Interference management and antenna downtilt in multi-antenna CoMP systems

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***Abstract*— Long Term Evolution (LTE)-Advanced has regarded both Coordinated Multi-Point (CoMP) and Multiple Input Multiple Output (MIMO) technologies as an efficient means of meeting the International Mobile Telecommunications (IMT)-Advanced requirements. In this context, efficient Radio Resource Allocation (RRA) strategies are required to exploit the available spatial degrees of freedom, coordinate the resources usage and manage the interference in order to obtain performance gains. This paper provides system-level analyses in a downlink multi-antenna CoMP system for the performance gains achieved with the inter-cell interference management through antenna downtilt and the use of interference estimates in RRA strategies such as spatial precoding and power allocation. For both spatial diversity and multiplexing schemes, the results showed that quite high performance gains in terms of system spectral efficiency are achieved through antenna downtilt and that RRA strategies always benefit from estimates of the inter-cell interference.**

***Keywords*— Interference management, Coordinated Multi-Point (CoMP), precoding algorithms.**

I. INTRODUCTION

In order to improve the performance of conventional cellular networks, multi-cell coordinated transmission is one of the techniques proposed in the context of Long Term Evolution (LTE)-Advanced. By allowing coordination among adjacent Enhanced Node Bs (eNBs), coordinated transmission strategies can be applied at the same time that the interference is managed [1]–[3]. Indeed, one key challenge inherent to the Coordinated Multi-Point (CoMP) systems is to mitigate the interference [4].

In [2], [3], Radio Resource Allocation (RRA) strategies that exploit the cooperative transmission in CoMP systems are investigated in order to manage the intra-cell interference. The Channel State Information (CSI) available in CoMP systems is used to mitigate intra-cell interference and efficiently separate streams intended to different User Equipments (UEs) through spatial precoding and adaptive Space Division Multiple Access (SDMA) grouping. However, CoMP systems are also strongly influenced by the inter-cell interference. Even though it is unknown to RRA strategies, an estimate can be used and so the cooperative transmission can be significantly improved. Besides RRA strategies, downtilt antenna is also a practical solution to reduce this inter-cell interference. Networks that adequately adjust the antenna tilt have a much better cell isolation against the inter-cell interference [5].

An inter-cell interference estimate and antenna downtilt can be used to improve RRA strategies and manage the interference. The main contribution of this paper is to provide system-level analyses for the performance gains achieved with the RRA strategies for rate maximization in downlink multi-antenna CoMP systems, as described in the following:

- Analysis of CoMP with multi-antenna nodes considering spatial multiplexing and diversity modes;
- An inter-cell interference estimate is used on precoding and power allocation algorithms;
- Analysis of the antenna downtilt on mitigating the inter-cell interference.

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. x^+ is the maximum between x and zero. p_j denotes the j^{th} component of a vector $\mathbf{p}$. $\mathrm{diag}\{\mathbf{p}\}$ denotes a diagonal matrix, whose elements of the main diagonal are given by the vector $\mathbf{p}$. The $(i,j)^{\mathrm{th}}$ entry of a matrix is written as $[\cdot]_{i,j}$. $\|\cdot\|_2$ and $\|\cdot\|_{\mathrm{FRO}}$ denote 2- and Frobenius norms, respectively. $(\cdot)^{\dagger}$ represents the pseudo-inverse. Finally, $(\cdot)^{\mathrm{T}}$ and $(\cdot)^{\mathrm{H}}$ denote transpose and conjugate transpose, respectively.

The remainder of this paper is organized as follows. In section II, the system model is addressed. The RRA strategies are presented in section III. Simulation results are discussed in section IV. Finally, some conclusions are drawn in section V.

