Distributed Scheduling Algorithm for Multiuser MIMO Downlink with Adaptive Feedback

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Abstract—**We propose a distributed scheduling algorithm for multiuser MIMO downlink with adaptive feedback. In this algorithm each mobile station (MS) selects transmission scheme, including beamforming (BF) and spatial multiplexing (SM) according to its channel state and then feeds back channel state information (CSI) adaptively. The base station (BS) receives CSI from each MS and selects user subset based on minimum spatial correlation criteria or system capacity maximization. The proposed user scheduling algorithm is carried out by MSs and BS corporately. The system feedback load depends on each MS's channel state. Compared with existing schemes the proposed algorithm can achieve high system capacity as well as good BER performance.**

Index Terms—**Multiuser, MIMO, Downlink, Substream, Adaptive feedback, Precoding, Scheduling, Beamforming, Spatial Multiplexing**

I. Introduction

Multiuser MIMO (MU-MIMO) is a set of advanced MIMO (Multiple-input and multiple-output) technologies that exploit the availability of multiple independent mobile users in order to enhance the communication capabilities of each individual user. This technique has attracted much attention due to its advantage in capacity as well as the ability to support multiple users simultaneously [1], [2]. In MU-MIMO one major subject is co-channel interference (CCI) elimination. Dirty Paper Coding (DPC) is the optimal (capacity achieving) strategy in MIMO broadcast channels (MIMO-BC or downlink) [3]. However DPC is difficult to implement in practical systems due to the high computational burden and the assumption of perfect CSI at the transmitter. Some suboptimal but low-complexity coding schemes have been devised such as block diagonalization [4], and some orthogonal projection based methods [5], [6]. In these coding schemes BS needs CSI feedback from MSs.

Another important issue in MU-MIMO BC is multiuser scheduling [6]-[11], which is always discussed in company with CCI elimination. In MU-MIMO BC BS is equipped with limited number of antennas while the number of MSs is always large. By multiuser scheduling a user subset is selected and multiuser diversity is achieved. In existing user scheduling strategies CSI feedback is needed. In [6]-[8] full CSI is fed back from MSs. The feedback load increases significantly with the number of users. Other techniques [9]-[11] utilize partial CSI for scheduling. In [9] only principal eigenmodes of MSs are scheduled. The feedback load is reduced but capacity loss results. In [10], [11] only MSs whose channel quality exceed a predefined threshold α feed back CSI. The feedback load can be reduced but precisely determining α is difficult.

MIMO channel can be equivalent to a set of decoupled parallel subchannels by singular value decomposition (SVD). There are mainly two basic transmission schemes in MIMO including beamforming (BF) and spatial multiplexing (SM). In single user MIMO scenario some techniques [11], [12] adaptively select transmission mode to improve system performance.

For simplicity some MU-MIMO BC works assume only one antenna at MS or select the best antenna of MS to communicate with BS, i.e. BS transmits to each active MS using BF [9]. This scheme can maximize the simultaneously supported users but result in capacity loss because multiple subchannels of good quality may belong to one user.

In this paper we propose a distributed scheduling algorithm for multiuser MIMO downlink with adaptive feedback. In this algorithm each MS selects appropriate transmission scheme from BF and SM according to its channel state and then feeds back CSI to the BS. The user scheduling is carried out by MS and BS corporately.

The paper is organized as follows. In Section II we describe the system model. In Section III user scheduling algorithms at BS are given. In Section IV we introduce the distributed scheduling algorithm with adaptive feedback. Numerical results and conclusion are given in Section V and Section VI, respectively.

II. System Model

Consider the downlink of a single cell MU-MIMO system with N_T transmit antennas at BS and L MSs. User-

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k is equipped with N_k receive antennas. Assume each MS undergoes frequency non-selective fading. The channel matrix of user-k is denoted by an $N_k \times N_T$ matrix $\mathbf{H}_k$. Consider the Rayleigh fading channel model, the entries of $\mathbf{H}_k$ are independent and identically distributed (i.i.d.) complex Gaussian random variables with zero mean and unity variance. For simplicity, path loss and shadowing are not considered. Make reasonable assumption that $N_T > N_k$, as MS always has rigorous size constraint compared with BS.

