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Robust Multiuser Precoder for Base Station Cooperative Transmission with Non-ideal Channel Reciprocity

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Abstract—**In this paper we present a method to alleviate the performance degradation led by non-ideal channel reciprocity in TDD downlink base station (BS) cooperative transmission systems, which comes from imperfect antenna calibration among BSs. By exploiting the statistics of the ambiguity factors between uplink and downlink channels, a robust multiuser precoder is proposed aimed at maximizing the lower bound of the average signal-to-leakage-plus-noise ratio (SLNR). The precoder is able to adaptively control the cooperation level among the coordinated BSs according to the antenna calibration accuracy among BSs. Simulation results demonstrate an evident performance gain of the proposed robust precoder over the non-robust precoder.**

I. INTRODUCTION

Inter-cell interference is one of the major bottlenecks to improve spectral efficiency in future cellular networks. Except for various interference mitigation techniques, recently a concept of base station (BS) cooperative transmission, also known as coordinated multi-point transmission (CoMP), has attracted much attention [1–4]. A typical centralized CoMP system consists of a control unit (CU) and multiple BSs connected to the CU via low-latency backhaul links. When the channel state information (CSI) from all users to all BSs can be gathered in the CU, CoMP with multi-user precoding can achieve the sum capacity of the system with a 'super' BS [1].

It is widely recognized that time division duplex (TDD) is more applicable for CoMP systems than frequency division duplex (FDD), because the latter needs prohibitive feedback overhead for providing CSI at the transmitter. In TDD systems, the downlink channels are obtained by the BS via estimating the uplink channels exploiting the channel reciprocity. However, the uplink and downlink channels are only reciprocal for propagation channels, which is invalid in practical systems due to the mismatch of radio frequency (RF) chains used in reception and transmission for antennas [5–7]. This will severely degrade the performance of CoMP systems [8].

To exploit channel reciprocity, antenna calibration is often used to compensate the mismatch of RF chains [9]. Self calibration is a popular antenna calibration method used in single-cell systems [5, 10], which adjusts all antennas to achieve the same RF analog gain as that of a reference antenna, and hence ensures a constant scalar ambiguity between the uplink and downlink channels for all antennas. Such a scalar ambiguity does not affect the performance of single-cell single-user (SU) systems [8]. Yet as will be explained in next section, self calibration among BSs is hard to implement in CoMP systems. This leads to multiple ambiguity factors between the uplink and downlink channels at different coordinated BSs, unless precise reference antennas are used at different BSs to achieve identical RF analog gain, which is of high cost in practice. Over-the-air calibration is another method applied in single-cell systems [11], which can be extended straightforwardly to CoMP systems. However, its performance is highly dependent on the performance of channel estimation [6]. Since channel estimation is challenging in CoMP systems, its calibration performance is not acceptable.

In this paper we strive for improving the performance of CoMP systems with imperfect uplink-downlink reciprocity. Instead of developing advanced antenna calibration methods, we put emphasis on designing a robust multiuser precoder against the ambiguity between uplink and downlink channels.

We assume that the statistics of the ambiguity factors are available, which depend on the analog devices used in RF chains. Based on these statistics, we propose a robust multiuser precoder aimed at maximizing the lower bound of the average signal-to-leakage-plus-noise ratio (SLNR) of each user. The realistic per-BS power constraints (PBPC) are considered, which are justified by the fact that power sharing among spatially distributed BSs is impossible. We also examine the impact of the proposed robust precoder on the accuracy requirement of the reference antenna used in self calibration. Compared with the non-robust SLNR precoder [12] that simply regards the estimated uplink channels as the downlink channels, simulation results show that the proposed robust precoder provides an evident performance gain.

II. ANTENNA CALIBRATION AND SYSTEM MODEL

A. Antenna Self Calibration

We first consider a single-cell SU TDD systems as shown in Fig. 1, where each antenna is equipped with a high power

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amplifier (HPA) in the transmitter circuit and a low noise amplifier (LNA) in the receiver circuit.