II. SYSTEM MODEL

In this section, the models adopted to evaluate the system performance are presented. The considered scenario corresponds to a multi-cell network with eNBs uniformly distributed over its coverage area. It is assumed that frequency resources can be fully reused in all cells. For downlink CoMP, the 3rd Generation Partnership Project (3GPP) specifies the use of 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) [6]. Channel coherence bandwidth is assumed larger than the bandwidth of a PRB, leading to flat fading over each PRB. There exist N_{PRB} PRBs in the system.

We consider a centralized transmission architecture for enabling the CoMP processing, where N_{eNB} eNBs connected to a central controller through a backhaul network [2] correspond to a CoMP-cell. We assume that the CoMP system is composed of C CoMP-cells, indicated by $c = 1, 2, \ldots, C$.

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Let us assume that each eNB is placed on the corner shared by the cells of the 3-cell site and that each cell is represented by a regular hexagon. The number of cells per CoMP-cell is denoted by $N_{\text{CELL}} = 3N_{\text{eNB}}$. Let us assume that each cell is equipped with N_{TX} directional co-located antennas and serves a number N_{UE} of UEs, each one equipped with N_{RX} co-located antennas. In general, each CoMP-cell serves a number $J = N_{\text{CELL}}N_{\text{UE}}$ of UEs uniformly distributed over its coverage area, indicated by $j = 1, 2, \dots, J$. We also assume that a CoMP-cell comprises $M = N_{\text{CELL}}N_{\text{TX}}$ transmission points, indicated by $m = 1, 2, \dots, M$, whose resource usage and transmission strategies are coordinated. In this system, each UE j can receive $L_j \leq N_{\text{RX}}$ data streams and the transmitter can send up to $S \leq M$ data streams, indicated by $s = 1, 2, \dots, S$, such that $S = \sum L_j$ and $s = (j-1)L_j + l$.

In the following, the discussion is restricted to one PRB n, such that the index n will be omitted for simplicity of notation. The modeling of the complex channel coefficients includes propagation effects on the wireless channel, namely, path loss, shadowing, short-term fading and also includes antenna gains. For a given PRB, the complex channel coefficients correspond to those associated with the middle subcarrier of the considered PRB. The channel matrix $\mathbf{H}_{j,c} \in \mathbb{C}^{N_{\text{RX}} \times M}$ that models the link between all N_{RX} receive antennas of the UE j and all M transmit antennas of the CoMP-cell c is given by

$$\mathbf{H}_{j,c} = \begin{bmatrix} \mathbf{h}_{1,j,c}^{\text{T}} & \mathbf{h}_{2,j,c}^{\text{T}} & \cdots & \mathbf{h}_{N_{\text{RX}},j,c}^{\text{T}} \end{bmatrix}^{\text{T}}, \tag{1}$$

where $\mathbf{h}_{r,j,c} \in \mathbb{C}^{1 \times M}$ denotes the complex channel vector that models the link between the receive antenna r of the UE j and all M transmit antennas of CoMP-cell c, for $1 \leq r \leq N_{\text{RX}}$.

In the Joint Processing (JP) transmission approach, for each PRB and CoMP-cell c, L data streams are transmitted from M multiple transmission points to several UEs through pre- and post-processing at transmitter and receiver, respectively. Each transmitted stream s, which is associated to UE j in the CoMP-cell c, is decoded by a receive filter, which is denoted by $\mathbf{d}_{s,c} \in \mathbb{C}^{1 \times N_{\text{RX}}}$, and coded by a transmit filter $\mathbf{m}_{s,c}$, which is given by

$$\mathbf{m}_{s,c} = \mathbf{w}_{s,c}\sqrt{p_{s,c}}, \tag{2}$$

where $\mathbf{w}_{s,c} \in \mathbb{C}^{M \times 1}$ is the precoding vector and $p_{s,c} \in \mathbb{R}$ is the transmit power allocated for the transmitted stream s.

