Impact Evaluation of Imperfect Channel State Information on the Performance of Downlink CoMP Systems

Rodrigo L. Batista, Tarcisio F. Maciel, Yuri C. B. Silva and Francisco R. P. Cavalcanti

***Abstract*— Coordinated Multi-Point (CoMP) systems promise very high performance in terms of spectral efficiency and coverage benefits when perfect Channel State Information (CSI) is available at the transmitter. However, perfect CSI is difficult to obtain in CoMP systems due to an increased number of channel parameters to estimate at the receiver and to be fed back to the transmitter. So, the performance of such systems is compromised when the CSI is not perfectly known during CoMP processing such that it is an important problem to be addressed. This paper provides system-level analyses for strategies of Radio Resource Allocation (RRA) in CoMP systems, which consider dynamic Space Division Multiple Access (SDMA) grouping and joint precoding and power allocation for Signal to Interference-plus-Noise Ratio (SINR) balancing, and assumes imperfect CSI in order to achieve more accuracy with regard to the real-world implementations. Our results show a critical degradation on performance of the CoMP systems due to imperfect CSI.**

***Keywords*— CoMP, SDMA grouping, SINR balancing, imperfect CSI.**

I. INTRODUCTION

In Long Term Evolution (LTE)-Advanced, several Antenna Ports (APs) can be connected to a central controller, termed here Enhanced Node B (eNB), through a fast backhaul and then constitute a Coordinated Multi-Point (CoMP) system. Indeed, using the backhaul, CoMP systems become able to exchange data, control information and Channel State Information (CSI) with all APs under the command of the eNB and, consequently, coordinate interference. The CSI available at the eNB can be used to mitigate intra-cell interference and efficiently separate streams intended to different User Equipments (UEs) [1]. Considering that CoMP is a serious candidate to boost system throughput and to allow for an efficient Radio Resource Allocation (RRA), it is important to highlight that its benefits are strongly constrained to practical aspects.

In [1], an Space Division Multiple Access (SDMA) grouping algorithm selects a set of spatially compatible UEs that can efficiently share the same resource in space while the spatial multiplexing of signals conveyed through them is done using precoding. However, the system throughput might be improved in [1] with an adaptive size of the UEs set, such that it can be dynamically adapted according to channel conditions and the load of UEs. The throughput of the scheduled UEs can be improved when each one is subject to a Signal to Interference-plus-Noise Ratio (SINR) constraint. An iterative algorithm to maximize the minimum SINR of a set of co-channel links is proposed in [2] such that data streams are transmitted from multiple antennas to several single-antenna UEs under a sum power constraint. However, this solution has some limitations in the CoMP scenario, in which UEs are subject to strong inter-cell interference and there is a power limitation per antenna [1].

These implementations have assumed an instantaneous, complete and error-free CSI. However, CSI at the UE is obtained through channel estimation, which is in general inaccurate and thus the measured channel is only an erroneous estimate of the actual channel [3], [4]. In general, the channel estimation is also limited since each UE is not able to estimate their channels for all the APs in the CoMP system, but instead it performs estimation only for the strongest channels. Other limitation with respect to limited CSI is concerning the number of channels that can be reported to the eNB via feedback channel [5]. Since each receiver has performed channel estimation, the UE should inform its CSI to the transmitter by using the uplink feedback channel. But there is always a time delay between the instant of CSI measurement and the actual instant of transmission of the data. From this it follows that the CSI available at the transmitter is outdated [6].

In a more realistic CoMP scenario, channel estimation errors, partial CSI feedback and outdated CSI shall be assumed in an imperfect CSI model. The main contribution of this paper is to provide system-level analyses for the impact of imperfect CSI on the performance of the RRA strategies for downlink CoMP systems described in the following:

- The objective of the dynamic SDMA grouping is to find a suitable set of UEs for spatial multiplexing [1];
- The SINR balancing aims to ensure a certain level of link quality and thus provide a more reliable communication for the scheduled UEs in an SDMA group[2].

Some notational conventions are adopted: we use italic letters for scalars, lowercase boldface letters for vectors and uppercase boldface letters for matrices. Calligraphic letters are used to represent sets and $|\cdot|$ denotes the set cardinality. $\mathbb{E}$ denotes the expectation of a random variable. $\|\cdot\|_1$ and $\|\cdot\|_2$ denote 1- and 2-norms, respectively. $(\cdot)^T$ and $(\cdot)^H$ denote transpose and conjugate transpose, respectively. Finally, the j^{th} component of a vector $\mathbf{p}$ is denoted by p_j.

