Evaluating the capacity gains from Coordinated MultiPoint Transmission and Reception

Anais Vergne, Salah Eddine Elayoubi

Evaluating the capacity gains from Coordinated MultiPoint Transmission and Reception

Anais Vergne and Salah Eddine Elayoubi
Orange Labs
38-40 rue du Général Leclerc - 92130 Issy-Les-Moulineaux - France
{anais.vergne,salaheddine.elayoubi}@orange-ftgroup.com

Abstract—**This paper evaluates and compares different Coordinated MultiPoint (CoMP) Joint Processing (JP) schemes. We consider the LTE-Advanced codebook-based schemes, where the serving beams are taken from a pre-determined codebook. We namely consider Single User Joint Processing (SUJP) and Multiple Users Joint Processing (MUJP) with two variants: Least Interfering Beams (MUJPLIB) and Most Interfering Beams (MUJPMIB). We follow a cross-layer approach where both PHY and MAC layers mechanisms are taken into account by a realistic system-level simulator, whereas the higher level performance is assessed by a Markovian analysis. This latter considers the coupling between the different cells and derives the flow level capacities of the different solutions. Our results show that, globally, MUJP achieves the best performance for low to medium traffic, while all JP schemes do not perform well for large loads.**

I. Introduction

Future cellular networks are expected to provide high data rates to all users in the covered area. However, this objective is difficult to attain for cell edge users as they are limited by interference received from adjacent cells. A radio interface that is robust to interference is thus necessary. Coordinated Multi-Point is a candidate technique proposed in LTE Advanced [1] for alleviating this performance discrepancy between cell edge and cell center users. The aim of this technique is to coordinate base stations, that select their transmission beam in a manner that minimizes interference or maximizes received signal in the adjacent cells.

An important category of CoMP is codebook based Joint Processing. By codebook-based, we mean that each transmitter selects the best beam from a pre-determined set [2][3]. On the other hand, Joint Processing (JP) means that a User Equipment (UE) is served simultaneously by several Base Stations (BS). JP is expected to increase throughput substantially at cell edge, but needs a large amount of signaling as the same information must be sent by different BSs at the same time.

While a large number of papers deal with the physical layer aspects of CoMP, we are not aware of any flow level evaluation of the expected gains. Indeed, actual evaluations are based on link or system level simulations with fixed numbers of users in the different cells; they do not take into account the dynamic behavior of users that arrive to the system and depart from it following stochastic processes. In particular, these system level simulators do not reflect the real distribution of users in the cell, knowing that cell edge users will stay longer in the cell and contribute more to the cell load.

The approach we follow in this paper is a cross-layer one that considers the physical layer techniques, the MAC inter and intra-cell scheduling, as well as the traffic characteristics. It is worth noting that the time scales between these layers is different: PHY and MAC layers operate at the granularity of milliseconds, as they are governed by the fast fading variations, whereas upper layer mechanisms operate at larger time scales (seconds or even minutes), governed by the dynamics of arrivals and departures of flows. In order to model the complex behavior of PHY/MAC layers, we use a realistic system level simulator that implements in details the PHY/MAC mechanisms and gives, as outputs, the throughput achieved by a user at different positions in the cells, knowing the different coordination settings that may happen. These throughputs are then used as inputs for our flow level Markovian analysis that catches the dynamics of the arrival and departure processes and calculates the user-perceived QoS, namely blocking rates and file download times.

The original contributions of this work are as follows:

- A flow level analytical model that evaluates realistic gains of CoMP schemes in a dynamic setting.
- A complete PHY/MAC simulator that implements the main CoMP schemes.
- A cross layer evaluation method that combines physical layer simulations with flow level capacity analysis.
- A comparison of the Erlang-like capacity regions of the different JP implementations.

The remainder of this work is organized as follows. In Section II, we develop a flow level analytical model for Coordinated Beamforming. Then, in Sections III and IV, this model is extended to Single User Joint Processing and Multiple User Joint Processing, respectively. The CoMP simulator used for evaluating the PHY/MAC throughput gains is presented in Section V. Section VI compares, thanks to both CoMP simulator and flow level analysis, the different CoMP schemes and determines the Erlang-like capacity regions. Section VII eventually concludes the paper.

