User Scheduling for Large-Scale MIMO Downlink System Over Correlated Rician Fading Channels

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Abstract. In this paper, we investigate the downlink transmission, especially the user scheduling algorithm for single-cell multiple-input multiple-output (MIMO) system under correlated Rician fading channels. Under the assumption of only statistical channel state information (CSI) at the base station (BS), the statistical beamforming transmission is derived by maximizing the lower bound of the average signal-to-leakage-plus-noise ratio (SLNR). Based on this beamforming transmission algorithm, three user scheduling algorithms are proposed exploiting only statistical CSI: (1) maximum SLNR: schedule the user with the maximum SLNR; (2) most dissimilar: schedule the user that is most dissimilar to the already selected users; (3) modified-treating interference as noise (TIN): treat the inter-user interference as uncorrelated noise to each user's useful signal and schedule the user with the largest signal-to-noise factor. Simulation results show that the proposed user scheduling algorithms perform well in achieving considerable sum rate.

Keywords: User scheduling · Rician fading · Downlink

1 Introduction

In recent years, massive multiple-input multiple-output (MIMO) has been recognized as one of the key techniques in future wireless communication systems [1] due to its channel-hardening effect and high potential in interference mitigation [2]. Scaling up the number of antennas in practice, however, faces several challenges. As point out in [1], the acquisition of the channel state information (CSI) at the BS is difficult. Most cellular systems today are in frequency-division duplexing (FDD) mode [3], where the BS gets access to the CSI through a feedback channel. Obviously, the instantaneous CSI feedback causes great overhead in the feedback link for transmission and scheduling algorithms as the number of antennas at the BS grows large. An alternative approach is to exploit the statistical information of the channel [4,5], which varies at a much slower rate

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and can be accurately obtained through long-term feedback. In [4], a two-stage precoding algorithm exploring both statistical and part of instantaneous CSI was proposed under Rayleigh fading channels. Moreover, the corresponding user scheduling algorithm was investigated in [6].

Note that most prior works on massive MIMO adopt the simple Rayleigh fading channel model, although this channel model assumption greatly simplifies the analysis, it can not capture the characteristics of the line-of-sight (LOS) component between the transmitter and the receiver. This is especially the case in millimeter-wave communication systems [7] in which LOS propagation dominates. Therefore it is of great importance to consider the more general fading channels which take into account the LOS conditions, i.e., Rician fading channels [8]. The work in [10] investigates the downlink transmission and scheduling algorithm for full-dimension (FD) MIMO systems under uncorrelated Rician fading channels. In reality, correlation effects should be considered due to the space limitation of user equipments (UEs), the antenna configurations and the Doppler spread [11]. Under the assumption of the same correlation matrix for all users, [9] investigates the ergodic sum rate of downlink massive MIMO system with perfect CSI at BS.

Motivated by the above observations, in this paper, we consider a single-cell multiuser downlink transmission system under the more general correlated Rician fading channel. With only statistical CSI at BS, the statistical beamforming algorithm proposed under Rayleigh and uncorrelated Rician fading is extended to the correlated Rician fading channel by maximizing the lower bound on the average signal-to-leakage-plus-noise ratio (SLNR). Based on the beamforming algorithm, three user scheduling algorithms are proposed, which are the maximum SLNR, the most dissimilar, and the modified-treating interference as noise (TIN). Simulation results reveal that the proposed algorithms perform well in terms of the achievable sum rate.

2 System Model

We consider a single-cell MIMO downlink transmission system with L single-antenna user terminals. A uniform linear array with M antenna elements is employed at the BS. The distances between two neighboring antenna elements is $\lambda/2$, where λ is the wavelength of the carrier. The BS can serve at most U users.

2.1 Signal Model

Assume that a total of U_t ($U_t \leq U$) users are scheduled. The received signal at user u can be expressed as

$$y_u = \sqrt{p_u}\mathbf{h}_u^T\mathbf{w}_u x_u + \sum\nolimits_{i=1, i\neq u}^{U_t} \sqrt{p_i}\mathbf{h}_u^T\mathbf{w}_i x_i + n_u, \tag{1}$$

where $\mathbf{h}_u^T \in \mathbb{C}^{1\times M}$ represents the channel vector between the BS and user u, $\mathbf{w}_i \in \mathbb{C}^{M\times 1}$ is the unit-norm beamforming vector of user i, x_i is the data symbol for user i satisfying $\mathrm{E}\{|x_i|^2\} = 1$, $n_u \sim CN(0, \sigma_u^2)$ is the complex additive white Gaussian noise, p_i is transmit power for user i with total power constraint $\sum_{i=1}^{U_t} p_i \leq P$. In this paper, we assume equal power allocation among the scheduled users, i.e., $p_i = P/U_t$.