The remainder of this paper is organized as follows: In Section II, the system model is addressed. Section III presents the formulations for the SDMA grouping and SINR balancing problems. In Section IV we show some RRA strategies in CoMP systems. Section V presents and discusses simulation results. Finally, Section VI draws the main conclusions.

Rodrigo L. Batista, Tarcisio F. Maciel, Yuri C. B. Silva and Francisco R. P. Cavalcanti, Departamento de Engenharia de Teleinformática, Universidade Federal do Ceará, Fortaleza, Ceará, Brasil, e-mails: {rodrigobatista, maciel, yuri, rodrigo}@gtel.ufc.br

II. System Model

In this section, the models adopted to evaluate the system performance are presented. We consider a CoMP system composed of C CoMP-cells, where each one consists of one eNB and several 3-sector cells under its control. In this model each sector of the 3-sector cell is represented by a regular hexagon and the transmission points, termed here APs, are placed on the corner shared by the sectors [1].

For downlink CoMP, 3rd Generation Partnership Project (3GPP) specifies the Orthogonal Frequency Division Multiple Access (OFDMA) technology. Usually, due to signaling constraints, subcarriers are not allocated individually, but in blocks of adjacent subcarriers, which represent the Physical Resource Blocks (PRBs) [7]. Channel coherence bandwidth is assumed larger than the bandwidth of a PRB leading to flat fading over each PRB. There exist N PRBs in the system and each of them might be assigned to one or more UEs in each CoMP-cell. In this paper, Equal Power Allocation (EPA) among PRBs is considered and the total transmit power P_{total} available on each sector is equally divided among the N PRBs, i.e., the maximum power allocated to each PRB is $P_{max} = P_{total}/N$.

Each CoMP-cell c controls a number M of APs and serves a number J of single-antenna UEs, which are uniformly distributed over its coverage area. In the following, our discussion is restricted to one PRB n, such that we will omit the index n for simplicity of notation. The modeling of the link between a UE j and an AP includes propagation effects on the wireless channel, namely, path loss, shadowing, short-term fading and also includes the antenna gains. Considering these effects, the signal $y_{j,c}$ received by UE j on a given PRB from all M APs in CoMP-cell c may be written as

$$y_{j,c} = \mathbf{h}_{j,c}\mathbf{x}_{j,c} + \underbrace{\sum_{j'\neq j}^{\mathrm{J}} \mathbf{h}_{\mathrm{j,c}}\mathbf{x}_{\mathrm{j',c}}}_{z_{j,c}^{intra}} + \underbrace{\sum_{c'\neq c}^{\mathrm{C}} \sum_{j'}^{\mathrm{J}} \mathbf{h}_{\mathrm{j},c'}\mathbf{x}_{\mathrm{j'},c'}}_{z_{j,c}^{inter}} + \eta_{j,c}, \quad (1)$$

where $j = 1, 2, \ldots, J$, $c = 1, 2, \ldots, C$, $\mathbf{h}_{j,c} \in \mathbb{C}^{1\times M}$ is the complex channel vector whose elements combine all the previously mentioned propagation effects and which models the link between the j^{th} UE and all M APs in CoMP-cell c, $\mathbf{x}_{j,c} \in \mathbb{C}^{M\times 1}$ is the symbol vector transmitted by the M APs of CoMP-cell c to the j^{th} UE, $\eta_{j,c} \in \mathbb{R}$ is the Additive White Gaussian Noise (AWGN), with zero mean and variance σ_η^2, perceived by the j^{th} UE in CoMP-cell c. The intra-CoMP-cell interference $z_{j,c}^{intra}$ is known to the eNB, since we assume the eNB can have perfect channel knowledge about all links of its APs. Even though the inter-CoMP-cell interference $z_{j,c}^{inter}$ is unknown to the eNBs it can be estimated by the UE j and reported to its APs via feedback channel.