II. Physical layer throughputs

We focus on our analysis on a certain cell, called cell 0, surrounded by N interfering cells numbered from 1 to N. Each cell site is equipped by 3 directive 120° antennas, as illustrated in Figure 1. In this section, we describe the different CoMP techniques studied in this paper, and derive, in each case, the corresponding SINR expression.

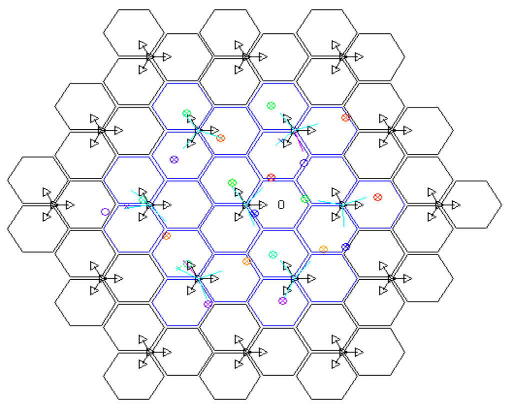

Fig. 1. Network layout.

A. Single User Joint Processing

1) Description: We consider here CoMP with clusters of 2 cells, constructed as in [4]. If, for a TTI (Transmission Time Interval), a cell j has scheduled a cell edge user, it tries to form a cluster with the most interfering cell, called cell x, reported by this user. Either cell x is already part of a cluster, then cell j selects randomly another user to serve in this TTI. Or cell x is not already in a cluster, then a cluster is formed in which cell j is the master cell, and cell x the slave cell. The constraints for the slave cell are very important in this type of CoMP. Indeed, the slave cell does not schedule any user during this TTI, and both master cell and slave cell transmit useful signal to the scheduled user in the master cell. The slave cell uses the most impacting beam reported by the user for this transmission.

2) SINR: In JP, the calculation of the throughput is modified for the cell edge users getting CoMP, due to the useful signal from 2 different cells: the serving cell and the slave cell in cluster for the served user. Let us call i_0 the serving cell, and i_1 the slave cell.

We begin by calculating the SINR for users that are not subject to CoMP, i.e. cell center users. The Signal to Interferences plus Noise Ratio $SINR$ for user j, when served by the target cell i_0 is calculated following the formula:

$$SINR_j = \frac{P_{Tx}\left|w^H h_j^{i_0}\right|^2}{{w_j^{i_0}}^H R_j^{i_0} w_j^{i_0}} \tag{1}$$

where

- P_{Tx} is the transmit power
- for cell i, $h_j^{i_0} = H_j^{i_0} p_j^{i_0}$ where $H_j^{i_0}$ is the channel matrix and $p_j^{i_0}$ the precoding vector.
- $R_j^{i_0} = \sum_{i \neq i_0} P_{Tx} h_j^{i_0} {h_j^{i_0}}^H + P_{noise}$ is the correlation matrix.
- $w_j^{i_0} = (R_j^{i_0} + P_{Tx} h_j^{i_0} {h_j^{i_0}}^H)^{-1} h_j^{i_0}$ is the Minimum Mean Square Error (MMSE) equalizer.

Then, the user throughput when allocated a bandwidth B is given by Shannon's equation:

$$T_j = B \times log_2(1 + SINR_j) \tag{2}$$

As of cell edge users subject to coordination, we use a composed channel matrix and a composed precoding vector:

$$H_j^{tot} = \left(H_j^{i_0}, H_j^{i_1}\right), \text{ and } p_j^{tot} = \begin{pmatrix} p_j^{i_0} \\ p_j^{i_1} \end{pmatrix}$$

So, $h_j^{tot} = H_j^{tot} p_j^{tot}$

Then, the other variables are:

- $R_j^{tot} = \sum_{i \neq i_0, i_1} P_{Tx} h_j^{tot} {h_j^{tot}}^H + P_{noise}$
- $w_j^{tot} = (R_j^{tot} + P_{Tx} h_j^{i_0} {h_j^{i_0}}^H + P_{Tx} h_j^{i_1} {h_j^{i_1}}^H)^{-1} h_j^{tot}$

