A scheduling scheme based on the SLNR criterion

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***Abstract*—In multiuser MIMO downlink link, maximizing signal to leakage and noise ratio (SLNR) is a good criterion for the design of precoders. In this text, we consider a user scheduling scheme based on this novel criterion. By replacing the WORST user with a Better one again and again according to the proposed updating scheme, we can keep the minimum SLNR of the scheduling users set as large as possible. Simulation results show that the proposed scheme can improve the system performance dramatically.**

Keywords-MU-MIMO; user scheduling; SLNR; generalized eigenvalue problem

I. INTRODUCTION

Recently, the multiuser multiple-input-multiple-output (MU-MIMO) technology has attracted enormous interest for the next-generation wireless communications due to its advantage in spectrum-efficiency and capacity [1]. In MU-MIMO downlink communications, a base station communicates with several co-channel users in the same frequency and time slots. Therefore, the co-channel interference (CCI) arises at the user side. In order to suppress CCI, the maximal SLNR precoder is proposed because it realizes a good trade-off between the performance and complexity [2]-[3].

On the other hand, if the channel state information (CSI) is available at the base station (CSI-T), some gains can be achieved by a user scheduling scheme. Some prior research works have proposed scheduling schemes on the basis of channel direction information (CDI), sum capacity and so on [4]-[6]. To the best of our knowledge, little attention has been paid on the user scheduling based on the SLNR criterion. Thus, in this text we will consider a user scheduling scheme based on this novel criterion. Due to the object of the SLNR criterion is to maximize SLNR of each user, selecting the users set so that its minimum SLNR is large enough is a reasonable strategy to achieve performance gain. The above proposed scheme is confirmed in this text by simulation results.

This text is organized as follows: Section II describes the MU-MIMO system model. The SLNR criterion is reviewed in Section Ⅲ. Section Ⅳ presents the new user scheduling scheme. Simulation results are shown in Section Ⅴ. The final Section is conclusion.

II. SYSTEM MODEL

Consider a multiuser downlink environment with a base station communicating with K users simultaneously. The base station employs N transmit antennas and user i is equipped with M_i receive antennas. A block diagram of the system is shown in Figure 1.

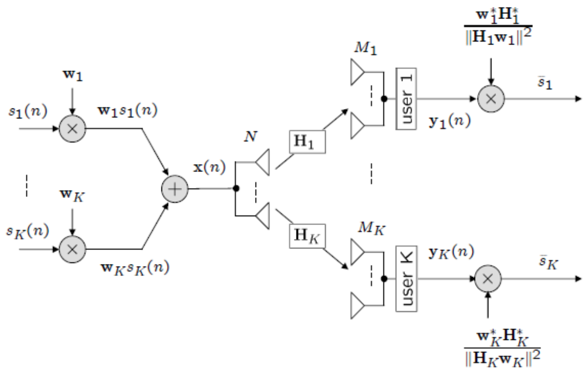

Fig.1 A block diagram of a MU-MIMO system

Assuming a narrow-band channel which means frequency flat fading for each user, the $M_i \times N$ channel matrix $\mathbf{H}_i$ of user i can be written as

$$\mathbf{H}_i = \begin{bmatrix} h_i^{(1,1)} & \cdots & h_i^{(1,N)} \\ \vdots & \cdots & \vdots \\ h_i^{(M_i,1)} & \cdots & h_i^{(M_i,N)} \end{bmatrix}, \quad 1 \le i \le K \tag{1}$$

where $h_i^{(m,n)}$ is the fading coefficient between the n th transmit antenna and the m th receive antenna of user i. In this text, $h_i^{(m,n)}$ is assumed to be independent and identically distributed (i.i.d) circularly symmetric complex Gaussian variable with zero-mean and unit-variance. Furthermore, the additive noise vector is assumed to have independent complex Gaussian elements with variance σ^2 and is spatially and temporarily white. This model can also be applied to the frequency selective fading case using OFDM.