Let us also assume that σ_η^2 denotes the variance of Additive White Gaussian Noise (AWGN) perceived at each UE of the CoMP system. The downlink Signal to Interference-plus-Noise Ratio (SINR) $\gamma_{s,c}$ of the transmitted stream s associated to UE j in the CoMP-cell c is obtained by

$$\gamma_{s,c} = \frac{|\mathbf{d}_{s,c}\mathbf{H}_{j,c}\mathbf{m}_{s,c}|^2}{z_{s,c}^{intra} + z_{s,c}^{inter} + \sigma_\eta^2}, \tag{3a}$$

where

$$z_{s,c}^{intra} = \sum_{s' \neq s}^{S} |\mathbf{d}_{s,c}\mathbf{H}_{j,c}\mathbf{m}_{s',c}|^2, \tag{3b}$$

$$z_{s,c}^{inter} = \sum_{c' \neq c}^{C} \sum_{s'}^{S} |\mathbf{d}_{s,c}\mathbf{H}_{j,c'}\mathbf{m}_{s',c'}|^2. \tag{3c}$$

In the following, the discussion is restricted to one CoMP-cell c, such that the index c will be omitted for simplicity of notation. In the LTE downlink, the UEs measure the perceived CSI and report it to set of transmission points. In CoMP systems, the availability of CSI allows the coordination by RRA strategies. The explicit feedback mechanism in support of downlink CoMP is characterized by having a channel part and an interference part [4]: $\mathbf{H}_j$ and z_s^{inter} for all stream s in a given CoMP-cell. Even though inter-CoMP-cell interference z_s^{inter} is unknown to the eNBs, it can be estimated by the UE and reported to its antennas via feedback channel. The intra-CoMP-cell interference z_s^{intra}, which is originated from antennas of a same CoMP-cell, can be efficiently managed by RRA strategies, since it is assumed perfect channel knowledge about all links within a CoMP-cell.

In this paper, RRA strategies are performed independently for each CoMP-cell and PRB, and can be organized into: SDMA grouping, precoding and power allocation. SDMA grouping algorithm will select a set $\mathcal{G} \subseteq \{1, 2, \dots, J\}$ of UEs within a CoMP-cell 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 define the channel matrix $\mathbf{H}_{\mathcal{G}} = \begin{bmatrix} \mathbf{H}_1^{\text{T}} & \mathbf{H}_2^{\text{T}} & \dots & \mathbf{H}_G^{\text{T}} \end{bmatrix}^{\text{T}} \in \mathbb{C}^{N_{\text{RX}}G \times M}$, which is used by the precoding algorithm to mitigate the intra-CoMP-cell interference and efficiently separate streams intended to UEs belonging to the SDMA group $\mathcal{G}$. Herein, the precoding matrix for $\mathcal{G}$ is defined as $\mathbf{W}_{\mathcal{G}} = \begin{bmatrix} \mathbf{w}_1 & \mathbf{w}_2 & \cdots & \mathbf{w}_S \end{bmatrix} \in \mathbb{C}^{M \times S}$.

An equivalent channel matrix $\bar{\mathbf{H}}_{\mathcal{G}}$ including the effect of the receive filter can be used by any spatial precoding algorithm instead of the channel matrix $\mathbf{H}_{\mathcal{G}}$. This approach is called coordinated Rx-Tx processing and is used for Multiple Input Multiple Output (MIMO) single-cell processing in [7]. Here, it is applied for CoMP-cell processing. Let $\mathbf{D}_j = \begin{bmatrix} \mathbf{d}_{1,j}^{\text{T}} & \mathbf{d}_{2,j}^{\text{T}} & \dots & \mathbf{d}_{L_j,j}^{\text{T}} \end{bmatrix}^{\text{T}} \in \mathbb{C}^{L_j \times N_{\text{RX}}}$ be a matrix consisting of L_j beamformers that the UE j employs in receiving data, the equivalent channel matrix $\bar{\mathbf{H}}_{\mathcal{G}} \in \mathbb{C}^{S \times M}$ is given as follows

$$\bar{\mathbf{H}}_{\mathcal{G}} = \begin{bmatrix} (\mathbf{D}_1\mathbf{H}_1)^{\text{T}} & (\mathbf{D}_2\mathbf{H}_2)^{\text{T}} & \dots & (\mathbf{D}_G\mathbf{H}_G)^{\text{T}} \end{bmatrix}^{\text{T}}. \tag{4}$$