Define S_j^B and Y_j^B as the transmit and receive analog gain of the jth antenna at the BS, and S_i^U and Y_i^U as the transmit and receive analog gain of the ith antenna at the user. Then the equivalent uplink channel h_{ij}^U and downlink channel h_{ij}^D between the basebands at user's ith antenna and at the BS's jth antenna are expressed as [6]

$$h_{ij}^U = S_i^U c_{ij}^U Y_j^B, \tag{1}$$

$$h_{ij}^D = S_j^B c_{ij}^D Y_i^U, \tag{2}$$

where c_{ij}^U and c_{ij}^D are the uplink and downlink propagation channels between the antenna pair, which are reciprocal according to electromagnetic theory.

Define $\gamma_i^B = S_i^B / Y_i^B$ and $\gamma_i^U = S_i^U / Y_i^U$, then from (1) and (2) we have

$$h_{ij}^D = \frac{\gamma_j^B}{\gamma_i^U} h_{ij}^U. \tag{3}$$

We can see from (3) that there exists an ambiguity factor $g_{ij} = \gamma_j^B / \gamma_i^U$ between the equivalent uplink and downlink channels of the antenna pair. Since all antennas at both the BS and the user have different RF chains, the ambiguity factors of different pair of uplink and downlink channels differ, which destroys the reciprocity of the equivalent channels.

To exploit the channel reciprocity in TDD systems, antenna calibration is necessary. Self calibration is a popular antenna calibration method used in single-cell systems, which operates as follows [5, 10]. One of the antennas at the BS is used as a reference antenna, say the first antenna, which transmits a test signal to the second antenna over the propagation channel. Then the second antenna transmits the same test signal to the first antenna. Based on the received signals at the first and the second antenna of the BS, an appropriate calibration parameter can be obtained then the second antenna is calibrated, which leads to the same ambiguity factor for the two antennas. By performing the same procedure to other antennas, a constant scalar ambiguity factor exists for all antennas, which does not affect the performance of single-cell SU systems [8].

The self calibration is readily to implement when the antennas are co-located. To calibrate the antennas located in different BSs in the same way, time and frequency domain synchronization among BSs is required and information sharing protocol needs to be defined, which is infeasible at least in the near future. On the other hand, when the self calibration is performed at individual BS, the ambiguity factors between multiple coordinated BSs differ. This leads to severe performance loss for CoMP systems, which will be shown by simulations later.

B. Calibration Error Model

We next consider the model of the ambiguity factors, which will be used for robust precoder design in CoMP systems.

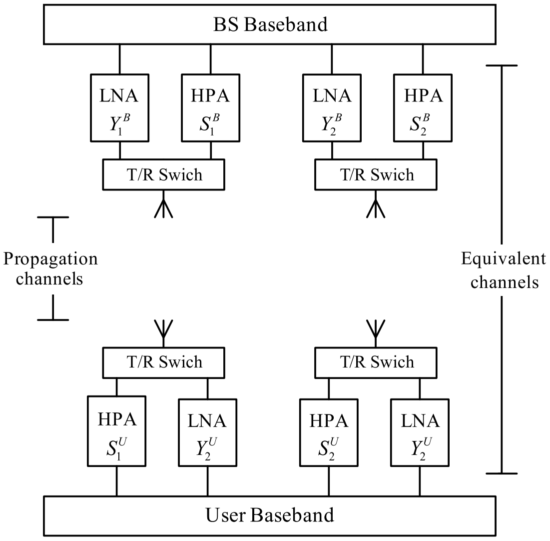

Fig. 1. Antenna calibration model in TDD systems.

As have been mentioned before, self calibration within each BS results in different ambiguity factors at multiple coordinated BSs, which are called port error and denoted as $g_{ij}^{(1)}$ in the context. Theoretically, the ambiguity factors of all antennas in the same BS should be identical after self calibration, which, however, are actually time-varying since the analog gain of RF chains varies with temperature, humidity, etc.. We call the time-varying ambiguity as residual error and denote it as $g_{ij}^{(2)}$. Then we can express the ambiguity factors as

$$g_{ij} = g_{ij}^{(1)} g_{ij}^{(2)}, \tag{4}$$

where $g_{ij}^{(1)}$ and $g_{ij}^{(2)}$ are independent from each other, and both are usually modeled as random variables with log-uniformly distributed amplitudes and uniformly distributed phases [5].

C. CoMP System Model

Consider a CoMP system consisting of N_c coordinated BSs and N_u uniformly distributed users. Each BS is equipped with N_t antennas and each user has one antenna.