The number of substreams for user-k is denoted as T_k, named as mode, which satisfies $0 \le T_k \le N_k$ and $\sum_{k=1}^{K} T_k \le N_T$. When T_k=1 BS transmits to MS using BF. While T_k>1 BS uses SM. We employ an $N_T \times 1$ vector $\mathbf{s} = [\mathbf{s}_1^T, \cdots, \mathbf{s}_K^T]^T$ to denote the symbol vector of K users, of which the length-T_k vector $\mathbf{s}_k = [s_{k,1}, \cdots, s_{k,T_k}]^T$ stands for the data streams intended to user-k, satisfying $\varepsilon[\|\mathbf{s}\|_2^2] = N_T$ and $\varepsilon\{|s_{k,i}|^2\} = 1$.

At the BS, $\mathbf{s}_k$ is first transformed into a length-N_T symbol vector by multiplying an $N_T \times T_k$ precoding matrix $\mathbf{M}_k = [\mathbf{m}_{k,1}, \cdots, \mathbf{m}_{k,T_k}]$. The symbol vectors of selected K users are then linearly superimposed and launched from the antenna array simultaneously. $\mathbf{M}_k$ (k=1, $\cdots$,K) of K selected users compose the pre-processing matrix $\mathbf{P} = [\mathbf{M}_1, \cdots, \mathbf{M}_K]$. Apply SVD to $\mathbf{H}_k$, we have $\mathbf{H}_k = \mathbf{U}_k \mathbf{\Lambda}_k \mathbf{V}_k^H$. Employ $\mathbf{V}_k$ as the precoding matrix for user-k, i.e. $\mathbf{M}_k$=$\mathbf{V}_k$ and $\mathbf{m}_{k,i}$= $\mathbf{v}_{k,i}$, where $\{\mathbf{v}_{k,i}\}_{i \in \{1,\cdots,T_k\}}^{k \in \{1,\cdots,K\}}$ is the right singular vector (RSV) corresponding to the ith singular value of user-k. The power allocation matrix at BS is denoted as $\mathbf{Q} = diag(\mathbf{q}_1, \cdots, \mathbf{q}_K)$, an $N_T \times N_T$ diagonal matrix, where $\mathbf{q}_k = diag(q_{k,1}, \cdots, q_{k,T_k})$. The power assigned to user-k is $P_k = \sum_{i=1}^{T_k} q_{k,i}$. And the total transmit power satisfies $\sum_{k=1}^{K} P_k = tr(\mathbf{Q}) = E_s$.

At the user side, the received signal vector for user-k is

$$\mathbf{r}_k = \mathbf{H}_k \mathbf{P} \mathbf{Q}^{1/2} \mathbf{s} + \mathbf{n}_k = \mathbf{H}_k \sum_{i=1}^{K} \mathbf{M}_i \mathbf{q}_i^{1/2} \mathbf{s}_i + \mathbf{n}_k \tag{1}$$

where $\mathbf{Q}^{1/2}$ stands for the algebra square root operation of $\mathbf{Q}$'s entry. And $\mathbf{n}_k$ is the noise vector whose elements are i.i.d. zero mean complex Gaussian random variable with variance N_0.

