits of these users with good channel conditions will be outputted, and the influence of multiple access interference on users with bad channel conditions in the second stage will be decreased. Theoretical analysis and simulation results show that the symbol error rate of the proposed algorithm is slightly better than that of the two-stage MMSE-PIC, and the complexity is reduced. In the meanwhile, the computational complexity is significantly reduced without SER performance degradation when compared with MMSE-SIC algorithm.

Keywords: *Multi-User Shared Access, non-orthogonal multiple access, successive interference cancellation, parallel interference cancellation, symbol error rate*

1. Introduction

In the mobile communication system [1], multiple access technique is to allow users to share the scarce radio resources and communicate simultaneously. From the first to the fourth generation mobile communication, FDMA, TDMA, CDMA and OFDMA are used as the main multiple access schemes, all of them are orthogonal multiple access. However, in order to meet the demands of massive connections, high spectrum efficiency, and high capacity and low latency [2-3] of the fifth generation mobile communication [4-5], non-orthogonal multiple access has attracted a lot of considerations. So far, there are three well-known proposals in the community of non-orthogonal multiple access schemes in China: ZTE Corporation proposes Multi-User Shared Access (MUSA) [6], which achieves free scheduling transmission; Sparse Code Multiple Access (SCMA) [7] from Huawei Corporation, has realized the channel overload by 300%; Pattern Division Multiple Access (PDMA) [8], supported by Datang Telecom, reduces the realization complexity.

The key elements of MUSA system include complex multi-domain spreading codes [9-10] and advanced successive interference cancellation (SIC) receiver [11]. The spreading codes among various users are non-orthogonal in MUSA system, therefore the performance of the MUSA systems will be mainly affected by multiple access interference (MAI), also including multipath interference and noise. In order to meet the requirements of the fifth generation mobile communication such as massive connections, high spectrum efficiency, high capacity and low latency, how to increase the capacity and eliminate the MAI are major challenges for MUSA systems.

One of the key technologies to reduce the MAI of MUSA system is the multi-user detection algorithm i.e. minimum mean square error-successive interference cancellation (MMSE-SIC) algorithm. Users are sorted in ascending order according to the SINR of users, then the strongest user will be firstly detected, and the influence corresponding to the detected user will be subtracted from the received signal. Similar steps such as sorting and detecting will be repeated until all users are detected. It is obvious that the later detection order of the user is, the higher degree accuracy of the detection will be. However, the algorithm is an iterative procedures including ordering, estimation and subtraction, which require complex matrix

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computation e.g. matrix inversion due to the MMSE criterion. Unfortunately, the user number decide the number of iterative procedures, therefore the MMSE-SIC detection algorithm result in a high complexity and a large processing delay of the system when the user number is getting large. As is well-known, the classical MMSE-PIC algorithm, which has been widely used in CDMA and MIMO systems, has several characteristics such as low computational complexity and a small delay. In general, the MMSE-PIC algorithm requires multi-stage structure, and detects all users' signals in parallel. However at the case of parallel processing, those stronger users always influent weaker users, which raise the impact of MAI. In terms of the shortcomings of the MMSE-SIC and the traditional MMSE-PIC algorithm, a multi-stage partial parallel interference cancellation algorithm is proposed, which only needs once ordering and the number of matrix inversion with respect to the MMSE-SIC has significantly reduced. Theoretical analysis and simulation results show that the complexity of the proposed detection algorithm is significantly reduced without SER performance degradation when compared with MMSE-SIC algorithm.

2. System Model

Figure 1 describes the uplink MUSA system architecture. Assuming that there are K users, each user's data are spread by dedicated complex multi-domain spreading codes respectively. Then all spread symbols are transmitted over the same time-frequency resources.

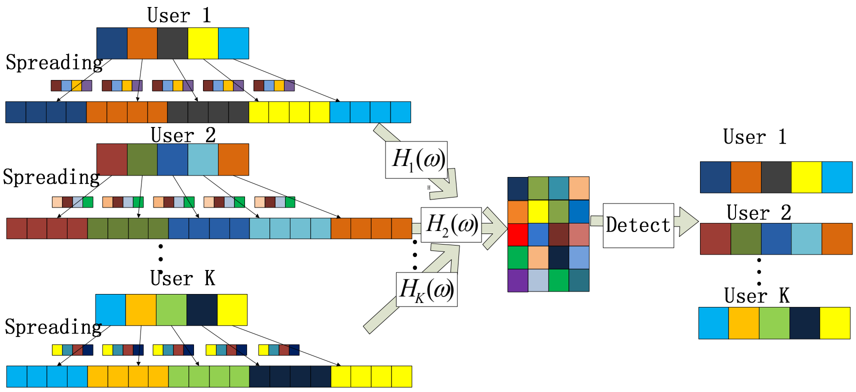

Figure 1. Uplink MUSA System

The received signal after the channel can be represented by:

$$r = \sum_{k=1}^{K} g_k s_k x_k + z \quad . \tag{1}$$

Where x_k is the transmitted symbol of user k, s_k is the spreading sequence of user k, g_k is the channel gain of user k, and z is a complex-valued noise taken from a zero mean Gaussian distribution with variance σ^2.

The received signal can be rewritten by vector as:

$$r = Hx + z \tag{2}$$

Where $r = (r_1, r_2, \cdots, r_N)^T$, $x = (x_1, x_2, \cdots, x_K)^T$, $z = (z_1, z_2, \cdots, z_N)^T$, $z \sim \mathcal{CN}(0, \sigma^2 I)$. H is the channel matrix, and h_k in the kth column of H is equal to $g_k s_k$. At the receiving end, MMSE-SIC receiver is used to demodulate and recover the data of each user from the superimposed symbols.

3. Multi-user Detection Algorithm
3.1. MMSE-SIC Detection Algorithm
The MMSE-SIC algorithm is based on the scheme of successive processing, which eliminates inter-interference step by step, and each step only detects one user. Therefore, if there are K users in the system, there should be K time's detections. Figure 2 shows the structure of the MMSE-SIC.

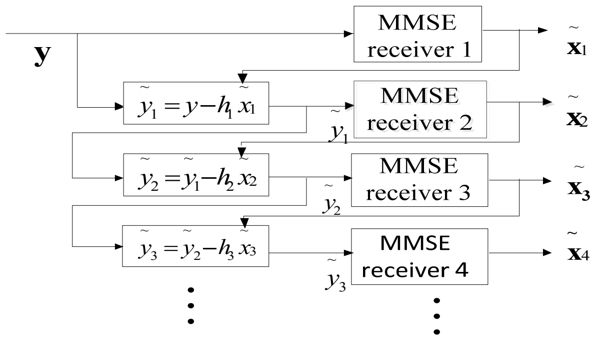

Figure 2. MMSE-SIC Structure

The main steps of the MMSE-SIC algorithm are as follows:
Step 1: Initialization

$$i = 1, r_1 = r, H_1 = H$$
$$G = (H^{\mathrm{H}} H + \sigma^2 I)^{-1} H^{\mathrm{H}}$$

Step 2: SIC

For i=1: K
Ordering: $k_i = \arg\max_{j \notin \{k_1, \cdots, k_{i-1}\}} (SINR_j)$

Nulling vector: $\omega_{k_i} = (G)_{k_i}$

Nulling: $y_{k_i} = \omega_{k_i} r_i$

Hard decision: $\tilde{x}_{k_i} = Q(y_{k_i})$

SIC: $r_{i+1} = r_i - (H)_{k_i} \tilde{x}_{k_i}$

Update the channel matrix: $r_{i+1} = r_i - (H)_{k_i} \tilde{x}_{k_i}$

Calculate the weight matrix: $G_{i+1} = (H_{i+1}{}^{\mathrm{H}} H_{i+1} + \sigma^2 I)^{-1} H_{i+1}{}^{\mathrm{H}}$

End

Where Q(.) and I respectively denote the quantization (slicing) operation and identity matrix, $H_{\bar{k}_i}$ denotes the matrix generated by deleting the k-th column of H. $(H)_k$ denotes the k-column of H. $\|H\|$ denotes the Frobenius norm of matrix H.

The SINR is given by:

$$SINR_i = \frac{\|G_i h_i\|^2}{\sum_{l \neq i} \|G_i h_l\|^2 + \sigma^2 \|G_i\|^2}$$

There will be K time's matrix inversion and K-1 times ordering and when there are K users in the system, therefore, the complexity is high and the delay is large. As for the demands of massive connection of 5G, those will be worse.