Let the total transmit power P_{TOT} available at each cell be equally divided among the N_{PRB} PRBs. Thus, the maximum transmit power allocated to each PRB is given by $P_{\text{PRB}} = P_{\text{TOT}}/N_{\text{PRB}}$ and it will draw only an upper bound on the per-PRB transmit power of a given cell, since each cell is shared among several UEs.

In this work, it has been assumed per-cell power constraints, since each transmitter has a separate power amplifier with a limited linear range per cell. However, the power allocation problem is solved for sum-power constraint on all cells together expressed as $P_{\text{SUM}} = N_{\text{CELL}}P_{\text{PRB}}$. Per-cell power constraints are respected with an additional step. Thus, RRA strategies consider the downlink of a CoMP-cell with N_{CELL} cells, such that a power allocation vector for each CoMP-cell is defined as $\mathbf{p}_{\mathcal{G}} = \begin{bmatrix} p_1 & p_2 & \cdots & p_S \end{bmatrix}^{\text{T}}$.

Considering the previous definitions, the matrix $\mathbf{M}_{\mathcal{G}} \in \mathbb{C}^{M \times S}$ comprised by the precoding matrix $\mathbf{W}_{\mathcal{G}}$ and by the power allocation vector $\mathbf{p}_{\mathcal{G}}$ can be written as

$$\mathbf{M}_{\mathcal{G}} = \begin{bmatrix} \mathbf{M}_1^{\mathrm{T}} & \mathbf{M}_2^{\mathrm{T}} & \cdots & \mathbf{M}_{N_{\mathrm{CELL}}}^{\mathrm{T}} \end{bmatrix}^{\mathrm{T}} = \mathbf{W}_{\mathcal{G}} \sqrt{\mathrm{diag}\left\{\mathbf{p}_{\mathcal{G}}\right\}}, \tag{5}$$

where $\mathbf{M}_i \in \mathbb{C}^{N_{\mathrm{TX}} \times S}$, $\forall\ 1 \leq i \leq N_{\mathrm{CELL}}$, is the part of the matrix $\mathbf{M}_{\mathcal{G}}$ relating to the cell i and all S streams.

III. RRA STRATEGIES

Initially, we focused on the RRA subproblem of determining a suitable set of UEs to spatially reuse a given radio resource among multiple geographically separated transmission points, having as objective the maximization of the total system throughput. After that, the multiple transmission points are treated as a distributed antenna array to perform Multi-User (MU)-MIMO and mitigate the intra-CoMP-cell interference and/or improve the received signal quality of grouped UEs $\mathcal{G}$. The degrees of freedom available due to the multiple antennas at both transmitter and receiver can be used for spatial multiplexing, spatial diversity or both. Once the set of the grouped UEs $\mathcal{G}$ is defined, it is necessary to perform an adequate power allocation among data streams. In order to achieve efficiency on the usage of considered resource, the effect due to spatial precoding as well as the effect of the inter-CoMP-cell interference can be considered by the power allocation algorithm.

Another important aspect to be considered by RRA strategies is the inter-CoMP-cell interference management. Even though the inter-CoMP-cell interference is unknown to CoMP-cell, it can be estimated and so the link adaptation can be significantly improved. In addition, by downtilting the transmit antennas, the inter-CoMP-cell interference is reduced and the link quality at the UE is improved [5].

In the following, a simple inter-CoMP-cell interference estimation mechanism and the transmit antenna downtilt feature are treated in section III-A. Spatial multiplexing and diversity schemes are introduced in section III-B, SDMA grouping is presented in section III-C, spatial precoding is described in section III-D, power allocation is detailed in section III-E and power scaling is treated in section III-F.