2.2 Channel Model

We consider the correlated Rician fading channel model. Under this model, the channel vector $\mathbf{h}_u$ consists of a specular component corresponding to the LOS signal and a Rayleigh-distributed random component accounting for the diffused multipath signals. The channel vector $\mathbf{h}_u$ between the BS and user u can be written as

$$\mathbf{h}_u^T = \sqrt{\frac{K_u}{K_u+1}}\overline{\mathbf{h}}_u^T + \sqrt{\frac{1}{K_u+1}}\mathbf{h}_{w,u}^T \mathbf{R}_u^{1/2}, \tag{2}$$

where $\overline{\mathbf{h}}_u \in \mathbb{C}^{M\times 1}$ is the deterministic component, K_u is the ratio between the LOS and non-LOS channel power, the entries of $\mathbf{h}_{w,u} \in \mathbb{C}^{M\times 1}$ are independent and identically distributed (i.i.d.) complex Gaussian random variables (RVs) with zero mean and unit variance, and $\mathbf{R}_u \in \mathbb{C}^{M\times M}$ is the transmit channel correlation matrix. For the considered uniform linear array (ULA), the deterministic component $\overline{\mathbf{h}}_u$ of user u can be given by [12]

$$\overline{\mathbf{h}}_u = \left[1, e^{-j\pi \sin\theta_u}, \cdots, e^{-j\pi(M-1)\sin\theta_u}\right]^T, \tag{3}$$

where θ is the angle of departure (AoD) of user u. For the transmit correlation, we consider the one-ring scattering model [4] to determine $\mathbf{R}_u$.

We assume that each user has perfect effective CSI of its own, while the BS has only statistical CSI of all users, i.e., K_u, σ_u^2, $\overline{\mathbf{h}}_u$, $\mathbf{R}_u$, which are calculated by the user via a long-term statistics and are obtained by the BS through long-term feedback.

3 Downlink Transmission

Under the assumption of only statistical CSI at BS, it is difficult to get simple analytical optimization result directly maximizing the ergodic sum rate with respect to $\mathbf{w}_i$, $i = 1, \cdots, U_t$, due to the lack of analytical expression of the ergodic sum rate. Inspired by [14], here, we use the average SLNR metric. In the following, we first derive a lower bound of the average SLNR and then derive the beamforming transmission algorithm by maximizing the lower bound.

The SLNR of user u which measures the amount of power leaked from its beamforming direction to other users' channel direction, can be given by

$$\mathrm{SLNR}_u = \frac{\frac{P}{U_t}\left|\mathbf{h}_u^T \mathbf{w}_u\right|^2}{\sigma_u^2 + \frac{P}{U_t}\sum_{i=1,i\neq u}^{U_t}\left|\mathbf{h}_i^T \mathbf{w}_u\right|^2}. \tag{4}$$

Note that the numerator and denominator of (4) are independent. Based on Mullen's inequality [13], i.e., $\mathrm{E}\{X/Y\} \geq \mathrm{E}\{X\}/\mathrm{E}\{Y\}$ if X and Y are independent random variables, we can obtain that

$$\mathrm{E}\{\mathrm{SLNR}_u\} \geq \mathrm{SLNR}_u^L = \frac{\frac{P}{U_t}\mathbf{w}_u^\dagger \mathrm{E}\left\{\mathbf{h}_u^* \mathbf{h}_u^T\right\}\mathbf{w}_u}{\sigma_u^2 + \frac{P}{U_t}\sum_{i=1, i\neq u}^{U_t} \mathbf{w}_u^\dagger \mathrm{E}\left\{\mathbf{h}_i^* \mathbf{h}_i^T\right\}\mathbf{w}_u}. \tag{5}$$

From (1), we can get that

$$\mathrm{E}\{\mathbf{h}_i^* \mathbf{h}_i^T\} = \frac{1}{K_i+1}\mathbf{R}_i + \frac{K_i}{K_i+1}\overline{\mathbf{h}}_i^* \overline{\mathbf{h}}_i^T, \qquad i = 1, \cdots, U_t. \tag{6}$$