Each user-k generates an estimate $\bar{\mathbf{r}}_k$ for $\mathbf{r}_k$ by multiplying $\mathbf{r}_k$ with the conjugate transpose of left singular vector matrix $\mathbf{U}_k$,

$$\begin{aligned} \bar{\mathbf{r}}_k = \mathbf{U}_k^H \mathbf{r}_k &= \mathbf{U}_k^H \mathbf{H}_k \mathbf{P} \mathbf{Q}^{1/2} \mathbf{s} + \mathbf{U}_k^H \mathbf{n}_k \\ &= \mathbf{\Lambda}_k \mathbf{V}_k^H \mathbf{P} \mathbf{Q}^{1/2} \mathbf{s} + \mathbf{U}_k^H \mathbf{n}_k \end{aligned} \tag{2}$$

where

$$\mathbf{V}_k^H \mathbf{P} \mathbf{Q}^{1/2} \mathbf{s} = \mathbf{q}_k^{1/2} \mathbf{s}_k + \begin{bmatrix} \sum_{i=1, i \ne k}^{K} \sum_{j=1}^{T_i} \langle \mathbf{v}_{k,1}, \mathbf{v}_{i,j} \rangle q_{i,j}^{1/2} s_{i,j} \\ \vdots \\ \sum_{i=1, i \ne k}^{K} \sum_{j=1}^{T_i} \langle \mathbf{v}_{k,T_k}, \mathbf{v}_{i,j} \rangle q_{i,j}^{1/2} s_{i,j} \end{bmatrix} \tag{3}$$

<**a**,**b**> denotes the inner product of vector **a** and **b**. We have

$$\bar{\mathbf{r}}_k = \mathbf{\Lambda}_k \left(\mathbf{q}_k^{1/2} \mathbf{s}_k + \mathbf{\Upsilon}_k \right) + \mathbf{U}_k^H \mathbf{n}_k \tag{4}$$

$\mathbf{\Upsilon}_k$ represents the second term of (3). If BF is used, i.e. BS transmits to MS k through its principal eigenmode, (2) becomes

$$\bar{\mathbf{r}}_{k,1} = \mathbf{u}_{k,1}^H \mathbf{r}_k = \lambda_{k,1} \left(q_{k,1}^{1/2} s_{k,1} + \sum_{i=1, i \ne k}^{K} \sum_{j=1}^{T_i} \langle \mathbf{v}_{k,1}, \mathbf{v}_{i,j} \rangle q_{i,j}^{1/2} s_{i,j} \right) + \mathbf{u}_{k,1}^H \mathbf{n}_k \tag{5}$$

where $\lambda_{k,1}$ is the maximum singular value of $\mathbf{H}_k$. $\mathbf{v}_{k,1}$ and $\mathbf{u}_{k,1}$ denote the principal right singular vector (PRSV) and principal left singular vector (PLSV) corresponding to $\lambda_{k,1}$, respectively. The second term in the bracket of (5) indicates the interference form other active users.

If CCI is zero, i.e. $\mathbf{\Upsilon}_k = 0$, (4) becomes

$$\bar{\mathbf{r}}_k = \mathbf{\Lambda}_k \mathbf{q}_k^{1/2} \mathbf{s}_k + \mathbf{U}_k^H \mathbf{n}_k \tag{6}$$

If BS communicates with all selected users using BF, i.e. T_i=1, $i \in \{1, \cdots, K\}$, precoding matrix $\mathbf{P}$ is composed of PRSVs of K active users as in [5]. Then (5) can be rewritten as

$$\bar{\mathbf{r}}_{k,1} = \lambda_{k,1} \left(q_{k,1}^{1/2} s_{k,1} + \sum_{i=1, i \ne k}^{K} \langle \mathbf{v}_{k,1}, \mathbf{v}_{i,1} \rangle q_{i,1}^{1/2} s_{i,1} \right) + \mathbf{u}_{k,1}^H \mathbf{n}_k \tag{7}$$

From (4) we have the signal to interference plus noise ratio ($SINR$) of the mth substream for user-k as follows,

$$SINR_{k,m} = \frac{q_{k,m} \lambda_{k,m}^2}{N_0 + \lambda_{k,m}^2 \sum_{i=1, i \ne k}^{K} \sum_{j=1}^{T_i} \left| \rho_{k,m}^{i,j} \right|^2 q_{i,j}} \tag{8}$$

where $\rho_{k,m}^{i,j} = \langle \mathbf{v}_{k,m}, \mathbf{v}_{i,j} \rangle$.