A. Inter-CoMP-cell interference management

In an effort to reduce the inter-CoMP-cell interference, we employed the downtilt feature. With this feature, the antenna orientation is adjusted towards a given region within the coverage area, thereby enhancing the desired signal and diminishing the interference received by a UE in that region. In other words, the downtilt feature can provide a better cell isolation. Although the antenna tilt may be achieved electrically and/or mechanically, herein we assumed just the electrical downtilt approach.

The horizontal-only antenna radiation pattern adopted by the 3GPP is given in dB as [8]:

$$G^{(a)}_{horizontal-only}(\theta) = -\min\left\{12\left(\theta/70\right)^2, 20\right\} + 14, \tag{6}$$

where θ is the azimuth in degrees. Note that this model does not allow one to model tilted antennas. In fact, the downtilt feature requires an antenna radiation pattern model defined over both the horizontal and vertical planes, such as that one described in [5], which is given in dB as:

$$\begin{aligned} G^{(a)}_{horizontal}(\theta) &= -\min\left(12\left(\theta/65\right)^2, 30\right) + 18, \\ G^{(a)}_{vertical}(\phi) &= \max\left(-12\left((\phi-\phi_{tilt})/6.2\right)^2, -18\right), \end{aligned} \tag{7}$$

where ϕ is the negative elevation angle and ϕ_{tilt} the electrical downtilt angle, all in degrees.

Furthermore, we considered an approach for inter-CoMP-cell interference estimation through which the link adaptation can be significantly improved. Taking the inter-CoMP-cell interference measurement capability of a given UE and PRB into account, we employed the last measured interference value, z_s^{inter} at the last Transmission Time Interval (TTI), as the inter-CoMP-cell interference estimate $\tilde{z}_s^{inter}$ of the stream s at current TTI [2], [3].

B. Spatial multiplexing and diversity schemes

In this paper, one of the following reception schemes is used for both precoding at the transmitter and demodulation at the UE when it is equipped with multiple antennas:

- Spatial multiplexing scheme: All N_{RX} available dimensions at each UE j are used, i.e., multiple-stream transmission per UE j is employed regarding $L_j = N_{\mathrm{RX}}$. The receive filter $\mathbf{D}_j$ for each UE j is selected by choosing $\mathbf{I} \in \mathbb{C}^{N_{\mathrm{RX}} \times N_{\mathrm{RX}}}$;
- Spatial diversity scheme: Only $L_j = 1$ stream is considered for each UE j, i.e., single-stream transmission per UE. Coordinated Rx-Tx processing is assumed, which is stated in section II. Herein, the total number of streams S per CoMP-cell is reduced from $S = N_{\mathrm{RX}}G \leq M$ to $S = G$. Let the Singular Value Decomposition (SVD) of $\mathbf{H}_j$ be represented by $\mathbf{H}_j = \mathbf{U}_j \mathbf{\Sigma}_j \mathbf{V}_j^{\mathrm{H}}$, where $\mathbf{U}_j$ contains the L_j dominant left singular vectors of $\mathbf{H}_j$. The receive filter $\mathbf{D}_j \in \mathbb{C}^{1 \times N_{\mathrm{RX}}}$ for each UE j is set to be the first line of $\mathbf{U}_j^{\mathrm{H}}$ [7].

C. SDMA grouping

Normally, SDMA grouping algorithms are heuristics composed by two elements: a grouping metric and a grouping algorithm [9]. While the metric measures the spatial compatibility among the UEs based on the CSI available at the CoMP-cell, the grouping algorithm, based on the grouping metric, builds and compares different SDMA groups. Here we consider the grouping metric (sum of channel gains with null space successive projections) and grouping algorithm (Best Fit) described in [2].

D. Spatial precoding

Assuming a particular PRB and a CoMP-cell subject to a sum power constraint, the spatial separation of S data streams is accomplished by employing spatial precoding techniques [10], which adaptively weigh the symbols transmitted from M transmit antennas.