3.2. Proposed Algorithm

The proposed MPPIC algorithm mainly adapts two stages MMSE-PIC construction instead of MMSE-SIC because of consideration of complexity and processing delay. Compared with traditional MMSE-PIC, proposed algorithm divide first stage detected users into two groups, stronger users will be outputs and weaker users will be passed to next stage detection. In general, users are sorted in ascend order according to their channel states, then MMSE-PIC algorithm is adopted in the first-stage detection. Interference of all users will be reconstructed according to the outputs of the first-stage detection and the channel estimation, and then the bits of these stronger users will be outputted. Final, the remaining users are detected again with the MMSE-PIC algorithm. Figure 3 presents the schematic diagram of the proposed algorithm.

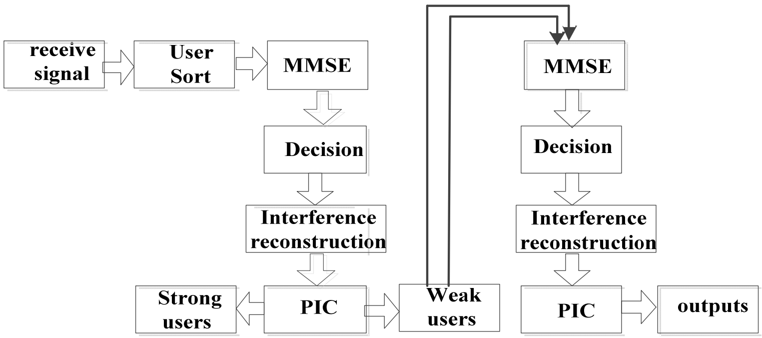

Figure 3. The Schematic Diagram of the Proposed Algorithm

The main steps of the two-stage partial parallel interference cancellation algorithm are as follows:

Step 1: Initialization

$$G = (H^{H} H + \sigma^2 I)^{-1} H^{H} \quad \text{(MMSE)}$$

$$\tilde{x} = Gr = [\tilde{x}_1(0), ..., \tilde{x}_K(0)]$$

Ordering: $k_i = \arg\max \|H_i\|$

Step 2: the first-stage PIC

For k=1: K

$$\hat{x}_k = [\tilde{x}_1(0), \cdots, \tilde{x}_{k-1}(0), 0, \tilde{x}_{k+1}(0), \cdots, \tilde{x}_K(0)]$$

PIC: $r_k = r - H\hat{x}_k$

Hard Decision: $\tilde{x}_k(1) = Q(H_k r_k)$

End

Step 3: the second-stage PIC

According to the ordering, users with larger $\|H_i\|$ will be outputted.

The remaining users will be detected again with PIC algorithm.

The number of matrix inversion and user ordering is significantly reduced when compared with MMSE-SIC algorithm, especially when the number of users is large. In addition, as the PIC detector [12] adopts the interference cancellation in parallel, and the influence caused by the others users is always existed, which affects the performance of the system. While the proposed algorithm outputs the stronger users in the first stage, which in return reduce the MAI of the weaker users in the second stage.

The proposed algorithm is similar to the traditional detection algorithm, two-stage MMSE-PIC []. However, the main difference is that the proposed algorithm outputs the stronger users in the first detection stage, which reduce the MAI of the weaker users in the second detection. While the traditional two-stage MMSE-PIC does not output signals in the first stage, and the MAI which is caused by these stronger users has a large influence on these weaker users. In addition, the influence is always existed, thus the weaker users will suffer large MAI in the second detection. Therefore, there will be performance loss when using the traditional two-stage MMSE-PIC algorithm. What's more, as the stronger users are outputted in the first stage, which in return reduce the complexity of the proposed algorithm.

4. Performance and Complexity Analysis

In this section, the performance and complexity of the proposed algorithm are discussed. For convenience, the proposed algorithm is labeled as MPPIC. Simulation parameters are as shown in Table 1. The length of spreading codes is N, and the number of users is K.

4.1. Performance Analysis

In this subsection, the symbol error rate (SER) performance of the proposed algorithm, two-stage MMSE-PIC and MMSE-SIC algorithm is compared. Figure 4 and Figure 5 show the SER performance results of the three algorithms with different number of users and different length of spreading codes. The others parameters are shown in Table 1.