In practice, channel knowledge is often obtained by sending known training symbols to the UE. However, we assume that it is done in a separate control channel. Assuming also Minimum Mean Square Error (MMSE) estimation, the channel estimate $\hat{\mathbf{h}}_{j,c}$ can be modeled, like in [8], by

$$\hat{\mathbf{h}}_{j,c} = \sqrt{1-\rho}\,\mathbf{h}_{j,c} + \sqrt{\rho}\,\mathbf{e}_{j,c}, \quad (2)$$

where $\mathbf{e}_{j,c} \in \mathbb{C}^{1\times M}$ is the complex channel estimation error vector whose entries are Zero-Mean Circular Symmetric Complex Gaussian (ZMCSCG) random variables with variance $\sigma_\mathbf{e}^2$ and ρ is a parameter that captures the quality of the channel estimation. By the property of MMSE estimation [9], the channel estimate $\hat{\mathbf{h}}_{j,c}$, whose entries are i.i.d. ZMCSCG variables with variance $\sigma_{\hat{\mathbf{h}}}^2$, is uncorrelated with $\mathbf{e}_{j,c}$. Assuming $\sigma_\mathbf{e}^2 = \sigma_\mathbf{h}^2$, we have that the estimated channel variance is given by $\sigma_{\hat{\mathbf{h}}}^2 = (1-\rho)\sigma_\mathbf{h}^2 + \rho\sigma_\mathbf{e}^2 = \sigma_\mathbf{h}^2$ and so the channel energy is preserved. Note that the parameter ρ models exactly the percent of channel error $\mathbf{e}_{j,c}$ in comparison to the estimated channel $\hat{\mathbf{h}}_{j,c}$, as we can see in the following

$$\frac{\mathbb{E}\left\{\left[\sqrt{\rho}\,\mathbf{e}_{j,c}\right]^2\right\}}{\mathbb{E}\left\{\left[\hat{\mathbf{h}}_{j,c}\right]^2\right\}} = \rho\frac{\sigma_\mathbf{e}^2}{\sigma_{\hat{\mathbf{h}}}^2} = \rho. \quad (3)$$

In our model, the UE is able to generate a meaningful estimate for the channels with the l highest channel gains among a number MC of APs in all the CoMP system. The set of the l strongest channels of a given UE j is denoted by $\mathcal{L}_j$. Each link among the UE j and the M APs of its CoMP-cell c that can not be estimated, i.e., do not belong to the set $\mathcal{L}_j$ and so can not be reported to eNB, is filled with zeros in the resulting channel vector, which is denoted by $\hat{\mathbf{h}}_{j,c}^{l}$.

The channel after estimation is reported to its APs via feedback channel in which time delays can occur. For the sake of simplicity, we assume that all UEs in the CoMP system experience the same time delay, which is denoted by a number $\Delta\tau$ of Transmission Time Intervals (TTIs). Then, the estimated channel and outdated in $\Delta\tau$ TTIs, i.e., the CSI used in CoMP processing, is denoted by $\tilde{\mathbf{h}}_{j,c} = \hat{\mathbf{h}}_{j,c}^{l,\Delta\tau}$.

Since the CSI is available at the eNB it can be used to mitigate intra-cell interference $z_{j,c}^{intra}$ and separate efficiently streams intended to different UEs. This task is accomplished, e.g., by employing precoding techniques [10] which adaptively weight the symbols transmitted from each antenna in the CoMP-cell. We write the transmitted signal $\mathbf{x}_{j,c}$ as

$$\mathbf{x}_{j,c} = \mathbf{w}_{j,c}\sqrt{p_{j,c}}\,s_{j,c}, \quad (4)$$

where $\mathbf{w}_{j,c} \in \mathbb{C}^{M\times 1}$ is the unitary-norm precoding vector for the link between UE j and the APs of the CoMP-cell c, $p_{j,c} \in \mathbb{R}$ is the transmit power allocated for the UE j and $s_{j,c} \in \mathbb{C}$ is the unit-variance data symbol to be sent to UE j.

For each PRB and CoMP-cell c, whose index is also omitted in the sequel for simplicity of notation, the SDMA grouping algorithm will select a set $\mathcal{G} \subset \{1, 2, \ldots, J\}$ of UEs to receive data, where the number of UEs it contains will be denoted by $G = |\mathcal{G}|$. Then, considering an SDMA group $\mathcal{G}$, we can also define a channel matrix $\tilde{\mathbf{H}} = \begin{bmatrix}\tilde{\mathbf{h}}_1^\mathrm{T} & \tilde{\mathbf{h}}_2^\mathrm{T} & \ldots & \tilde{\mathbf{h}}_G^\mathrm{T}\end{bmatrix}^\mathrm{T}$, a precoding matrix $\mathbf{W} = \begin{bmatrix}\mathbf{w}_1 & \mathbf{w}_2 & \ldots & \mathbf{w}_G\end{bmatrix}$ and a power allocation vector $\mathbf{p} = [p_1 \quad p_2 \quad \cdots \quad p_G]^T$.