Minimum Mean Square Error (MMSE) precoder can trade intra-CoMP-cell interference suppression against effective channel gains efficiency [11]. The precoding weights improve the ratio of the signal gain to the intra-CoMP-cell interference plus noise. Thus, precoding reaches a balance between achieving strong signal gain and limiting intra-CoMP-cell interference. The optimal MMSE precoder is given by [11]

$$\mathbf{W}_{\mathcal{G}} = \mathbf{H}_{\mathcal{G}}{}^{\mathrm{H}}\big(\mathbf{H}_{\mathcal{G}}\mathbf{H}_{\mathcal{G}}{}^{\mathrm{H}} + \mathbf{\Psi}_{\mathcal{G}}\big)^{-1}, \tag{8}$$

where $\mathbf{\Psi}_{\mathcal{G}} \in \mathbb{C}^{S \times S}$ is a diagonal matrix, whose s^{th} diagonal element is given by

$$[\mathbf{\Psi}_{\mathcal{G}}]_{s,s} = \begin{cases} \frac{\sigma_\eta^2}{P_{\text{PRB}}}, & \text{for SNR-based MMSE,} \\ \frac{\sigma_\eta^2 + \tilde{z}_s^{inter}}{P_{\text{PRB}}}, & \text{for SINR-based MMSE.} \end{cases} \tag{9}$$

E. Power allocation

Assuming a sum power constraint P_{SUM} for all cells of a CoMP-cell, as defined in section II, we shall consider the Water-filling (WF) power allocation scheme. WF is the optimal power allocation scheme to maximize system throughput when CSI is known at the transmitter when sum-power constraint is considered.

Given a certain spatial precoding, the sum-rate can be maximized by solving the following optimization problem [12]

$$\max \sum_{s=1}^{S} \log_2\left(1 + \frac{p_s}{\tilde{z}_s^{inter} + \sigma_\eta^2}\right), \quad \text{s.t.} \begin{cases} \sum\limits_{s=1}^{S} \lambda_s p_s \leq P_{\text{SUM}}, \\ p_s \geq 0. \end{cases}$$

The factor λ_s of the stream s is given by [12]

$$\lambda_s = \left[\big(\mathbf{H}_{\mathcal{G}}\mathbf{H}_{\mathcal{G}}{}^{\mathrm{H}} + \mathbf{\Psi}_{\mathcal{G}}\big)^{-1}\right]_{s,s}, \tag{10}$$

where the choice of this factor λ_s for MMSE precoding is only an approximation for the problem defined above, since the intra-CoMP-cell interference is not taken into account.

The optimal user power allocation can be obtained by the well-known WF solution [12].

$$p_s = \begin{cases} \left[\frac{\mu}{\lambda_s} - \sigma_\eta^2\right]^+, & \text{for SNR-based WF,} \\ \left[\frac{\mu}{\lambda_s} - \left(\tilde{z}_s^{inter} + \sigma_\eta^2\right)\right]^+, & \text{for SINR-based WF,} \end{cases} \tag{11}$$

where the water level μ is chosen to meet the sum power constraint, $\sum\limits_{s=1}^{S} \lambda_s p_s = P_{\text{SUM}}$. Note that the SINR-based power allocation depends on estimates of the inter-CoMP-cell interference, which can be dynamically adjusted.

F. Power scaling

Because no cell can use more power than P_{PRB} and the power ratio among elements of each column of the matrix $\mathbf{M}_{\mathcal{G}}$ cannot be changed in order to preserve the properties of the spatial precoding, the per-cell power constraints are respected by scaling the whole precoding matrix $\mathbf{M}_{\mathcal{G}}$ [2], [3]. Considering the precoding matrix $\mathbf{M}_{\mathcal{G}}$, the power scaling can be handled as follows. First, we choose the cell i^* which consumes the highest power: $i^* = \arg\max_{1 \leq i \leq N_{\text{CELL}}} \|\mathbf{M}_i\|_{\text{FRO}}$. Then, the scaling of the whole $\mathbf{M}_{\mathcal{G}}$ matrix is performed so that the squared norm of the row $\mathbf{M}_{i^*}$ with highest norm becomes equal to $\sqrt{P_{\text{PRB}}}$, i.e., $\mathbf{M}_{\mathcal{G}} = \mathbf{M}_{\mathcal{G}} / \|\mathbf{M}_{i^*}\|_{\text{FRO}}$.