We assume that the channel matrices $\mathbf{H}_i$,$1 \le i \le K$, are available both at the base station and the corresponding receiver i, but are not known by the other users. And the channel is assumed to be slow-fading which means that the

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channel coefficients are constant during a block of symbols periods, and then change independently from block to block.

III. THE OVERVIEW OF SLNR CRITERION

For notational simplicity we drop the time index n and the received signal of user i can be denoted as

$$\mathbf{y}_i = \mathbf{H}_i \mathbf{w}_i s_i + \mathbf{H}_i \sum_{k=1,k\neq i}^{K} \mathbf{w}_k s_k + \mathbf{v}_i \quad (2)$$

where s_i is the data stream and $\mathbf{w}_i$ the precoding vector for user i. In (2), the second term is the co-channel interference (CCI). It is therefore necessary to rely on the transmission scheme to suppress CCI in MU-MIMO system. In the multiuser case, several works have proposed schemes for CCI cancellation. There exist two main criterions which are named SINR (signal to interference and noise ratio) [7] and ZF (zero-forcing) [8] respectively. The solution for SINR criterion can only be obtained iteratively due to the coupled nature of the corresponding optimization problem. And the computational complexity usually makes it hard to implement in practice. The ZF criterion can completely cancel the CCI for each user. However, this criterion imposes a restriction on the system configuration in terms of the number of antennas. What's more, the ZF criterion can result in noise enhancement. Therefore, these two criterions are not good enough. To circumvent this problem, a novel criterion named SLNR (signal to leakage and noise ratio) is introduced in [2]. Start from (2) and note that the power of the interference that is caused by user i on the signal received by some other user k is given by $\|\mathbf{H}_k \mathbf{w}_i\|^2$. Thus, the leakage of user i, as the total power leaked from this user to all other users, can be denoted by $\sum_{k=1,k\neq i}^{K} \|\mathbf{H}_k \mathbf{w}_i\|^2$. Based on this novel concept, the SLNR criterion is defined as

$$\max \ SLNR_i = \frac{\|\mathbf{H}_i \mathbf{w}_i\|^2}{R\sigma^2 + \sum_{k=1,k\neq i}^{K} \|\mathbf{H}_k \mathbf{w}_i\|^2} \quad (3)$$

$$subject\ to\ \|\mathbf{w}_i^o\|^2 = 1, 1 \le i \le K$$

As presented in (3), the SLNR criterion circumvents the coupled difficulty encountered in SINR criterion because all the $SLNR_i, 1 \le i \le K$, are independent with respect to the precoding vectors $\mathbf{w}_i, 1 \le i \le K$. We can obtain the solution for SLNR criterion by generalized Rayleigh quotient. It has been shown in [2] that the solution of (3) is given by

$$\mathbf{w}_i^o \propto \max.\ \mathrm{eigenvector}\left[\left(R\sigma^2\mathbf{I} + \sum_{k=1,k\neq i}^{K} \mathbf{H}_k^H \mathbf{H}_k\right)^{-1} \mathbf{H}_i^H \mathbf{H}_i\right] (4)$$

in terms of the eigenvector corresponding to the largest eigenvalue of the matrix $\left(R\sigma^2\mathbf{I} + \sum_{k=1,k\neq i}^{K} \mathbf{H}_k^H \mathbf{H}_k\right)^{-1} \mathbf{H}_i^H \mathbf{H}_i$. Here, $[\cdot]^H$ denotes the conjugate transposition. The norm of $\mathbf{w}_i^o$ is adjusted to $\|\mathbf{w}_i^o\|^2 = 1$. Research works [2]-[3] have shown that the SLNR solution always outperforms the ZF solution even when the dimension requirement of the latter is satisfied. Therefore, in this text the maximal SLNR precoder is assumed to be applied to the system.