Define $\mathbf{h}_{D,i} = [\mathbf{h}_{i1}^D, \ldots, \mathbf{h}_{iN_c}^D] \in \mathbb{C}^{1 \times N_c N_t}$ as the downlink equivalent channels of the ith user, where $\mathbf{h}_{im}^D \in \mathbb{C}^{1 \times N_t}$ is the downlink equivalent channel vector from the mth BS to the ith user. When linear precoding is used, the signal received by the ith user is

$$y_i = \mathbf{h}_{D,i} \sum_{j=1}^{N_u} \mathbf{w}_j^H x_j + z_i, \tag{5}$$

where $\mathbf{x} = [x_1, \ldots, x_{N_u}] \in \mathbb{C}^{1 \times N_u}$ is the data symbols for all users, which entries are assumed as independent and identically distributed (i.i.d.) Gaussian random variables with zero mean and unit variance, z_i is the additive white Gaussian noise with zero mean and variance σ^2, $\mathbf{w}_j = [\mathbf{w}_{j1}, \ldots, \mathbf{w}_{jN_c}] \in \mathbb{C}^{1 \times N_c N_t}$ is the precoding vector at the CU for the jth user with $\mathbf{w}_{jm} \in \mathbb{C}^{1 \times N_t}$ representing the precoder vector at the mth BS, and the precoder for all users at the mth BS can be expressed as $\mathbf{W}_m = [\mathbf{w}_{1m}^H, \ldots, \mathbf{w}_{N_u m}^H] \in \mathbb{C}^{N_t \times N_u}$, $m = 1, \ldots, N_c$.

Denote the uplink equivalent channels of the ith user as $\mathbf{h}_{U,i} = [\mathbf{h}^U_{i1}, \ldots, \mathbf{h}^U_{iN_c}]$, where $\mathbf{h}^U_{im}$ is the uplink equivalent channel from the ith user to the mth BS. Then from (3) the relationship between uplink and downlink equivalent channels is expressed as

$$\mathbf{h}_{D,i} = \mathbf{g}_i \mathbf{H}_{U,i}, \tag{6}$$

where $\mathbf{H}_{U,i} = \mathrm{diag}\{\mathbf{h}_{U,i}\}$, $\mathrm{diag}\{\mathbf{a}\}$ represents a diagonal matrix with the elements of a vector $\mathbf{a}$, $\mathbf{g}_i = [\mathbf{g}_{i1}, \ldots, \mathbf{g}_{iN_c}]$, $\mathbf{g}_{im} = \left[g_{ik_{m1}}, \ldots, g_{ik_{mN_t}}\right]$ represents the ambiguity factors between uplink and downlink equivalent channels with respect to the mth BS, $k_{mn} = (m-1)N_t + n$, $m = 1, \ldots, N_c$, and $n = 1, \ldots, N_t$.

After the antenna self calibration within each BS, the port errors of the elements of $\mathbf{g}_{im}$ have the same value, which can be written as

$$\mathbf{g}_{im} = g^{(1)}_{im}\left[g^{(2)}_{ik_{m1}}, \ldots, g^{(2)}_{ik_{mN_t}}\right] \triangleq g^{(1)}_{im}\mathbf{g}^{(2)}_{im}. \tag{7}$$

III. MULTIUSER ROBUST PRECODER DESIGN

With the knowledge of the statistics of the ambiguity factors between uplink and downlink equivalent channels, in this section we design a robust multiuser precoder subject to PBPC. We assume perfect uplink CSI at the coordinated BSs, i.e., $\mathbf{h}_{U,i}$ is known for $i = 1, \ldots, N_u$. Due to the existence of the ambiguity factor vector $\mathbf{g}_i$, the downlink equivalent channels $\mathbf{h}_{D,i}$ are not the same as $\mathbf{h}_{U,i}$ for $i = 1, \ldots, N_u$.

A. Multiuser Robust Precoder

The signal-to-interference-plus-noise ratio (SINR) at the ith user can be obtained from (5) as

$$\mathrm{SINR}_i = \frac{\mathbf{w}_i \mathbf{h}^H_{D,i}\mathbf{h}_{D,i}\mathbf{w}^H_i}{\sigma^2 + \sum_{j \neq i} \mathbf{w}_j \mathbf{h}^H_{D,i}\mathbf{h}_{D,i}\mathbf{w}^H_j}. \tag{8}$$

It is desirable to maximize the average SINR for designing a robust precoder which is connected to maximize the sum rate. However, the coupled precoder vectors for multiple users in the expression of SINR make the problem intractable. Alternatively, we can use the SLNR based multiuser precoder [12], where the precoder vectors for users are decoupled.