IV. RESULTS

Through system-level simulations, this section provides a performance assessment of the RRA strategies introduced in section III on a multi-antenna CoMP system. Our simulation tool is aligned with the 3GPP LTE-Advanced architecture (specifications [4], [6], [8], and [13]), regarding the explicit feedback model defined in [4]. The main parameters considered are summarized in Table I.

TABLE I

SIMULATION PARAMETERS AND SETTINGS.

Parameter		**Value**
Number of CoMP-cells		7 (w/ wrap-around [1])
Number of cells per CoMP-cell		21
Number of antennas per UE		1 or 2
Number of antennas per cell		1 or 2
Environment cell		Urban-micro scenario, NLOS [8]
Site-to-site distance		500 m [8]
Antenna height	UE	1.5 m [8]
	eNB	12.5 m [8]
Average UE speed		3 km/h [6]
Carrier frequency		2.0 GHz [6]
Number of PRBs		6 [6]
Electrical downtilt angle		8° [5]
Path loss model		$35.7 + 38\log_{10}(\text{distance})$ dB [8]
Channel model		SCM [8]
Shadowing standard deviation		8 dB
CSI Knowledge		Ideal
Required SNR at the cell-edge		- 6.2 dB
Link adaptation		MCSs according to [13]
Transmission schemes		Spatial diversity and multiplexing
Transmit power	no downtilt	29.3 dBm
	w/ downtilt	40.0 dBm
SDMA algorithm		BF and SP [2]
Spatial precoding		ZF and MMSE [10], [11]
Power allocation		EPA and WF [12], [14]
Traffic model		Full buffer [8]
Snapshot duration		1 s
Effective TTI duration		1 ms

For the sake of simplicity, the configuration of co-located antennas at the cells and UEs is represented as $N_{\text{TX}} \times N_{\text{RX}}$. It is important to highlight that the transmit power per PRB for each cell is determined according to the scenario, viz. transmission scheme, antenna configuration and downtilt feature. Herein, it is determined in order to assure that any stream of UE at the cell edge should perceive the minimal Signal to Noise Ratio (SNR) required for achieving the lowest Modulation and Coding Scheme (MCS) without spatial precoding. Note that the maximum transmit power per PRB for spatial multiplexing schemes is N_{TX} (number of transmit antennas per cell) times the transmit power given in Table I.

In the following, we present the system spectral efficiency of the RRA strategy as a function of the offered load, for two basic multi-antenna scenarios: a spatial diversity-based scenario, in Fig. 1, and a spatial multiplexing-based scenario, in Fig. 2. For each scenario, we evaluate the effect of the use of the inter-CoMP-cell interference estimate as well as the benefits of achieving the transmit antennas downtilt.

As we can note in Fig. 1 , the gain achieved with the use of the estimate of the inter-CoMP-cell interference is practically negligible in a scenario with antenna downtilt. In scenario 1x1 without antenna downtilt, this gain was of about 12.73% for