III. USER SCHEDULING ALGORITHM AT BS

Assume each MS can estimate channel state exactly and send back CSI to BS through an error-free zero delay feedback channel. In the following discussion we employ N_T=4 and N_k=2, $k \in \{1, \cdots, K\}$. The number of active subchannels satisfies $\sum_{k=1}^{K} T_k = N_T$. To guarantee the fairness, transmit power E_s is equally allocated to the selected users. In this part two scheduling algorithms at BS are presented. In section A, BS activates a set of users with minimum spatial correlation. Section B aims at the sum capacity maximization, user subset is determined through subchannel exhaustive searching.

A. User scheduling based on spatial correlation

The number of MSs is L, of which K users are activated. Suppose $L>N_T$. Each selected user has index $\{\xi(k)\}_{k\in\{1,\cdots,K\}}$. If user-$m$ chooses BF, it feeds back $\mathbf{v}_{m,1}$. Otherwise SM is used and $\{\mathbf{v}_{m,j}\}$, $j\in\{1,\cdots,T_m\}$ are fed back, where T_m denotes user-m's mode. The spatial correlation based scheduling scheme is as follows:

Step 1) Construct $L\times L$ spatial correlation matrix $\mathbf{C}$. The element of $\mathbf{C}$ is denoted as $C_{m,n}$.

case 1: If both user m and n select BF, calculate $C_{m,n}=\left|\left\langle \mathbf{v}_{m,1},\mathbf{v}_{n,1}\right\rangle\right|^2$;

case 2: If user m selects BF and user n selects SM, calculate $C_{m,n}=\frac{1}{T_n}\sum_{j=1}^{T_n}\left|\left\langle \mathbf{v}_{m,1},\mathbf{v}_{n,j}\right\rangle\right|^2$;

case 3: If both user m and n select SM, calculate $C_{m,n}=\frac{1}{T_mT_n}\sum_{i=1}^{T_m}\sum_{j=1}^{T_n}\left|\left\langle \mathbf{v}_{m,i},\mathbf{v}_{n,j}\right\rangle\right|^2$.

$C_{m,n}$ indicates the spatial correlation degree of user m and n, where $m,n\in\{1,\cdots,L\}$. $|\cdot|$ denotes modular operation.

Step 2) Sort the elements in each row of $\mathbf{C}$ in ascending order to obtain $\tilde{\mathbf{C}}$. Sum up the first K elements in each row of $\tilde{\mathbf{C}}$ and $\mathbf{\Psi}=[\psi_1,\cdots,\psi_L]^T$ is acquired. The index of first user (i=1) is $\xi(i)=\arg\min_{k\in\{1,\cdots,L\}}\psi_k$.

While the number of active substreams does not exceed N_T, find the index of ith (i>1) user among L-(i-1) remaining users applying (9). Otherwise the algorithm terminates.

$$\xi(i)=\arg\min_{m\in\{1,\cdots,L\},m\neq\{\xi(1),\cdots,\xi(i-1)\}}\left(\sum_{q=1}^{i-1}C_{m,\xi(q)}\right) \tag{9}$$

There is a special case in applying the above algorithm: $\sum_{k=1}^{\tilde{K}-1}T_k\in[N_T-T_{\tilde{K}}+1,N_T-1]$ where $\tilde{K}\le K$, and user-$\tilde{K}$ selects SM, therefore $\sum_{k=1}^{\tilde{K}}T_k>N_T$. To solve this problem, only the rest $N_T-\sum_{k=1}^{\tilde{K}-1}T_k$ subchannels are assigned to user-$\tilde{K}$. Thus $\sum_{k=1}^{\tilde{K}}T_k=N_T$ is satisfied. As a result, the actual transmission mode of user-$\tilde{K}$ may be not the one it originally selected.

Some related works assume only one antenna at each MS, i.e. BS communicates with all the selected MSs using BF. Under this assumption $C_{m,n}$ are calculated in terms of case 1.