IV. THE PROPOSED USER SCHEDULING SCHEME

In this Section we will give our proposed user scheduling scheme based on the SLNR criterion. In other words, we will describe how to choose the subset of users at each time slot so that those users in this subset can exploit the available resource more efficiently. Since the maximal SLNR precoder aims to maximize SLNR of each user, how to utilize the information of SLNR is the key of our user scheduling scheme.

Suppose that the amount of users who are waiting for being scheduled is Kall and only K users will be selected from it to be served simultaneously at each time slot. It is obvious that the optimal user scheduling scheme is to enumerate all the combinations of users and then select the optimal one for scheduling. However, the combination number becomes rather large as Kall increases. Thus, we have to consider a suboptimal scheme. By intuition, we can optimize the scheduling set step by step from an initialization one. Hence, the first question is how to initialize this set. The Frobenius norm of the channel vector is a merit of the channel quality. Therefore, the initialization of the scheduling set can be based on the channel norm. Then, we update this set by replacing the undesirable user in it with a desirable one in the awaiting queue as long as this replacement can improve the minimum SLNR of the scheduling set. Now we present the specific user scheduling scheme in Table 1 at the top of the next page.

In the proposed scheme, by replacing the WORST user with a BETTER one again and again according to the updating strategy, we can keep the minimum SLNR of the scheduling users set as large as possible. Thus we call it MM-SLNR (Max-min SLNR) scheme. To guarantee that the times of update in this scheme is acceptable, we restrict that the maximal times of replacement round is Q. The parameter Q will be specified in next. Recall that the computation of SLNR in (3) is to compute the largest eigenvalue, so some fast algorithms such as power method can be adopted [9].

V. SIMULATION RESULTS

We will examine the performance of the MM-SLNR scheme in contrast to the Round-Robin method (where all the users are scheduled by turns) and the MaxH method (where the K users whose channel norms are larger are always scheduled). In simulation, each user is assumed to be equipped with one antenna. All simulations are conducted using a QPSK modulation and the results are averaged over 10000 channel realizations for the BER curves. Every channel realization during which the channel coefficients keep constant includes 200 symbol periods. The noise variance per receive antenna is σ^2, and the BER curves are plotted versus $1/\sigma^2$ as the SNR:

Table.1 Max-min SLNR user scheduling scheme

Initialization of the algorithm:

Initialization 1: Sort all the users according to their channel norms from large to small and pick out the first K ones as the initialization set of scheduled users (denote this set by B), and the sorted un-scheduling users set is denoted by queue C;

Initialization 2: Set the maximal times of replacement round Q;

Initialization 3: Compute the SLNR of each user in set B according to (3) and then pick up the user whose SLNR is the minimum (denote this user and its SLNR by u_d and $SLNR_{old}$ respectively);

Scheduling algorithm:

For index=1:1:Q

  Step 1: Replace the user u_d with the front of queue C, and delete the front of queue C;

  Step 2: Re-compute the minimum SLNR of the updated set B (denote this user and its SLNR by u_e and $SLNR_{new}$ respectively);

  Step 3: If $SLNR_{new} > SLNR_{old}$

    Substep 1: Accept the replacement in step 1, and update u_d and $SLNR_{old}$ with u_e and $SLNR_{new}$ respectively, i.e., $u_d \leftarrow u_e$ and $SLNR_{old} \leftarrow SLNR_{new}$;

    Substep 2: Update the queue C to all the un-scheduled users according to their channel norms from large to small;

  Else

    Substep 1: Reject the replacement in step 1;

      If queue C is not empty

        Go to Step 1;

      Else

        Break;

      Endif

  Endif

End

$1/\sigma^2$ functions as the SNR per receive antenna since the channel and precoding coefficients are all normalized. Similar to the expression (38) in [2], the matched filter is adopted in this text at each receiver.

The simulation results demonstrate that the MM-SLNR scheme always outperforms the Round-Robin and MaxH methods, especially in high SNR region. This result is reasonable. When SNR is low, the noise effect is dominant. However, in high SNR region, the interference is overwhelming. The MM-SLNR outperforms the other two considerably since it can find out the better combination of users to reduce the interference.