Finally, the formula used for the $SINR$ is:

$$SINR_j^{SUJP} = \frac{P_{Tx}\left|{w_j^{tot}}^H h_j^{tot}\right|^2}{{w_j^{tot}}^H R_j^{tot} w_j^{tot}} \tag{3}$$

B. Multiple Users Joint Processing

1) Description: The method used for the formation of clusters is still the same as before. About coordination, MUJP is a JP type of CoMP, so both master and slave cells of a cluster transmit to the user. Thanks to multiple users property, the slave cell can schedule a user of its own with constraints from the master cell. But as 2 beams are sent out from the slave cell, there may be huge interferences between the transmission to the user served in master cell (from both cells) and the transmission to the user served in slave cell (from only its cell). Therefore, the choice of the user in slave cell and its beam is decisive. So, we discern there 2 types of MUJP by the way the user to be served in slave cell is chosen:

- In case 1, the selection is based on the Most Impacting Beams (MIB), this case will be thus called MUJP(MIB). The user served in master cell reports the 3 most impacting beams from its most interfering cell that is the slave cell: the most impacting one is used for the transmission of the useful signal to it. Then, as in CBF, the slave cell must schedule a user served with none of these 3 beams (if such a user does not exist, there is no user scheduled in the slave cell).
- In case 2, the user served in master cell reports the 3 Least Impacting Beams (it is case MUJP(LIB)), as well as the most impacting beam (still used for the transmission to it). The user served in slave cell must be selected amongst the users served with one of the 3 least impacting beams. The slave cell does not schedule a user of its own if no user satisfying the constraints is found. The constraints are more selective in that case in the hope to reduce the interferences and so increase the SINR.

2) SINR: In MUJP, the method for the calculation of the $SINR$ is the same. However, the transmission power of a cell is divided between the users it serves (up to 2), and the interference term must take into account all the simultaneous transmissions, including that from its own cell if it exists. In CBF and SUJP, that problem does not exist because each cell serves only one user. We thus differentiate between three throughputs:

1) Case where the user in the master cell profits from all the power of the slave cell. This is the case when the slave cell does not find a user to schedule that verifies the master cell's constraints. The SINR is thus exactly as in SUJP (equation (3), and we obtain the throughput $T_j^{MUJP,1}$.
2) Case where the user in the master cell profits from all half of the power of the slave cell, because this latter schedules one of its own users in parallel. The SINR equation (3 has to be modified to take into account the fact that a part of the power of the slave cell is seen as interference. We denote by $T_j^{MUJP,2}$ the resulting throughput.
3) Throughput of the secondary transmission: In this case, the SINR is calculated as in CBF, including an interference term form its own cell as well. We denote by $T_j^{MUJP,3}$ the resulting throughput.

III. CoMP analysis on MAC layer

In the previous section, we presented the different CoMP schemes and their impacts on the SINR and physical throughputs. However, this analysis does not take into account the MAC layer mechanisms that allocate resources between cells, taking into account the cluster formation and the number of users in each cell. We expose in the following the impact of these mechanisms and the corresponding throughput, knowing the different events (simultaneous transmissions to different users, coordination of beams, etc.).

In this analysis, we differentiate between $C+1$ different classes of users, following their radio conditions (i.e. cell center and cell edge users), but also their interactions with neighboring cells. Let n_c^j be the number of users of class c in the cell j. The state of cell j is thus defined by the vector $\vec{n}^j = (n_0^j, ..., n_C^j)$. The relation between classes and neighboring cells is illustrated in Figure 2 where we represent the different classes in the target cell. In this figure, we can see the correspondence between classes and neighboring cells (class c in cell 0 corresponds to an interaction with cell numbered c). Of course, the shape of these zones is not regular but depends on the shadow fading with the different cells.

When a user of class c is served in cell 0, it is characterized by an average throughput T_c, obtained by averaging equation (2) over all class-c positions in the cell. Note that, for simplicity, we drop the superscript indicating the CoMP scheme from the throughputs.