B. User scheduling based on subchannel exhaustive searching

The channel state information obtained by user-k includes $\mathbf{V}_k$ and $\mathbf{\Lambda}_k$. The former is channel directional information (CDI), and the later is channel quality indicator (CQI). The strategy in previous section only makes use of CDI. In this section a user subset selection scheme based on subchannel exhaustive searching is described which utilizes both CDI and CQI.

Step 1) Initialization. Iteration time i=1, $\Lambda=\{\lambda_{1,1},\lambda_{1,2},\cdots,\lambda_{K,1},\lambda_{K,2}\}$, $\Psi=\{(1,1),(1,2),\cdots,(K,1),(K,2)\}$, $\Omega=\phi$ (null set) and $S=\phi$. Recall that we employ N_T=4 and N_k=2, for each user there are at most two substreams to be scheduled. Λ and Ψ comprise the CQI and indices of candidate substreams, respectively. Ω denotes the set of active users and S is the set of indices for selected substreams.

Step 2) Iteration. While $\Psi\neq\phi$ and $|\Omega|\le N_T$ (|A| denotes the size of set A), for every substream index $(k,m)\in\Psi$,

If i=1, Calculate $(\alpha_i,\beta_i)=\arg\max_{(k,m)\in\Psi}\lambda_{k,m}$.

If i>1, Let $C_{k,m}$ denote the sum capacity of substreams belonging to $\Omega\bigcup\{(k,m)\}$. We have

$$C_{k,m}=\sum_{(\alpha,\beta)\in\Omega\bigcup\{(k,m)\}}\log_2(1+SINR_{\alpha,\beta}) \tag{10}$$

$SINR_{\alpha,\beta}$ can be obtained using (11), which is the modification of (8).

$$SINR_{\alpha,\beta}=\frac{q_{\alpha,\beta}\lambda_{\alpha,\beta}^2}{N_0+\lambda_{\alpha,\beta}^2\sum_{(\bar{i},\bar{j})\in\Omega\bigcup\{(k,m)\},\bar{i}\neq\alpha}\left|\rho_{\alpha,\beta}^{\bar{i},\bar{j}}\right|^2 q_{\bar{i},\bar{j}}} \tag{11}$$

Note that $\bar{i}=\alpha$ when $\left|\rho_{\alpha,\beta}^{\bar{i},\bar{j}}\right|=0$. Each active user is allocated equal power $E_s/|S|$. The power coefficient of each substream is $q_{k,m}=E_s/(|S|\cdot T_k)$. Calculate $(\alpha_i,\beta_i)=\arg\max_{(k,m)\in\Psi}\{C_{k,m}\}$.

For each i, compute $\Omega=\Omega\bigcup\{(\alpha_i,\beta_i)\}$, $S=S\bigcup\{\alpha_i\}$, $\Psi=\Psi-\{(\alpha_i,\beta_i)\}$ and $i=i+1$.

Step 3) Sum rate computation. Calculate the sum capacity of substreams in set Ω in terms of (11), (12)

$$C=\sum_{(\alpha,\beta)\in\Omega}\log_2(1+SINR_{\alpha,\beta}) \tag{12}$$

The algorithm is finished.

IV. Distributed Scheduling Algorithm with Adaptive Feedback

In Section III two BS scheduling strategies are presented. Based on discussion above, a distributed scheduling technique with adaptive feedback is proposed. In this algorithm each MS selects transmission scheme according to its channel state and then adaptively feeds back CSI. User scheduling is carried out by MS and BS corporately. The approach is described as follows:

Step 1) User-k estimates $\mathbf{H}_k$ and selects transmission scheme. Let $C_{k,BF}^{inst}$ and $C_{k,SM}^{inst}$ denote the instantaneous capacity of user-k using BF and SM, respectively. They are given by (13) and (14) as follows,

$$C_{k,BF}^{inst}=\log_2\left(1+P_T\lambda_{k,1}^2/N_0\right) \tag{13}$$

$$C_{k,SM}^{inst} = \log_2 \det\left(\mathbf{I}_{N_k} + \frac{P_T}{N_T N_0} \mathbf{H}_k \mathbf{H}_k^H \right) = \sum_{i=1}^{rank(\mathbf{H}_k)} \log_2 \left(1 + \frac{P_T \lambda_{k,i}^2}{N_T N_0} \right) \quad (14)$$

P_T is the power allocated to user-k. MS selects the transmission mode with higher capacity and adaptively feeds back CSI. If BF is selected, PRSV is fed back; if SM is better, the right singular vector matrix $\mathbf{V}_k$ is fed back.