Following the definition in [12], the ith user's SLNR is,

$$\mathrm{SLNR}_i = \frac{\mathbf{w}_i \mathbf{h}^H_{D,i}\mathbf{h}_{D,i}\mathbf{w}^H_i}{\sigma^2 + \sum_{j \neq i} \mathbf{w}_i \mathbf{h}^H_{D,j}\mathbf{h}_{D,j}\mathbf{w}^H_i}. \tag{9}$$

Then given the statistics of the ambiguity factors, the problem of robust multiuser precoder design aimed at maximizing the average SLNR can be formulated as

$$\max_{\mathbf{w}_i} \ \mathbb{E}\{\mathrm{SLNR}_i\}, \ i = 1, \ldots, N_u, \tag{10a}$$

$$s.t. \ \mathrm{Tr}\left(\mathbf{W}_m \mathbf{W}^H_m\right) \leq P_0, \ m = 1, \ldots, N_c, \tag{10b}$$

where $\mathbb{E}\{\cdot\}$ denotes the expectation operator and is taken with respect to $\mathbf{h}_{D,i}$. Considering (6) and the fact that $\mathbf{h}_{U,i}$ is known, it is actually averaged over $\mathbf{g}_i$. (10b) reflects the PBPC, P_0 is the maximal transmit power of each BS, and $\mathrm{Tr}(\cdot)$ denotes the matrix trace.

We can find that precoder vectors of multiple users are still coupled in (10) due to the PBPC, although using the criterion of average SLNR is able to decouple them in the objective function of (10a). To obtain an explicit precoder, we try to find a suboptimal solution of the original optimization problem shown in (10) in the sequel. To this end, we first find a precoder that maximizes the average SLNR subject to per-user power constraints (PUPC) [2] that decouples the precoder vectors, then employ the equal power allocation [1] to make the PBPC satisfied.

However, the problem is still hard since the average SLNR has no explicit expression. Instead, we consider its lower bound based on Jensen's inequality as

$$\mathbb{E}\{\mathrm{SLNR}_i\} \geq \frac{\mathbf{w}_i \mathbb{E}\left\{\mathbf{h}^H_{D,i}\mathbf{h}_{D,i}\right\}\mathbf{w}^H_i}{\sigma^2 + \sum_{j \neq i}\mathbf{w}_i \mathbb{E}\left\{\mathbf{h}^H_{D,j}\mathbf{h}_{D,j}\right\}\mathbf{w}^H_i}. \tag{11}$$

Substituting (6) into (11), the optimization problem that maximizes the lower bound of average SLNR subject to PUPC can be written as

$$\max_{\mathbf{w}_i} \ \frac{\mathbf{w}_i \mathbf{H}^H_{U,i}\mathbb{E}\left\{\mathbf{g}^H_i \mathbf{g}_i\right\}\mathbf{H}_{U,i}\mathbf{w}^H_i}{\sigma^2 + \sum_{j \neq i}\mathbf{w}_i \mathbf{H}^H_{U,j}\mathbb{E}\left\{\mathbf{g}^H_j \mathbf{g}_j\right\}\mathbf{H}_{U,j}\mathbf{w}^H_i}, \tag{12a}$$

$$s.t. \ \mathbf{w}_i \mathbf{w}^H_i \leq N_c P_0 / N_u, \tag{12b}$$

where (12b) reflects the PUPC.

Define $\mathbf{v}_i = \sqrt{N_u/(N_c P_0)}\mathbf{w}_i$, then (12) turns into a generalized Rayleigh quotient problem with respect to $\mathbf{v}_i$ for $i = 1, \ldots, N_u$. The optimum $\mathbf{v}_{\mathrm{opt},i}$ is the eigenvector corresponding to the largest eigenvalue of the matrix

$$(N_u \sigma^2/(N_c P_0)\mathbf{I} + \sum_{j \neq i}\mathbf{\Omega}_j)^{-1}\mathbf{\Omega}_i, \tag{13}$$

where $\mathbf{\Omega}_i = \mathbf{H}^H_{U,i}\mathbb{E}\left\{\mathbf{g}^H_i \mathbf{g}_i\right\}\mathbf{H}_{U,i}$ [12]. Hence, the optimal $\mathbf{w}_{\mathrm{opt},i}$ is obtained as

$$\mathbf{w}_{\mathrm{opt},i} = \sqrt{N_c P_0 / N_u}\mathbf{v}_{\mathrm{opt},i}. \tag{14}$$