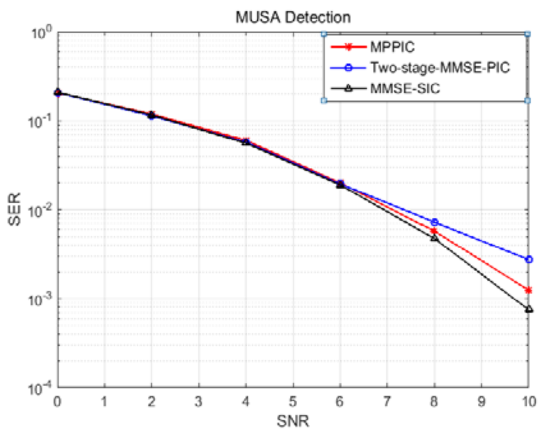

Figure 4. SER Performance of the three Algorithm for N=8, K=4

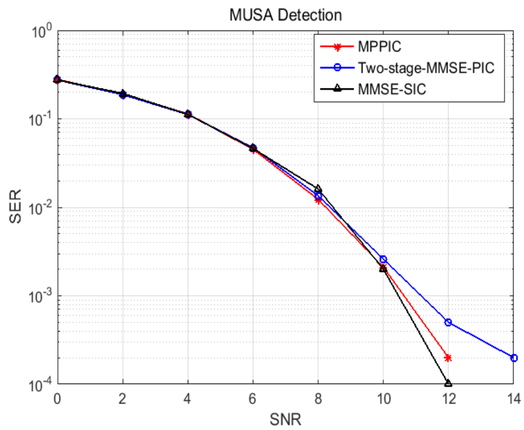

Figure 5. SER Performance of the Three Algorithm for N=16, K=10

Table1. Simulation Parameters

Parameters	Value
N	8,16
K	4,10
Channel model	Rayleigh fading channel
Channel Estimation	Ideal
SNR	0-14dB
Modulation	QPSK

As are shown in Figure 4 and Figure 5, the SER performance of the MPPIC algorithm is comparable to the MMSE-SIC, but it is better than that of the two-stage MMSE-PIC, with the change of K and N, which is due to the received signal through the MMSE detector first, and the MMSE detector makes a compromise between noise and MAI. What's more, the stronger users have been outputted in the first detection stage, which reduce the MAI of the weaker users in the second stage. Thus, the weaker users have more accurate detection, which in return improves the system performance.

4.2. Complexity Analysis

The complexity of the three algorithms is analyzed in this subsection, we consider all complex multiplications/divisions and complex additions/subtractions and use floating point operation (flop) as unit to measure complexity. One multiplication and one addition respectively correspond to 6 flops and 2 flops [13].

For a $m \times n$ channel matrix, the calculation of the weight matrix of MMSE requires $5/2\,n^2 m - n^2 + mn$ multiplications and $5/2\,n^2 m - 3/2\,n^2 - 2mn + 3/2\,n$ additions [14].

Table 2. Comparison of the Complexity

	Algorithm	Multiplications	Additions	Flops
K=4 N=8	MMSE-SIC	1106	804	8244
	Two-stage MMSE-PIC	800	596	5992
	MPPIC	620	453	4626
K=10 N=16	MMSE-SIC	24393	21090	188538
	Two-stage MMSE-PIC	8760	7710	67980
	MPPIC	6075	5264	46978

Table 2 shows the complexity of the three algorithms with different N and K. The MMSE-SIC has the highest complexity and the proposed algorithm has the lowest complexity. The complexity of the MMSE-SIC increases sharply with the increase of N and K, while the complexity of the MPPIC is increased relatively slow.

As the MMSE-SIC algorithm involves K-1 times ordering and K times matrix inversion when there are K users access to the system, while the proposed algorithm only requires once ordering and two times matrix inversion , and the matrix inversion has a large complexity. What's more, stronger users are outputted in the first detection stage, which reduce the complexity when compared with that of the two-stage MMSE-PIC. Therefore, MMSE-SIC has the largest complexity, while the proposed algorithm has the lowest complexity, especially when the number of access users is large in the massive connection scenario of 5G.

5. Conclusion

In this paper, a multi-stage partial parallel interference cancellation multiuser detection algorithm, MPPIC, is proposed for MUSA systems. It requires less matrix inversion and users ordering when compared with MMSE-SIC algorithm, which can achieve near MMSE-SIC performance while the complexity is significantly reduced, especially in the massive connections scenario of the fifth generation mobile communication, when the number of users and the length of the spreading codes are large. In addition, the SER performance and its complexity of the MPPIC algorithm are better than that of the two-stage MMSE PIC algorithm. As the proposed algorithm adopts the PIC structure, the complexity is low. What's more, the stronger users are outputted in the first stage detection, which benefits the weaker users in the second stage as the weaker users suffer less MAI. Therefore, it can guarantee the detection performance and keep a low complexity.

Acknowledgements

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