Step 2) On receiving the CSI feedback from MSs, BS activates a set of users applying the algorithm in III.A or III.B.

The feedback information is affected by each user's channel quality; our proposed algorithm can effectively reduce the feedback load as well as the computational complexity at BS.

Note that the power is equally allocated to each active user yet the size of selected user subset is uncertain, which results in the various system power values. This problem is treated as follows, mobile user selects transmission mode assuming its allocated power P_T=E_s/4, accordingly the total transmit power varies within [E_s/4, E_s]. To guarantee fairness, before applying (11), (12) to calculate the sum capacity, the total transmit power is modified to constant E_s, which is equally shared by active users.

The proposed algorithm may encounter two kinds of uncertainty. First, one user selects SM, but CCI deteriorates its *SINR*, as a result BF may be actually better. Second, MS selects transmission mode with a lower default power (E_s/4), but the number of active users may be less than N_T, i.e. an actual transmit power larger than E_s/4 resulted and SM may be optimal.

Furthermore, for one active user the potential increase of its actual transmit power may counteract the *SINR* deterioration caused by CCI. Numerical results in part V show that the proposed scheme can achieve high capacity and good BER performance with existence of the uncertainty discussed above.

V. Numerical Results

In this section, we use numerical results to demonstrate the advantage of the proposed scheduling algorithm. Assume L=8 MSs and antenna configuration N_T=4, N_k=2. The total number of active substreams is N_T. Three algorithms are under investigation: BF with partial CSI feedback (BF-PCSI), subchannel exhaustive searching with full CSI feedback (SES-FCSI), and the proposed distributed scheduling with adaptive CSI feedback (DS-ACSI). BF-PCSI and DS-ACSI select user subset according to III.A. SES-FCSI follows III.B.

In Fig.1 the capacity performance is shown. At low *SNR* BF is the preferable transmission scheme, with BF-PCSI and DS-ACSI the omitted channel information does not lead to capacity loss. As a result three schemes are of almost the same average sum capacity. Along with increasing *SNR* the partial CSI feedback would lead to non-optimal scheduling and capacity loss results. As shown in Fig.1 the sum capacity of DS-ACSI and SES-FCSI outperforms that of BF-PCSI as *SNR* increases. Note that at medium *SNR* (5dB<*SNR*<15dB) DS-ACSI performs slightly worse than SES-FCSI, this capacity degradation is due to the fact that the available CSI of DS-ACSI is not sufficient to result in as good capacity performance as that of the full CSI feedback scheme.

Recall that SES-FCSI activates four substreams in an iteration manner beginning with the best substream. This

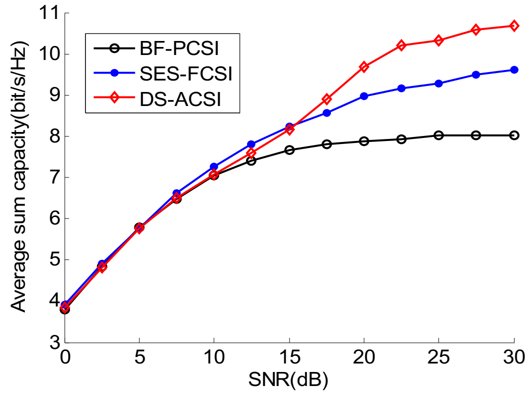

Figure 1. Average sum capacity.