Since only PUPC are considered, the obtained precoder $\mathbf{w}_{\mathrm{opt},i}$ may not satisfy the PBPC. We can ensure the PBPC by employing the equal power allocation given in [1] as

$$\mathbf{w}_i = \sqrt{p}\mathbf{w}_{\mathrm{opt},i}, \tag{15}$$

where p is the power equally allocated to all users, which ensures (10b) satisfied. Let $\mathbf{w}_{\mathrm{opt},i} = [\mathbf{w}_{\mathrm{opt},i1}, \ldots, \mathbf{w}_{\mathrm{opt},iN_c}]$ for $i = 1, \ldots, N_u$, then it is not hard to find that

$$p = \frac{P_0}{\max\limits_{m=1,\ldots,N_c} \mathrm{Tr}\left(\mathbf{W}_{\mathrm{opt},m}\mathbf{W}^H_{\mathrm{opt},m}\right)} \tag{16}$$

with $\mathbf{W}_{\mathrm{opt},m} = [\mathbf{w}^H_{\mathrm{opt},1m}, \ldots, \mathbf{w}^H_{\mathrm{opt},N_u m}]$.

B. Discussions

To gain some insight into the problem, we consider the form of the proposed robust multiuser precoder in two specific cases as follows.

If the antenna self calibration among antennas both within each BS and between BSs is perfect, the ambiguity factors

$g_{ik_{mn}} = 1$ for $i = 1, \ldots, N_u$, $m = 1, \ldots, N_c$ and $n = 1, \ldots, N_t$. Then it is easy to see that $\mathbf{\Omega}_i = \mathbf{h}_{U,i}^H \mathbf{h}_{U,i}$, and hence the precoder vector becomes

$$\mathbf{w}_i = \sqrt{\frac{pN_cP_0}{N_u}} \frac{\mathbf{h}_{U,i}(N_u\sigma^2/(N_cP_0) + \sum_{j\neq i}\mathbf{h}_{U,j}^H\mathbf{h}_{U,j})^{-1}}{\|\mathbf{h}_{U,i}(N_u\sigma^2/(N_cP_0) + \sum_{j\neq i}\mathbf{h}_{U,j}^H\mathbf{h}_{U,j})^{-1}\|}, \tag{17}$$

where $\|\cdot\|$ denotes the 2-norm.

In this case, the CoMP system can be regarded as a single-cell system with a "super" BS, and the proposed robust precoder reduces to the traditional SLNR precoder [12] except for the additional power allocation under the PBPC.

If the antenna self calibration is only conducted within each BS and the phase of port error $g_{im}^{(1)}$ is assumed to be i.i.d. and uniformly distributed between $[-180°, 180°]$, then we can show that only one $\mathbf{w}_{im}$ included in the ith user's precoder vector $\mathbf{w}_i$ is nonzero in the following.

Based on the model of ambiguity factors in (7), we have $\mathbb{E}\{\mathbf{g}_{im}^H\mathbf{g}_{im}\} = \mathbb{E}\{|g_{im}^{(1)}|^2\}\mathbb{E}\{\mathbf{g}_{im}^{(2)H}\mathbf{g}_{im}^{(2)}\}$ and $\mathbb{E}\{\mathbf{g}_{im}^H\mathbf{g}_{in}\} = 0$ for $m \neq n$, where the uniform distribution of the phase of $g_{im}^{(1)}$ is used. Therefore, $\mathbb{E}\{\mathbf{g}_i^H\mathbf{g}_i\}$ is a block diagonal matrix, i.e., $\mathbb{E}\{\mathbf{g}_i^H\mathbf{g}_i\} = \mathrm{diag}\{\mathbb{E}\{\mathbf{g}_{i1}^H\mathbf{g}_{i1}\}, \ldots, \mathbb{E}\{\mathbf{g}_{iN_c}^H\mathbf{g}_{iN_c}\}\}$.