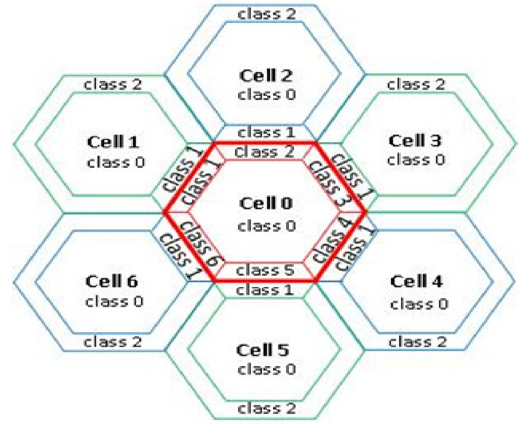

Fig. 2. User classification.

A. SUJP

1) Throughputs of the different classes: We focus on cell 0 and want to calculate the throughput of a class c user. As the slave cell does not schedule any user, there is only primary scheduling in SUJP.

Let us first consider the event A_c, stating that the transmission to users of class c is in conflict with some other transmission in a neighboring cell ($\bar{A}_c$ is the complementary event with $Pr[A_c] + Pr[\bar{A}_c] = 1$). When a user of class c is scheduled, its throughput is equal to T_c under event $\bar{A}_c$ and to qT_c under event A_c if we consider that a cell stays master during a time proportion equal to q.

Without conflict, i.e. under event $\bar{A}_c$, a user is served during the fraction of time $\frac{1}{n^0}$, and in case of conflict (event A_c) a user in one cell is served only if its cell is master during the TTI, that is during the fraction of time $q\frac{1}{n^0}$. Thus, the throughput for one user of class c in cell 0 is:

$$\bar{T}_c(\vec{n}^0, \vec{n}^c) = \frac{1}{n^0} T_c (Pr[\bar{A}_c|\vec{n}^c] + qPr[A_c|\vec{n}^c]) \qquad (4)$$

In this expression, $1/n^j$ is the fraction of time a user is served in cell j as a primary user, with $n^j = \sum_c n_c^j$.
Note that the throughput of class-c users in cell 0 depends on the number of users in all adjacent cells. This dependence will be further studied in the next section.

2) Interactions between cells: In order to calculate the probabilities of events A_c, we must understand the behaviors of cell edge and cell center users. Indeed, cell edge users are those who can initiate CoMP operation, while cell center users may only impact transmissions in other cells.

There is conflict between the transmissions in 2 neighboring cells as soon as one is impacting or being impacted by the other, and a coordination occurs that modify the slave cell scheduling. Center users are still considered as not impacted by transmissions in neighboring cells, and can only impact them. Thus, a transmission to a cell j center user can only be in conflict with a transmission to a neighboring cell x edge user. And as SUJP process preempts totally the slave cell, $Pr[A_0|\{\vec{n}^j; j \in [1,C]\}]$ is the probability to have cell edge users of class j in any neighboring cell; it is calculated by

$$Pr[A_0|\{\vec{n}^j; j \in [1,C]\}] = \sum_{n=1}^{C}(-1)^{n-1} \sum_{E \in \mathcal{E}_n} \prod_{j \in E} \gamma_j \quad (5)$$

where $\mathcal{E}_n$ is the set of sets E of cardinality $|E| = n$ and whose elements are integers between 1 and C.
In this equation, γ_j is the probability of conflict between cell j and center users of cell 0, calculated by:

$$\gamma_j = \begin{cases} \frac{n_1^j}{n^j}, & n^j > 0 \\ 0, & \text{otherwise} \end{cases}$$

On the other hand, any transmission to a cell edge user implies coordination with the most interfering cell. Therefore, the transmission to cell j edge user of class x is in conflict with any transmission in cell x, and there is conflict as soon as cell x is not empty:

$$Pr[A_c] = \begin{cases} 1, & n^c > 0 \\ 0, & \text{otherwise} \end{cases}$$

for all integer $c \in [1, C]$.