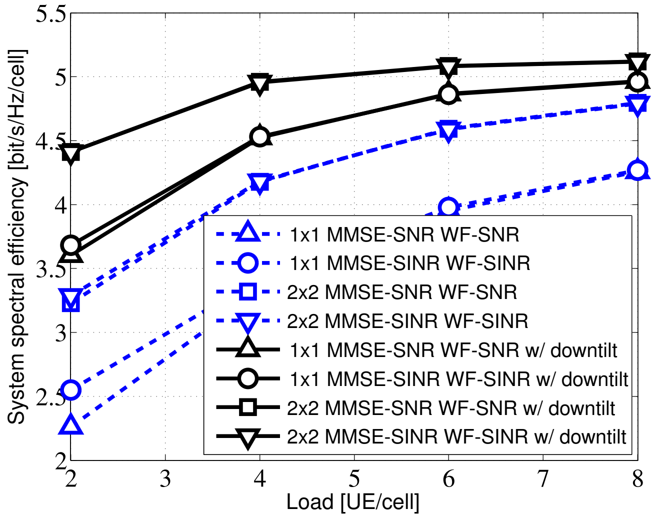

Fig. 1. Spatial diversity analysis.

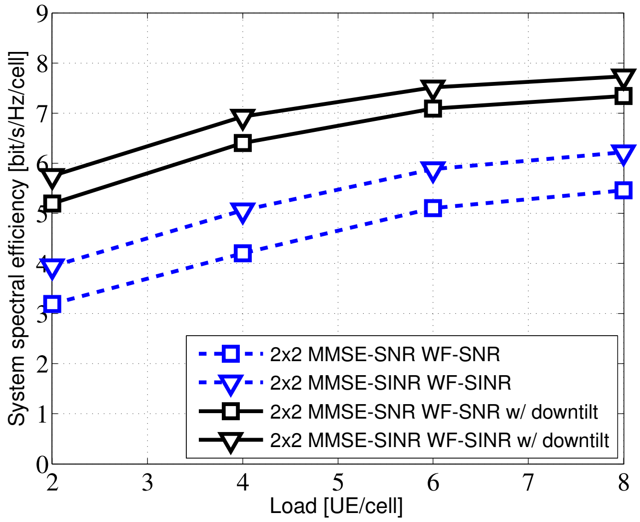

Fig. 2. Spatial multiplexing analysis.

the lowest load. In fact, the antenna downtilt has better cell isolation, reducing the inter-CoMP-cell interference and thus enhancing the received signal power through a better antenna orientation, such that the estimate of the inter-CoMP-cell interference is not so necessary. Besides that, we observed that the performance improvement due to spatial diversity gain is also possible with the downtilt feature: regarding the lowest load, the gain in performance achieved from the configuration 1x1 to the configuration 2x2 is of about 20% and 28.9%, respectively, with and without antenna downtilt.

From Fig. 2, it can be seen that the use of an estimate for the inter-CoMP-cell interference in the scenario 2x2 with antenna downtilt also provided a significant gain as well as it was provided in the scenario without antenna downtilt, although now lower gains are achieved. This gain is between 5% and 10% while in the scenario without antenna downtilt the observed gain ranges between 13% and 23% for all considered loads. This is because the antenna downtilt feature reduces the inter-CoMP-cell interference.

V. CONCLUSIONS

The main objective of this work was to study RRA strategies that aim at maximizing the throughput of a multi-antenna CoMP system. The results showed that quite high throughput gains are achieved through intelligent RRA strategies.

In the case with antenna downtilt, we have seen that the spatial diversity-based transmission scheme has provided satisfactory gains, especially for low loads in UEs per cell. The spatial diversity-based multi-antenna CoMP system has performance close to its maximum capacity in situations of high diversity of UEs per cell. In fact, the antenna downtilt has better cell isolation reducing the inter-CoMP-cell interference and thus enhancing the received signal power through a better antenna orientation. In general, MMSE and WF always benefit from estimates of the inter-CoMP-cell interference, achieving performance gains in terms of spectral efficiency. Finally, the results indicate that the multi-antenna CoMP communication is a very promising technology to increase the spectral efficiency in the LTE-Advanced context. In further works, a dynamic SDMA group size as well as an FTP-like traffic model could be considered in order to analyze the impact of fluctuations on inter-CoMP-cell interference estimates.

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