Considering that $\mathbf{H}_{U,i}$ is a diagonal matrix, both $\mathbf{\Omega}_i$ and $(N_u\sigma^2/(N_cP_0)+\sum_{j\neq i}\mathbf{\Omega}_j)^{-1}\mathbf{\Omega}_i$ are block diagonal matrices. It is easy to find that the eigenmatrix of a block diagonal matrix is also block diagonal, thus $\mathbf{v}_{\mathrm{opt},i}$ is a row of the eigenmatrix. Then from (15) we know that $\mathbf{w}_i$ includes only one nonzero vector $\mathbf{w}_{im}$.

This implies that each user is served by only one BS, but each BS may serve multiple users in multiple cells. In this case, the proposed robust multiuser precoder acts like BS selection. Nonetheless, the precoder exploits the channels of users in other cells to avoid the interference to them. Each BS does not independently use the maximal ratio transmission [13], which is optimal for single-user scenario. Therefore, the CoMP transmission is not the traditional macro diversity.

When the antenna self calibration among antennas performs beyond these two cases, the proposed robust multiuser precoder can adaptively control the cooperation level among the coordinated BSs according to the statistics of the ambiguity factors which are able to be known *a priori*.

IV. Simulation Results

In this section we evaluate the performance of the proposed robust multiuser precoder via simulations by comparing it with the case of perfect antenna calibration, and the non-robust SLNR precoder [12] for both CoMP systems and non-CoMP systems. In non-CoMP systems, the user is only served by its master BS (the BS that provides the maximum received power), where the inter-cell interference exists. The simulation setup is based on [14]. In particular, we consider a CoMP system consisting of 3 coordinated cells as shown in Fig. 2. The BS-to-BS distance is 500 m, and the channel bandwidth is 10 MHz. The BSs transmit with a maximal power of 40 W, and the users have a receiver noise figure of 9 dB. The path loss exponent is 3.76, the average power loss at the reference distance of 1 m is 36.3 dB, and the minimum distance between user and BS is 35 m. The users are uniformly distributed in 3 cooperative cells. For each drop of users, the Rayleigh fading channels consisting of i.i.d. complex Gaussian variables with zero mean and unit variance are assumed. All the results are averaged over 100 drops.

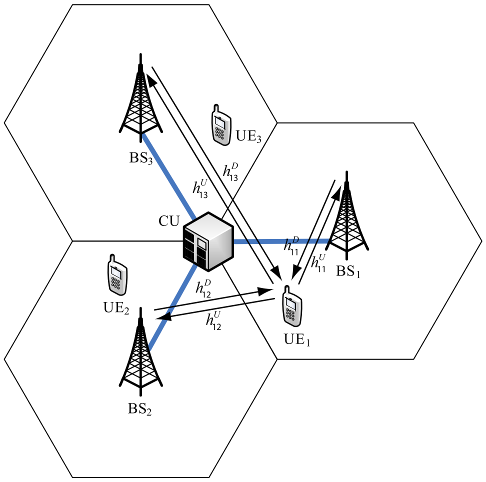

Fig. 2. Network layout for simulation: a cooperative cluster consisting of 3 coordinated BSs connected to the CU via low-latency backhaul.

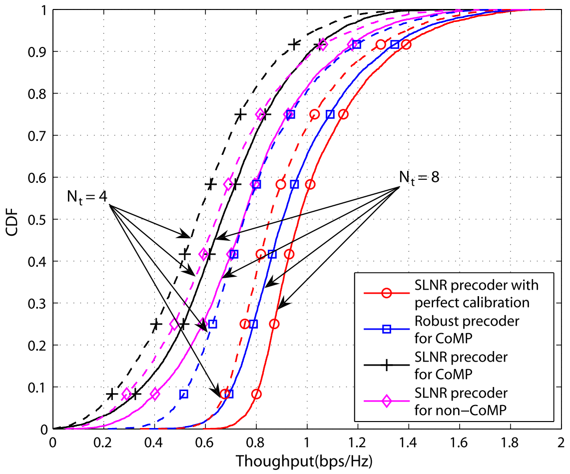

Fig. 3. The CDF of the throughput achieved by each individual user with defferent multiuser precoders, $N_t = 4$ and $N_t = 8$.