On each TTI we consider instantaneous spatial covariance values instead of values calculated with the expectation, during which the time-fluctuating fading channel is assumed constant over all the symbols. Defining the approximate spatial covariance matrices as

$$\mathbf{R}_j = \tilde{\mathbf{h}}_j^H \tilde{\mathbf{h}}_j, \qquad \forall j \in \mathcal{G}, \quad (5)$$

the SINR $\gamma_j(\mathbf{W},\mathbf{p})$ perceived by UE j can be given by

$$\gamma_j(\mathbf{W},\mathbf{p}) = \frac{p_j \mathbf{w}_j^H \mathbf{R}_j \mathbf{w}_j}{\underbrace{\sum_{j' \neq j}^{G} p_{j'} \mathbf{w}_{j'}^H \mathbf{R}_j \mathbf{w}_{j'}}_{z_j^{intra}} + z_j^{inter} + \sigma_\eta^2}, \forall j \in \mathcal{G}. \quad (6)$$

III. Problem Statement

While the spatial multiplexing of signals intended to different UEs is done using precoding, spectral efficiency gains are often obtained by transmitting to spatially compatible UEs, i.e., a given group of UEs whose channels are propitious for the spatial separation of signals conveyed through them [11]. The problem to be solved here is to choose a set $\mathcal{G}$ of UEs that can efficiently share the same PRB in space. We present the formulation for this SDMA grouping problem in Section III-A.

In order to provide a more reliable communication for the UEs of the SDMA group $\mathcal{G}$, it is desirable to support a certain level of link quality, which mainly depends on the SINR. Hence, the quality of UEs' links might be assured if individual target SINR values are met [2]. We present the SINR balancing problem in a CoMP scenario where each UE is subject to an SINR constraint in Section III-B.

A. SDMA Grouping Problem

To solve this problem, SDMA grouping algorithms which avoid placing UEs with highly correlated channels in the same SDMA group $\mathcal{G}$ are usually employed [11]. Normally, SDMA grouping algorithms are heuristics composed by two elements: a **grouping metric** and a **grouping algorithm** [11]. While the metric measures the spatial compatibility among the UEs in an SDMA group based on the CSI available at the eNB of the CoMP-cell, the grouping algorithm, based on the grouping metric, builds and compares different SDMA groups. Once the SDMA group $\mathcal{G}$ is determined, **precoding**, **power allocation** and link adaptation can be realized. After that, performance gains can be achieved with dynamic adaptation of SDMA group size.

B. SINR Balancing Problem

In order to provide a more reliable communication to the UEs grouped in the SDMA group $\mathcal{G}$, target SINR values $\gamma_j^t, \forall j \in \mathcal{G}$ to be met with the SINR balancing algorithm are defined by the link adaptation. For this purpose, consider a total power constraint on all antennas of each CoMP-cell expressed as $P_{sum} = GP_{max}$. Thus, the SINR balancing problem can be written as

$$C(P_{sum}) = \max_{\mathbf{W},\mathbf{p}} \min \frac{\gamma_j(\mathbf{W},\mathbf{p})}{\gamma_j^t}, \qquad \forall j \in \mathcal{G}, \quad (7a)$$

$$\text{subject to } \|\mathbf{w}_j\|_2 = 1, \quad (7b)$$

$$\|\mathbf{p}\|_1 \leq P_{sum}. \quad (7c)$$

IV. RRA Strategies

In Section IV-A, an SDMA grouping algorithm is employed in order to find a suitable set of UEs for spatial multiplexing. Next, in Section IV-B, the SINR balancing problem (7) is solved efficiently in the CoMP scenario by an iterative beamformer and power update algorithm [2].

A. SDMA Grouping Algorithm

In the following, grouping metric, grouping algorithm, precoding, power allocation and dynamic adaptation of SDMA group size are described.

Grouping metric: Here, we consider the sum of channel gains with null space successive projections as grouping metric [11]. For this metric, the channels of a set of UEs are successively projected onto the null space of the channels of previously selected UEs for the SDMA group. In [1], this metric is described in more details.