Substituting (6) into (5), and after some manipulation, we have

$$\mathrm{SLNR}_u^L = \frac{\mathbf{w}_u^\dagger \left(\frac{1}{K_u+1}\mathbf{R}_u + \frac{K_u}{K_u+1}\overline{\mathbf{h}}_u^* \overline{\mathbf{h}}_u^T\right)\mathbf{w}_u}{\sigma_u^2 + \frac{P}{U_t}\sum_{i=1, i\neq u}^{U_t} \mathbf{w}_u^\dagger \left(\frac{1}{K_i+1}\mathbf{R}_i + \frac{K_i}{K_i+1}\overline{\mathbf{h}}_i^* \overline{\mathbf{h}}_i^T\right)\mathbf{w}_u}. \tag{7}$$

Let us define

$$\mathbf{\Lambda}_u = \mathbf{F}_M^\dagger \mathbf{R}_u \mathbf{F}_M, \tag{8}$$

and

$$\mathbf{A}_u = \mathbf{F}_M^\dagger \overline{\mathbf{h}}_u^* \overline{\mathbf{h}}_u^T \mathbf{F}_M, \tag{9}$$

where $\mathbf{F}_M \in \mathbb{C}^{M\times M}$ is unitary DFT matrix, with the (i,j)-th element $[\mathbf{F}_M]_{i,j} = \frac{1}{\sqrt{M}} e^{-j\frac{2\pi}{M}(i-1)(j-1-M/2)}$, $i, j = 1, \cdots, M$.

According to [4], for ULA of large dimension, $\mathbf{\Lambda}_u$ becomes diagonal matrix with a few adjacent non-zero diagonal elements [14], i.e.,

$$\mathbf{\Lambda}_u = \mathrm{diag}\left\{0, \cdots, 0, \overbrace{\lambda_u^{(k_1)}, \cdots, \lambda_u^{(k_2)}}^{\text{nonzero}}, 0, \cdots, 0\right\}, \tag{10}$$

where $\lambda_u^{(k)}$, $k \in [k_1, k_2]$ denotes the k-th diagonal element of $\mathbf{\Lambda}_u$. In [10], it was shown that for ULA of large dimension, $\mathbf{A}_u$ is a diagonal matrix with only one non-zero diagonal element, i.e.,

$$\mathbf{A}_u = \mathrm{diag}\left\{0, \cdots, 0, a_u^{(j_0)}, 0, \cdots, 0\right\}, \tag{11}$$

where $a_u^{(j_0)}$ denotes the j_0-th diagonal element of $\mathbf{A}_u$.

Based on these results, we have that when $M \to \infty$,

$$\mathrm{SLNR}_u^L = \frac{\frac{P}{U_t}\mathbf{w}_u^\dagger \mathbf{F}_M \mathbf{\Omega}_u \mathbf{F}_M^\dagger \mathbf{w}_u}{\sigma_u^2 + \frac{P}{U_t}\sum_{i=1, i\neq u}^{U_t} \mathbf{w}_u^\dagger \mathbf{F}_M \mathbf{\Omega}_i \mathbf{F}_M^\dagger \mathbf{w}_u}. \tag{12}$$

where $\mathbf{\Omega}_i = \frac{1}{K_i+1}\mathbf{\Lambda}_i + \frac{K_i}{K_i+1}\mathbf{A}_i$, $i = 1, \cdots, U_t$. Then, when $M \to \infty$, SLNR_u^L can be upper bound as

$$\mathrm{SLNR}_u^L \leq \frac{\frac{P}{U_t}\omega_u^{\max}}{\sigma_u^2 + \frac{P}{U_t}\sum_{i=1, i\neq u}^{U_t} \omega_i^{\min}}, \tag{13}$$

where $\omega_u^{\max}$ is the maximum diagonal element of $\mathbf{\Omega}_u$, and $\omega_i^{\min}$ is the minimum diagonal element of $\mathbf{\Omega}_i$. Assuming that the largest diagonal element of $\mathbf{\Omega}_u$ is the $\overline{m}_u$-th diagonal element. It can be seen that the upper bound in (13) can be achieved if and only if the beamforming vector is given by

$$\mathbf{w}_u = (\mathbf{F}_M)_{\overline{m}_u}, \tag{14}$$

and the $\overline{m}_u$-th diagonal element of $\mathbf{\Omega}_i$, $i \neq u$ is its minimum diagonal element which is zero, where $(\mathbf{X})_i$ denotes the i-th column of matrix $\mathbf{X}$. Therefore, to maximize the lower bound of the average SLNR, the BS should transmit to the user with beamforming vector (14) and the scheduled users should satisfy that the maximum diagonal element of $\mathbf{\Omega}_u$ is orthogonal to the non-zero diagonal element of $\mathbf{\Omega}_i$.