When Kall is large, we can pre-select the first 3K users out of all according to their channel norms as the candidates for scheduling to further reduce the computational burden. This scheme is marked with the simplified MM-SLNR curve in the simulation. According to the figures, a trade-off between the performance and computational burden is realized. Last but not least, by numerical simulation, the average value of the parameter Q in Section IV for algorithm convergence is not more than K when Kall is set to different value. From this point, we can conclude that the times of replacement round are acceptable in practice. As demonstrated in Fig.4 and Fig.5, the simplified MM-SLNR algorithm can reduce the computational burden dramatically at the expense of the minor loss of BER in high SNR region.

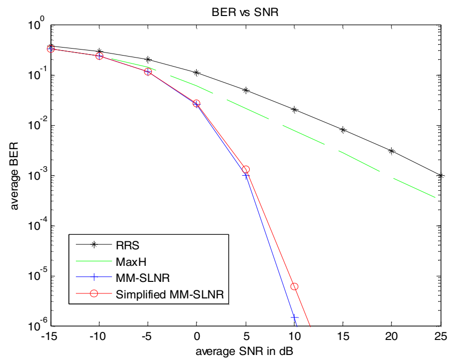

Fig.2 BER of N=4, K=4 and Kall=25

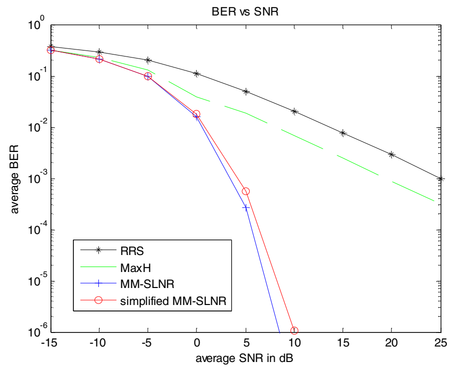

Fig.3 BER of N=4, K=4 and Kall=50

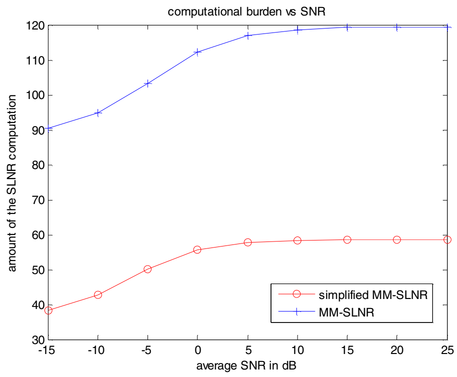

Fig.4 Computation times of N=4, K=4 and Kall=25

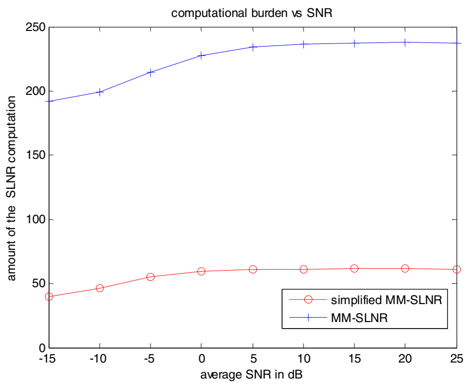

Fig.5 Computation times of N=4, K=4 and Kall=50

VI. CONCLUSION

In this text, a user scheduling scheme based on the novel SLNR criterion has been presented. The users are selected to guarantee that the minimum SLNR is large enough. The computation of SLNR is just a generalized eigenvalue problem which is easy to implement in practice. The initialization and updating strategy of the user scheduling set is proposed based on the SLNR information. This scheme is called MM-SLNR scheme. It is shown that the proposed scheme considerably outperforms the traditional cases, especially in high SNR region. The computational burden is also considered and the simplified MM-SLNR scheme has been proposed to realize a trade-off between the performance and computational burden.

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