Grouping algorithm: In this work, we consider the Best Fit (BF) algorithm [1], which is a greedy scheduler. Starting from an SDMA group containing an initial UE j', the BF algorithm extends the group by sequentially admitting the most spatially compatible UE with respect to the UEs already admitted to the SDMA group. Adding UEs is done until the group size G reaches the target SDMA group size $G^\star$.

Spatial precoding: In this approach, Zero-Forcing (ZF) precoding is considered, which steers a beam towards UE j direction and nulls in the direction of the UEs $j' \neq j$, thus eliminating intra-CoMP-cell interference [10]. For the SDMA group $\mathcal{G}$ with channel matrix $\tilde{\mathbf{H}}$, the precoding vectors $\mathbf{w}_j$ building the precoding matrix $\mathbf{W}$ are given by

$$\mathbf{w}_j = \tilde{\mathbf{h}}_j^\dagger / \|\tilde{\mathbf{h}}_j^\dagger\|_2, \qquad \forall j \in \mathcal{G}, \quad (8)$$

where $\tilde{\mathbf{h}}_j^\dagger$ represents the j^{th} column of the pseudo-inverse $\tilde{\mathbf{H}}^\dagger = \tilde{\mathbf{H}}^{\mathrm{H}} \left(\tilde{\mathbf{H}}\tilde{\mathbf{H}}^{\mathrm{H}}\right)^{-1}$ of the group channel matrix $\tilde{\mathbf{H}}$ of $\mathcal{G}$.

Power scaling: Because no AP can use more power than P_{max}, power scaling is necessary. Since the vector $\mathbf{p}$ considers EPA among the UEs, the power scaling is simply performed by scaling the whole precoding matrix $\mathbf{W}$ so that the squared norm of the row with highest norm becomes equal to one [1].

Dynamic SDMA Group Size: The previous steps may be insufficient to ensure a reliable transmission of all UEs in an SDMA group $\mathcal{G}$. Sequential Removal Algorithms (SRAs) remove UEs from an SDMA group $\mathcal{G}$ while throughput gains are achieved. Thus, the released power in each removal could be allocated to the remaining UEs so that these can achieve transmission or get more gains on their performance. The UE j^* with the lowest effective channel gain is removed as defined below [8]

$$j^* = \arg\min_j \|\tilde{\mathbf{h}}_j \mathbf{w}_j\|_1^2, \qquad \forall j \in \mathcal{G}. \quad (9)$$

B. SINR Balancing

The downlink SINR values (6) of all UEs are coupled by the intra-cell interference z_j^{intra}, which depends on both beamforming vectors $\mathbf{w}_{j'}$ and transmission powers $p_{j'}$. Thus, the power allocation and the beamforming cannot be optimized separately. The downlink problem (7) is much hard to solve, but its uplink dual can be more easily solved by an iterative uplink beamformer and power update algorithm [2].

However, in [2], a single-cell case is considered and inter-cell interference z_j^{inter} is not included in the model. In this section, we investigate this solution with small modifications in a CoMP scenario, in which there is a power limitation by AP and UEs are subject to strong inter-CoMP-cell interference. In order to achieve similar conditions, we incorporate the effect of z_j^{inter} into the effect of noise such that, now, we shall scale matrices $\tilde{\mathbf{R}}_j = \mathbf{R}_j/(\sigma_\eta^2 + z_j^{inter})$, $\forall j \in \mathcal{G}$. In the following, we present power assignment, beamforming and power scaling due to the power limitation P_{max} per AP.

Power assignment: For fixed beamformers $\tilde{\mathbf{W}}$, the downlink problem (7) reduces to a pure power assignment. The authors in [2] give the proof that the optimum of the downlink power assignment is achieved for $\|\mathbf{p}\|_1 = P_{sum}$. An eigensystem can be formulated for problem (7) such that the optimal downlink power vector $\mathbf{p}$ is obtained by the dominant eigenvector associated to the maximal eigenvalue [2].

Beamforming: For a given power allocation $\tilde{\mathbf{p}}$, the beamformers $\mathbf{w}_j$, $\forall j \in \mathcal{G}$, are obtained by G decoupled problems, where the optimal beamformer of each UE is the solution of a generalized eigenvector problem [2].