When $K_u = 0$, the channel becomes Raleigh fading channel. In this case, $\overline{m}_u$ in (14) reduces to the index of the largest diagonal element of $\mathbf{\Lambda}_u$. When $\mathbf{\Lambda}_u = \mathbf{I}_M$, the channel becomes uncorrelated Rician fading channel. In this case, $\overline{m}_u$ reduces to the index of the largest diagonal element of $\mathbf{A}_u$. These are consistent with result in [14] and [10] when 2D antenna array reduces to ULA. Therefore, in this paper, we employ the beamforming vector (14) for scheduled user u. However, the constraint that for $u \neq i$, the maximum diagonal element of $\mathbf{\Omega}_u$ should be orthogonal to the non-zero diagonal element of $\mathbf{\Omega}_i$ is too strict. In the next section, we will discuss the scheduling algorithm for the system we considered.

4 User Scheduling Algorithms

Based on the previous statistical beamforming algorithm, in this section, we focus on the user scheduling algorithm exploiting only statistical CSI under correlated Rician fading channel. Three user scheduling algorithms are proposed, which are the maximum SLNR, the most dissimilar and the modified-TIN.

4.1 Maximum SLNR

In the previous section, we get the statistical beamforming method by maximizing the SLNR lower bound. In the following user scheduling algorithm, we also consider the maximization of the SLNR lower bound. To achieve high sum rate, we would like that the SLNR of the selected user won't decrease much due to the power leaked to the candidate user's channel direction, while the candidate user could have high SLNR.

Based on the derived beamforming vector, and after some manipulation, we get

$$\mathrm{SLNR}_u^L = \frac{\omega_u^{(\overline{m}_u)}}{\sum_{i=1,i\neq u}^{U_t} \omega_i^{(\overline{m}_u)} + \frac{U_t \sigma_u^2}{P}}, \tag{15}$$

where $\omega_i^{(j)}$ denotes the j-th diagonal element of matrix $\mathbf{\Omega}_i$, $i = 1, \cdots, U_t$. Let's rewrite (15) as

$$\mathrm{SLNR}_u^L = \frac{1}{\sum_{i=1,i\neq u}^{U_t} r_{u,i}^{-1}}, \tag{16}$$

where

$$r_{u,i} = \frac{\omega_u^{(\overline{m}_u)}}{\omega_i^{(\overline{m}_u)} + \frac{\sigma_u^2 U_t}{P(U_t-1)}}. \tag{17}$$

It can be seen that lower bound (16) increases as $r_{u,i}$ increases. Define Q to be the set of already selected users and Ξ to be the set of unselected users. To make sure that the SLNR of the selected user u won't decrease much due to the candidate user i, and SLNR of the candidate user could be high, we would like that the minimum of $r_{i,u}$ and $r_{u,i}$ is as large as possible. Therefore, in this algorithm, we schedule the user with the largest

$$R_i = \min\left(\min_{u\in Q} r_{i,u}, \min_{u\in Q} r_{u,i}\right), \qquad i \in \Xi, \tag{18}$$

among the candidate users.

Based on the above analysis, we propose the following user scheduling algorithm. Firstly initialize Q to be empty. Select the user that can achieve the largest R_i, $i \in \Xi$. Since no user has been selected, that is to select the user with the largest $\omega_i^{(\overline{m}_i)}$. Add it into the set of selected users Q, and remove it from Ξ. Next, add the user with the largest R_i in Ξ into Q, and remove it from Ξ. Then, repeat the previous process for users in Ξ until there is no user left in Ξ or U_t users have been selected. The details of the proposed user scheduling algorithm are as follows:

Algorithm 1 Maximum SLNR

- Initialization:

(1) $N = 1$.