may result in non-optimal scheduling, i.e. the later activated substream may not enhance but on the contrary impair the sum capacity because more CCI is induced. With DS-ACSI, substreams are selected according to the minimum spatial correlation criterion. As *SNR* increases more CSI is available at BS and higher sum capacity could be achieved. As Fig.1 shows, at high *SNR* (*SNR*>15dB) DS-ACSI can lead to considerable capacity gain over the other two schemes. Especially when *SNR*>20dB the sum capacity of DS-ACSI exceeds that of SES-FCSI and BF-PCSI up to 1bit/s/Hz and 2bit/s/Hz, respectively. Under the influence of CCI, sum capacity of BF-PCSI saturates as *SNR*>15dB, while the other two schemes saturates as *SNR*>30dB.

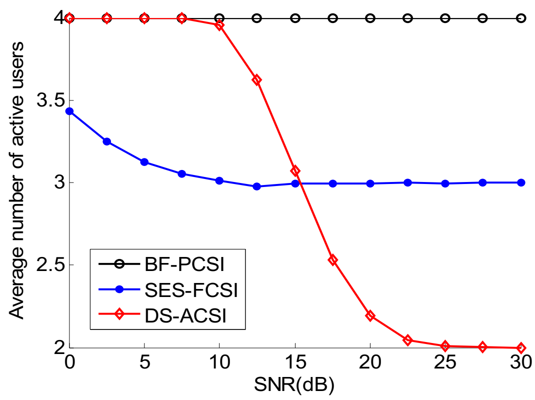

Figure 2. Average number of active users.

Fig.2 shows the average number of active users. With BF-PCSI the size of user subset is constant N_T=4. While for SES-FCSI this number approaches 3 as *SNR* increases. By simulation tracking, we find that at high *SNR* SES-FCSI activates two subchannels belonging to one user with high probability. Then the other two subchannels are selected separately, which always belong to different users. At high *SNR* CCI becomes the dominant factor affecting *SINR* of each substream. There is no CCI among subchannels belonging to one user as they are mutually orthogonal. But among different users CCI do exist as there is no inter-user cooperation. For DS-ACSI, MS selects BF at low *SNR* and feeds back PRSV which is the same as BF-PCSI. Along with increasing *SNR*, MS of good channel quality selects SM and feeds back the right singular vector matrix **V**. When *SNR*>22dB DS-ACSI approximates to full CSI feedback and two SM users are activated simultaneously.

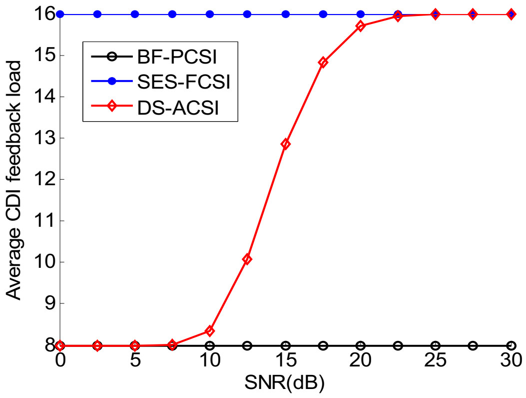

Figure 3. Average CDI feedback load.

Fig.3 shows the average CDI feedback load. The y-axis represents the number of RSVs BS receives from *L* users. The feedback load of BF-PCSI and SES-FCSI are constant, determined by $L \times N_k$. With DS-ACSI, MS adaptively feeds back CDI in terms of its channel state. At low *SNR* BF is preferable scheme. Accordingly the feedback load is mainly composed of PRSVs. As *SNR* increases, SM outperforms BF statistically, thus more MS selects SM and the right singular vector matrix **V** is fed back. From Fig.3 it can be seen that the feedback load of DS-ACSI increases with *SNR* and gradually approaching that of SES-FCSI. Furthermore, BF-PCSI and DS-ACSI activate users based on their spatial correlation and there is no CQI feedback. Yet with SES-FCSI both CDI and CQI feedback are needed.