Power scaling: Differently from power scaling under ZF precoding, the power assignment of SINR balancing achieves different power allocations for each UE. Thus, the power scaling must be performed by scaling the whole matrix $\mathbf{U} = \mathbf{W}\sqrt{\text{diag}\{\mathbf{p}\}}$ and in this case the squared norm of the row with highest norm becomes equal to P_{max}.

V. Analysis

The RRA problems described in Section III are analysed here through system-level simulations. These are organized in snapshots, during which the path loss and shadowing are assumed to remain constant for all the UEs while the time variations of fast fading are considered. In order to capture the impact of long term propagation effects on the system performance, several snapshots are simulated. The main parameters considered in the simulation are summarized in Table I.

Regarding the knowledge assumed about the inter-CoMP-cell interference for a given UE and PRB, we use the last measured interference value as the inter-CoMP-cell interference estimate of the current TTI. In order to capture communication errors and their impact on the system throughput, we employed a model to determine packet loss based on the Packet Error Rate (PER). The Quadrature Amplitude Modulation (QAM) modulation scheme for each transmission is chosen such that the average throughput is maximized, where q is the number of bits/symbol and L the number of symbols being transmitted on a single PRB during one TTI.

In the following we will investigate the impact of imperfect CSI on the performance of the RRA strategies described in Sections IV-A and IV-B, namely, SDMA grouping and SINR balancing algorithms, respectively. Their performances are compared to the performance achievable with perfect CSI by analyzing the system spectral efficiency for two system loads given in number of UEs per sector.

Table I

Simulation parameters.

Parameter	Value
Number of CoMP-cells (C)	7 (with wrap-around) [1]
Number of APs per CoMP-cell	21 (7 three-sectorized cells)
Sector radius	334 m
Minimum AP-UE distance	50 m
Snapshot duration	1 s
Effective TTI duration	1 ms
Number of symbols/TTI	14
Carrier frequency	2 GHz
Subcarrier bandwidth	15 kHz
Number of subcarriers per PRB	12
Number of PRBs (N)	6
System bandwidth	1.92 MHz
Path loss model	$35.3 + 37.6\log_{10}(d)$ dB [12]
Antenna pattern	$A(\theta^\circ) = -\min\left\{12\left[\frac{\theta^\circ}{70^\circ}\right]^2, 20\right\}$ dB [13]
Channel profile	Typical Urban (TU) [13]
Shadowing standard deviation	8 dB
Required SNR at the cell border	10.7 dB
Traffic model	Full buffer
User distribution	Uniform in entire network
Number of UEs per sector	3 and 12
Average UEs' speed	3 km/h
Power control	EPA among PRBs
Modulation scheme	4-QAM, 16-QAM, 64-QAM
BER for uncoded QAM	BER $\approx \frac{4}{q}\left(1-\frac{1}{\sqrt{2^q}}\right)Q\left(\sqrt{\frac{3}{2^q-1}\gamma_j}\right)$ [14]
PER	$\text{PER} = 1-(1-\text{BER})^{Lq}$ [14]
Modulation scheme	$M^\star = \underset{M=2^q, q\in\{2,4,6\}}{\arg\max}\{(1-\text{PER})Lq\}$

The effect of channel estimation error on the system spectral efficiency is shown in Fig. 1.

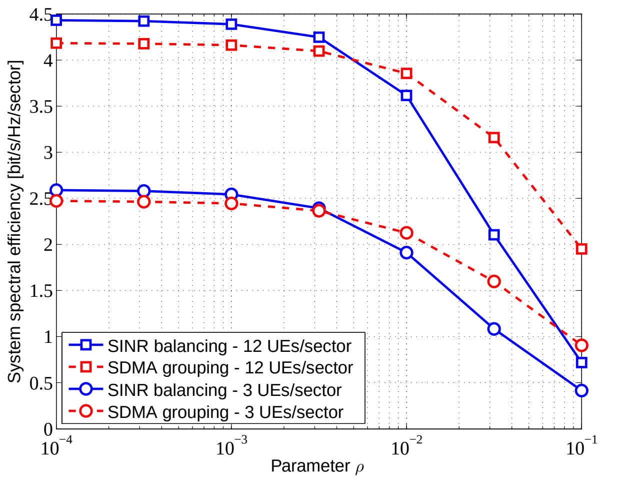

Fig. 1. Channel estimation errors for $l = 21$ antennas and $\Delta\tau = 0$ TTIs.