(2) Find user $\hat{s}_1$ such that $\hat{s}_1 = \arg\max_{i\in\Xi} \omega_i^{(\overline{m}_i)}$.

(3) Set $Q = \{\hat{s}_1\}$, $\Xi = \Xi \backslash \hat{s}_1$.

- Iteration:

(4) Increase N by 1.

(5) Find user $\hat{s}$ such that $\hat{s} = \arg\max_{i\in\Xi} R_i$.

(6) Set $Q = Q \cup \hat{s}$, $\Xi = \Xi \backslash \hat{s}$.

(7) If $\Xi = \varnothing$ or $N = U_t$, stop. Otherwise, go to 4) and repeat the iteration.

4.2 Most dissimilar

In Sect. 3, it was shown that user u and user i can perfectly be served simultaneously if $\omega_i^{(\overline{m}_u)} = 0$ and $\omega_u^{(\overline{m}_i)} = 0$. The worst case that user u and i can not be served simultaneously is that $\overline{m}_u = \overline{m}_i$.

Let us define

$$\mathbf{b}_{u,i} = \left[\omega_u^{(\overline{m}_u)}, \omega_u^{(\overline{m}_i)}\right]^T, \tag{19}$$

and

$$\mathbf{b}_{i,u} = \left[\omega_i^{(\overline{m}_u)}, \omega_i^{(\overline{m}_i)}\right]^T, \tag{20}$$

for user u and user i, respectively. Note that the cosine similarity between $\mathbf{b}_{u,i}$ and $\mathbf{b}_{i,u}$ is defined as

$$s_{u,i} = \frac{\mathbf{b}_{u,i}^T \mathbf{b}_{i,u}}{|\mathbf{b}_{u,i}||\mathbf{b}_{i,u}|}. \tag{21}$$

It can be seen that $0 \leq s_{u,i} \leq 1$, user u and user i can perfectly be served simultaneously when $s_{u,i} = 0$, and can not be served simultaneously at all when $s_{u,i} = 1$. Therefore, $s_{u,i}$ can be employed to measure whether user u and user i can be served simultaneously. The closer $s_{u,i}$ is to zero, the more dissimilar $\mathbf{b}_{u,i}$ and $\mathbf{b}_{i,u}$ are to each other, the more user u and user i can be served simultaneously. Therefore, the user with the smallest

$$S_u = \max_{i \in Q} s_{u,i}, \tag{22}$$

should be scheduled, i.e., the user which is most dissimilar to the already selected users.

Note that user u and user i are completely unsuitable to be served simultaneously when $\overline{m}_u = \overline{m}_i$. Therefore, to reduce the search complexity, there is no need to consider the user i, $i \in \Xi$, that satisfy $\overline{m}_i = \overline{m}_u$ for any user $u \in Q$.

Based on the above analysis, we propose the following user scheduling algorithm. Firstly initialize Q to be empty. Select the first user that can achieve the largest $\omega_i^{(\overline{m}_i)}$, $i \in \Xi$, since no user has been selected before. Add it into the set of select users Q and remove it from Ξ. Next, check the remaining user in set Ξ, and remove the user i in Ξ that does not satisfy $\overline{m}_i \neq \overline{m}_u$, for $\forall u \in Q$. By successively removing the users, the searching complexity for each selection is reduced. Then, add the user with the smallest S_i in Ξ into Q, and remove it from Ξ. Repeat the previous process for users in Ξ. The algorithm terminates when no more users in Ξ which indicates that the resulting set is maximal or U_t users have been selected. The details of the proposed user scheduling algorithm are as follows:

4.3 Modified-TIN

In this section, we propose a user scheduling algorithm by treating the inter-user interference as uncorrelated noise to each user's useful signal. Obviously, to achieve high sum rate, we would like that for each scheduled user, the useful signal power of it would be large, and the inter-user interference could be small.