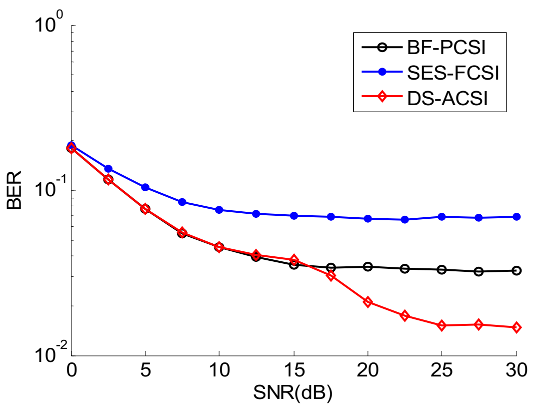

Figure 4. BER performance.

In Fig.4 the average BER of active user subset is shown, using BPSK modulation. It can be seen that the BER performance of SES-FCSI is obviously inferior to that of BF-PCSI. At low *SNR* DS-ACSI performs the same as BF-PCSI; with both schemes MS selects BF with high probability. As *SNR* increases, SM becomes preferable. Due to the fact that the two substreams belonging to one user do not interfere with each other, CCI is reduced and BER performance improves. As shown in Fig.4, the BER performance of DS-ACSI outperforms that of BF-PCSI at high *SNR*. Note that the SVD aided precoding method applied in our discussion can not eliminate CCI, the BER performance in Fig.4 is poor and an error floor occurs at higher *SNR*.

For completeness, cumulative distribution functions (CDF) of BER with three scheduling strategies under different *SNR* values are plotted in Fig.5. When *SNR*=5dB, CDF curves of DS-ACSI and BF-PCSI are overlapped and show better performance than that of SES-FCSI. Under *SNR*=20dB DS-ACSI outperforms BF-PCSI, SES-FCSI is still the worst. Moreover, given a target BER, say 10^{-2}, the outage probability of the proposed scheme under *SNR*=20dB is about 56%. As for the other two strategies this value exceeds 90% and 99%, respectively. The results from Fig.5 are consistent with those in Fig.4.

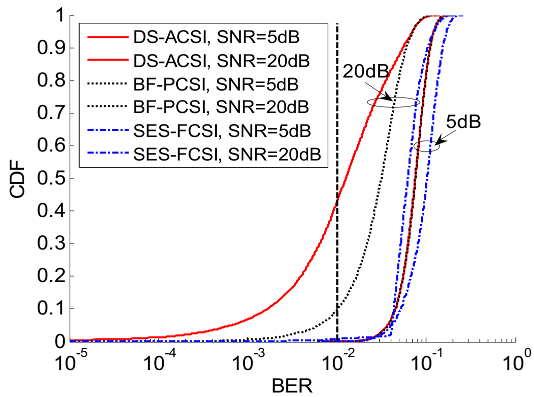

Figure 5. Distribution of BER values for *SNR*=5dB, 20dB.

From Fig.1, Fig.4 and Fig.5 it can be concluded that DS-ACSI can achieve high system capacity as well as good BER performance.

VI. Conclusion

We propose a distributed scheduling algorithm for MU-MIMO downlink with adaptive feedback (DS-ACSI). In this scheme each MS selects transmission mode according to its channel state and then feeds back CSI adaptively. BS receives CSI from each MS and activates user subset consequently. The proposed user scheduling algorithm is carried out by MS and BS corporately. Numerical results show that the proposed scheme can achieve high system capacity while maintaining good BER performance.

In this paper an SVD aided precoding method is used, which is simple but of poor performance. If block diagonalization [4] or some orthogonal projection based methods [5], [6] are employed the capacity and BER performance could be greatly enhanced. Furthermore, the precision of MS's *SINR* estimation affects whether it can select appropriate transmission mode and furthermore the feedback load. Existing MU-MIMO downlink works assume no cooperation among users, so MS is not able to obtain its CCI exactly. If the CCI estimation can be done with more accuracy the performance of the algorithm could be further improved.

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