As we can see in Fig. 1, in the absence of errors on channel estimation, or when these are negligible, the SINR balancing provides significant gains in relation to SDMA grouping for both loads in UEs, because it performs a better power distribution. However, the SINR balancing is more sensitive to imperfections on channel estimation than the SDMA grouping. The losses in the spectral efficiency are apparent just from a given value of ρ. We observed that for 12 UEs/sector and $\rho = 10^{-2}$ the spectral efficiency decreases significantly for both algorithms. Note that $\rho = 10^{-2}$ represents the introduction of estimation errors in the estimated channel vector $\hat{\mathbf{h}}_j$ with 10% of magnitude of the error vector $\mathbf{e}_j$.

Fig. 2 shows the effect of partial CSI feedback on the system spectral efficiency.

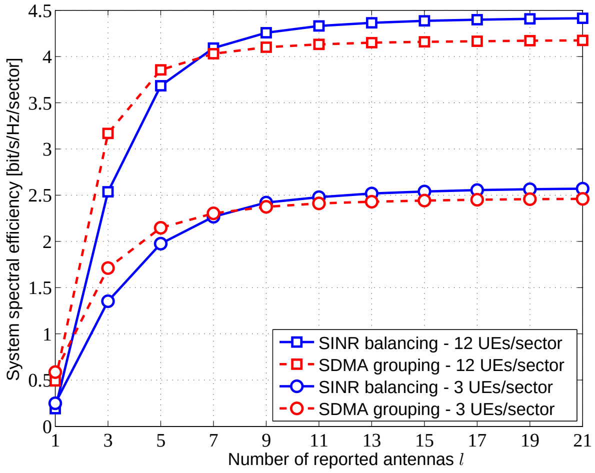

Fig. 2. Partial CSI feedback for $\rho = 0$ and $\Delta\tau = 0$ TTIs.

From Fig. 2, we can see that just a small part of the CSI of all available APs in a CoMP system is necessary for maintaining the performance achieved with complete CSI. Besides, since each UE reports just the CSI relative to its coordinated group instead of the CSI from all APs it can estimate in the CoMP system, it is important to mention that the amount of signaling reported by each UE varies depending on the UE's location. Note also that the reduction of overhead is much more significant than the performance loss due to partial CSI feedback.

The effect of feedback delay on the system spectral efficiency is shown in Fig. 3.

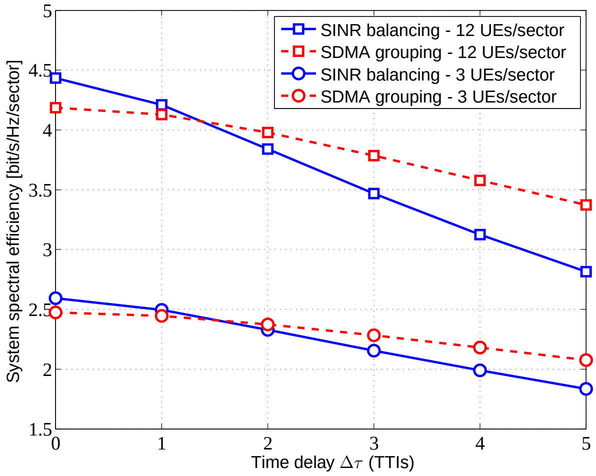

Fig. 3. Outdated channel knowledge for $\rho = 0$ and $l = 21$ antennas.

As we can see in Fig. 3, the system spectral efficiency decreases almost linearly with the feedback delay such that its effect could not be neglected when modeling CoMP systems.

VI. Conclusions

Basically we evaluated the performance of RRA algorithms over models for imperfect CSI. The performance of the SINR balancing outperforms the performance of SDMA grouping when perfect CSI is assumed. However, the SINR balancing shows a more critical degradation on its performance due to imperfect CSI in comparison to SDMA grouping.

Results about channel estimation errors corroborated that it is a very critical point on the performance of CoMP systems. It is known that a large amount of signaling is required to ensure the complete CSI by the eNB. Indeed, we run into the trade-off between the potential performance gains of cooperation versus the increased signaling overhead. We verified that just a substantial amount of signaling is required to ensure a reliable cooperative transmission. Results about outdated channel knowledge showed that it deserves attention specially if some feedback delay constraint is assumed.

From the results, we can see that the performance loss due to imperfect CSI is inherent to CoMP systems. Thus, practical aspects such as channel estimation errors, limited feedback and feedback delay can not be neglected by the cooperative transmission techniques of CoMP systems.

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