Let us define

$$t_u = \frac{\frac{P}{U_t}\left|\mathbf{h}_u^T \mathbf{w}_u\right|^2}{\max\limits_{i \in Q, i \neq u} \frac{P}{U_t}|\mathbf{h}_u^T \mathbf{w}_i|^2 \times \max\limits_{i \in Q, i \neq u} \frac{P}{U_t}|\mathbf{h}_i^T \mathbf{w}_u|^2}, \tag{23}$$

for user u. It can be seen that t_u increases as the useful signal power of user u increases and decreases as the inter-user interference increases. Therefore, in

Algorithm 2 Most dissimilar

. Initialization:
(1) $N = 1$.
(2) Find user $\hat{l}_1$ such that $\hat{l}_1 = \arg\max_{i\in\Xi} \omega_i^{(\overline{m}_i)}$.
(3) Set $Q = \{\hat{l}_1\}$, $\Xi = \Xi \backslash \hat{l}_1$.
. Iteration:
(4) Increase N by 1.
(5) Remove user i that satisfy $\overline{m}_i = \overline{m}_u$, for $\forall u \in Q$ from Ξ.
(6) Find user $\hat{l}$ such that $\hat{l} = \arg\min_{i\in\Xi} S_i$.
(7) Set $Q = Q \cup \hat{l}$, $\Xi = \Xi \backslash \hat{l}$.
(8) If $\Xi = \varnothing$ or $N = U_t$, stop. Otherwise, go to 4) and repeat the iteration.

order to maximize the useful signal power and minimize the inter-user interference, we would like to schedule user u with the largest t_u.

Note that user scheduling based on t_u requires instantaneous CSI at BS, which leads to large amount of feedback overhead for FDD systems, especially when the number of users is large. Here, we would like to exploit only statistical CSI. Inspired by [15], we treat the inter-user interference as uncorrelated noise to the useful signal of each user, and use the following signal-to-noise factor

$$T_u = \frac{\frac{P}{U_t}\mathrm{E}\{\left|\mathbf{h}_u^T\mathbf{w}_u\right|^2\}}{\max\limits_{i\in Q, i\neq u} \frac{P}{U_t}\mathrm{E}\{\left|\mathbf{h}_u^T\mathbf{w}_i\right|^2\} \times \max\limits_{i\in Q, i\neq u} \frac{P}{U_t}\mathrm{E}\{\left|\mathbf{h}_i^T\mathbf{w}_u\right|^2\}}, \tag{24}$$

to design the user scheduling algorithm. Substituting (14) into (24), we have

$$T_u = \frac{\frac{P}{U_t}D_u}{\max\limits_{i\in Q, i\neq u} \frac{P}{U_t}I_{u,i} \times \max\limits_{i\in Q, i\neq u} \frac{P}{U_t}I_{i,u}}, \tag{25}$$

where $D_u = \omega_u^{(\overline{m}_u)}$, $I_{u,i} = \omega_u^{(\overline{m}_i)}$ and $I_{i,u} = \omega_i^{(\overline{m}_u)}$. To make sure that the quality of service of both selected user u and the candidate user i are acceptable, and also to reduce the searching complexity of the scheduling procedure, we would like that T_u and T_i are both above a certain threshold γ. Candidate users that do not satisfy this constraint are removed from the set of candidate users, and will not be considered in the rest part of the scheduling procedure. Then, schedule the user with the largest T_i among the remaining candidate users.

Based on the above analysis, we propose the following user scheduling algorithm. Firstly initialize Q to be empty. Since no user has been selected before, add the first user with the largest D_i, $i \in \Xi$ into Q and remove it from Ξ. Next, check all remaining users in set Ξ, and remove the user i that does not satisfy

$$T_i = \frac{\frac{P}{U_t}D_i}{\max\limits_{j\in Q} \frac{P}{U_t}I_{i,j} \times \max\limits_{j\in Q} \frac{P}{U_t}I_{j,i}} \geq \gamma, \tag{26}$$

or due to its addition, the already selected user u, $u \in Q$ can not satisfy

$$T_u = \frac{\frac{P}{U_t} D_u}{\frac{P}{U_t} \max\left(\max_{j \in Q, j \neq u} I_{u,j}, I_{u,i}\right) \times \frac{P}{U_t} \max\left(\max_{j \in Q, j \neq u} I_{j,u}, I_{i,u}\right)}. \quad (27)$$

Then, add the user with the largest T_i in Ξ into Q, and remove it from Ξ. Repeat the previous process until U_t users have been selected or no more users in Ξ. The details of the proposed user scheduling algorithm are as follows:

Algorithm 3 Modified-TIN

- Initialization:

(1) $N = 1$.
(2) Find user $\hat{k}_1$ such that $\hat{k}_1 = \arg\max_{i \in \Xi} D_i$.
(3) Set $Q = \{\hat{k}_1\}$, $\Xi = \Xi \backslash \hat{k}_1$.