We assume that the port errors $g_{im}^{(1)}$ of different BSs are independent. Their amplitudes are modeled as a log-uniformly distributed variable within [-3,3] dB, and their phases are modeled as a uniformly distributed variable within $[-180°, 180°]$ [5]. The residual errors $g_{ik_{mn}}^{(2)}$ are assumed to be independent for all antennas in coordinated BSs. Their amplitudes are modeled as a log-uniformly distributed variable within [-1,1] dB, and their phases are modeled as a uniformly distributed variable within$[-10°, 10°]$ [9].

Figure 3 shows the cumulative distribution function (CDF) of user throughput of the considered four scenarios. 4 or 8 antennas at each BS are used, and 3 users located in different cells are served. Compared with the non-CoMP systems, the CoMP systems do not always perform better, which depends on the accuracy of the reciprocity between uplink and downlink channels. When perfect antenna calibration is assumed, the cooperation of multiple BSs can effectively eliminate inter-cell interference, and significantly improve the system performance. Yet, with imperfect antenna calibration and the traditional non-robust SLNR precoder that naively regards the uplink channels as the downlink channels, the performance of CoMP systems is even inferior to that of non-CoMP systems. By using the proposed robust precoder, an evident performance gain can be observed over the non-robust SLNR precoder for both CoMP and non-CoMP systems, where both the cell-average throughput and the cell-edge throughput[1] are significantly improved, which are the common metrics for performance evaluation of CoMP systems.

Comparing the CDF of the user throughput of the systems with 4 and 8 antennas at the BS, we find that the performance gain of the proposed robust precoder over the non-robust SLNR precoder increases with the growth of the number of antennas. This is because the proposed robust precoder is able to make better use of the more spatial degree of freedom to combat the interference than the non-robust SLNR precoder.

To examine the impact of using the proposed precoder on the accuracy requirement of the reference antenna used in self calibration, we assume that the phases of port errors are uniformly distributed within $[-\theta, \theta]$. Fig. 4 plots the cell-average throughput of the proposed robust precoder and the non-robust SLNR precoder as a function of θ. It can be seen that to achieve 80% of the cell-average throughput of a CoMP system with perfect antenna calibration, the non-robust SLNR precoder requires θ to be less than $20°$, whereas the proposed robust precoder allows θ to be less than $75°$. This means that a much lower accuracy is required for the reference antenna when using the proposed robust precoder. It suggests that simple self calibration within each BS using a less accurate reference antenna is sufficient for antenna calibration in CoMP systems when the proposed robust precoder is used. This is very attractive since the manufacture of high-accuracy antennas is hard and of high cost.

V. CONCLUSION

In this paper we considered the non-ideal channel reciprocity in TDD CoMP systems led by imperfect antenna calibration. To alleviate the performance degradation due to the loss of channel reciprocity, we proposed a robust multiuser precoder aimed at maximizing the lower bound of each user's average SLNR subject to PBPC. Simulation results show that the proposed robust precoder can significantly improve the performance of CoMP systems compared with the non-robust SLNR precoder. We also show that the self calibration within each BS using a relatively low accurate reference antenna is sufficient for retrieving the reciprocity in CoMP systems when the proposed robust precoder is applied.

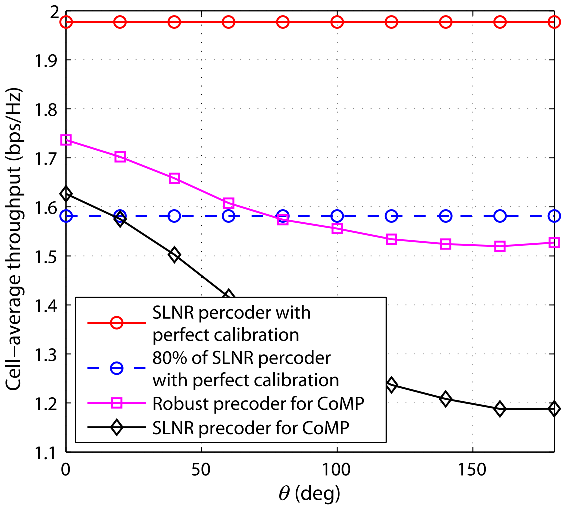

Fig. 4. The influence of different multiuser precoders on the accuracy requirements of the reference antenna for self calibration with each BS, $N_t = 2$.

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[1] The cell-edge throughput is defined as the 5% point of the CDF of the user spectral efficiency. In the simulations, the user capacity is obtained via the Shannon capacity formula.