- Iteration:

(4) Increase N by 1.
(5) Remove user i that does not satisfy $T_i \geq \gamma$ and $T_u \geq \gamma$ for $\forall u \in Q$ from Ξ.
(6) Find user $\hat{k}$ such that $\hat{k} = \arg\max_{i \in \Xi} T_i$.
(7) Set $Q = Q \cup \hat{k}$, $\Xi = \Xi \backslash \hat{k}$.
(8) If $\Xi = \varnothing$ or $N = U_t$, stop. Otherwise, go to 4) and repeat the iteration.

5 Simulation

In this section, we present numerical results to validate the performance of the proposed user scheduling algorithms. In all simulations, $M = 64$, $L = 100$, the noise level of all users are the same, i.e., $\sigma_u^2 = \sigma^2$. The BS can serve 16 users at most. The results are obtained by averaging over 500 user drops. Here, we take the user scheduling algorithm in [14] as a performance baseline which divides the users into 16 clusters, so that user u in i-th cluster satisfying $\overline{m}_u \in [4(i-1)+1, 4i]$ and the user with the largest $\omega_u^{(\overline{m}_u)}$ in each cluster is selected.

Figure 1 shows the average sum rate of the single-cell MIMO downlink transmission systems over correlated Rician fading channel under different user scheduling algorithms. In this figure, the Rician K-factor of each user is uniformly distributed in $[K_{\min}, K_{\max}]$, where $K_{\min} = -10$ dB, $K_{\max} = 10$ dB, the AoD of each user is distributed uniformly in $(-90°, 90°)$, and the angle spread of each user is uniformly distributed in $(5°, 15°)$. The threshold for the modified-TIN algorithm is $\gamma = 5$. Compared to the scheduling algorithm in [14], all the three proposed scheduling algorithms improve the average sum rate of the system significantly. It can be clearly observed from the figure that under the considered environment, the performance of the most dissimilar and the modified-TIN

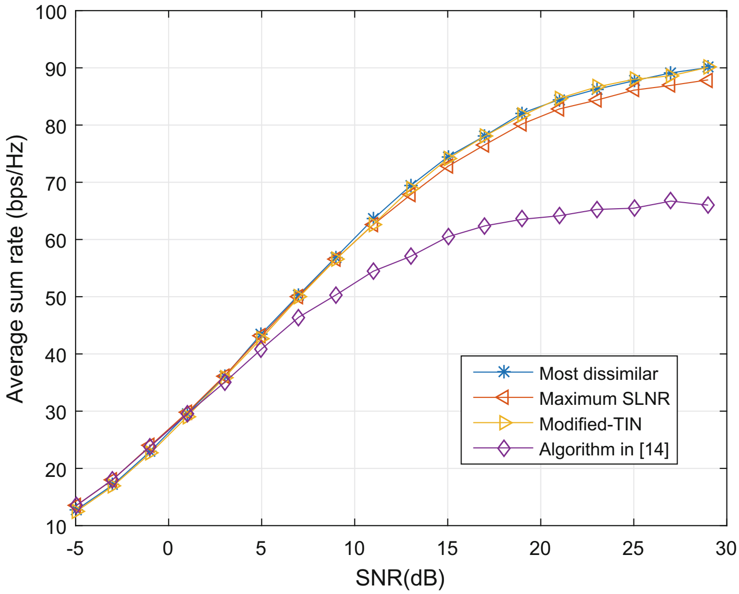

Fig. 1. Average sum rate of different user scheduling algorithms

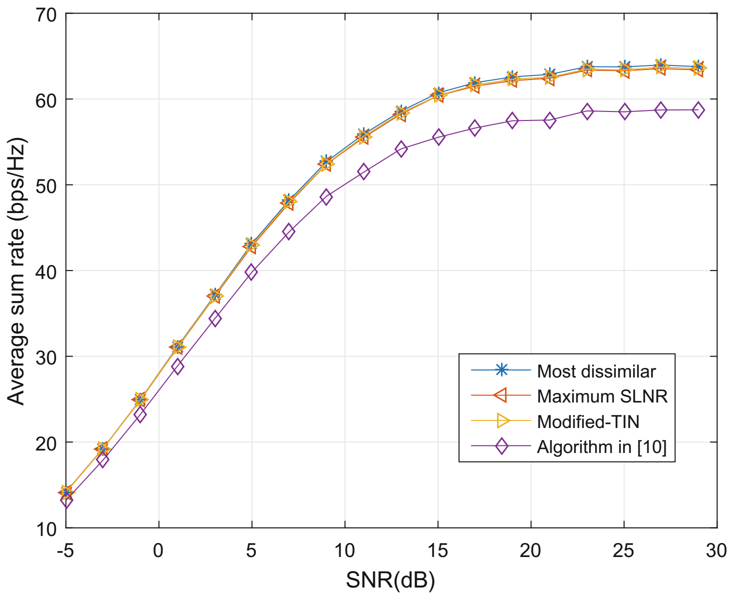

Fig. 2. Average sum rate of different user scheduling algorithms, $\mathbf{R}_i = \mathbf{I}_M$

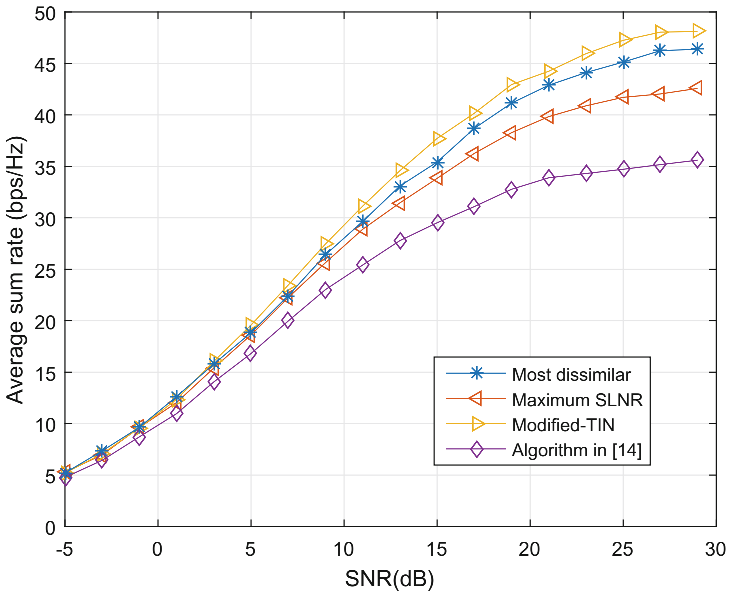

Fig. 3. Average sum rate of different user scheduling algorithms, $K_i = 0$

algorithm are almost the same, and is slightly superior to the performance of the maximum SLNR algorithm.

Figure 2 shows the average sum rate performance of the proposed scheduling algorithm when $\mathbf{R}_i = \mathbf{I}_M$, $i = 1, \cdots, L$, that is the channels of all the users are uncorrelated Rician fading. The Rician K-factor of each user is uniformly distributed in $[K_{\min}, K_{\max}]$, where $K_{\min} = -10$ dB, $K_{\max} = 10$ dB, the AoD of each user is distributed uniformly in $(-90°, 90°)$. The threshold for the modified-TIN algorithm is $\gamma = 5$. In this figure, the scheduling algorithm proposed in [10] for uncorrelated Rician fading channel is also presented. It can be seen that the performance of the proposed algorithms are almost the same, and all the proposed algorithms outperform the scheduling algorithm in [10].

Figure 3 shows the average sum rate of the single-cell MIMO downlink transmission systems when $K_i = 0$, $i = 1, \cdots, L$, that is the channel of each user is Rayleigh fading. In this figure, we assume that the AoD of each user is distributed uniformly in $(-90°, 90°)$, and the angle spread of each user is uniformly distributed in $(5°, 15°)$. The threshold for the modified-TIN algorithm is $\gamma = 5$. It can be seen that all the proposed algorithms still outperform the algorithm in [14] under this situation. And the modified-TIN performs best, while the maximum SLNR performs worst among the three proposed scheduling algorithm.

6 Conclusion

In this paper, we investigated the downlink transmission, especially the user scheduling algorithm for single-cell MIMO system under correlated Rician fading channels. With only statistical CSI of each user at BS, we derived the statistical beamforming transmission algorithm by maximizing the lower bound on the average SLNR. Then three user scheduling algorithms, which are the maximum SLNR, the most dissimilar and the modified-TIN, are proposed based on the statistical beamforming transmission algorithm. Simulation results showed that the proposed algorithms work well.

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