B. MUJP

1) Throughput calculations: In MUJP, there is primary and secondary scheduling. A user of class c is primarily scheduled under event $\bar{A}_c$ and also under event A_c in a proportion q of time. Its throughput during the time where it is primary scheduled depends on the state in the neighboring cells, following the different cases identified in section II-B2. However, during conflict event A_c, other users from other classes of radio conditions can be served by the same cell if they are not in conflict with the current transmissions in neighboring cells (this is called secondary scheduling). By symmetry, class c users will thus also profit from secondary transmissions, leading to the following throughput for one user of class c:

$$\bar{T}_c(\{\vec{n}^j; j \in [0,C]\}) = \frac{1}{n^0}(Pr[\bar{A}_c|\vec{n}^c] + qPr[A_c|\vec{n}^c])(T_c^1 Pr[B_c|\vec{n}^c] + T_c^2 Pr[\bar{B}_c|\vec{n}^c]) + T_c^3(1-q)\sum_{i \neq c} \frac{1}{n^0 - n_i^0}\frac{n_i^0}{n^0} Pr[\bar{A}_c \cap A_i|\vec{n}^c, \vec{n}^i]$$

where B_c is the event stating that there is no secondary transmission in the other cell participating in the cluster. Here, $\frac{1}{n^j - n_i^j}\frac{n_i^j}{n^j}$ is the fraction of time this same user (of class c) is secondary served with users of class $i \neq c$.

2) Interactions between cells: Let p_x^j be the probability that a cell center user in cell j enters in conflict with the transmission of a cell edge user in cell $x \neq j$. These probabilities are obtained by simulations. We now derive the probabilities of the events A_c, based on the p's and knowing the states (numbers of users) in all the cells.

There is conflict between the transmissions in 2 neighboring cells as soon as one is impacting or being impacted by the other, and a coordination occurs that modify the slave cell scheduling. Center users are still considered as not impacted by transmissions in neighboring cells, and can only impact them. Thus, a transmission to a cell j center user can only be in conflict with a transmission to a neighboring cell x edge user. And as SUJP process preempts totally the slave cell, $Pr[A_0|\{\vec{n}^j; j \in [1,C]\}]$ is the probability to have cell edge users of class j in any neighboring cell; it is calculated by

$$Pr[A_0|\{\vec{n}^j; j \in [1,C]\}] = \sum_{n=1}^{C}(-1)^{n-1} \sum_{E \in \mathcal{E}_n} \prod_{j \in E} \gamma_j$$

In this equation, γ_j is the probability of conflict between cell j and center users of cell 0, calculated by:

$$\gamma_j = \begin{cases} \frac{n_1^j}{n^j}, & n^j > 0 \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

On the other hand, any transmission to a cell edge user implies coordination with the most interfering cell. Therefore, the transmission to cell j edge user of class x is in conflict with any transmission in cell x, and there is conflict as soon as cell x is not empty:

$$Pr[A_c] = \begin{cases} 1, & n^c > 0 \\ 0, & \text{otherwise} \end{cases}$$

for all integer $c \in [1, C]$.

However, in MUJP(LIB), the probabilities of events A_c are modified because of the new way to schedule users in the slave cell. For a center user, there is conflict with a neighboring cell edge user, if it is not served by one of its 3 least interfering beams. Thus, the probability of conflict for cell center users is calculated by equation (5) and (6), with, however, a larger p_j^0 as it has more chance to be reported as an impacting beam. As of cell edge users, a transmission towards class $c \neq 0$ in the target cell can only be impacted by users in cell c. However, it can impact all the cells surrounding its own cell, except the opposite one as it will be, almost all the time, served with one of its least impacting beam . More explicitly, a cell edge user of class c can report as interfering, a center user of cell c with the probability p_c^0, or a cell edge user of the same cell c if it is anywhere but in the class diametrically opposed to cell 0, considering equi-distribution in the cell. On the other hand, it can be reported by a cell edge user of class j in any other neighboring cells except the one opposite to it. Calling class $\bar{j}$ the opposite class in cell x and $\bar{x}$ the opposite cell to cell x considering cell j, we have:

$$Pr[A_c|\{\vec{n}^j; j \in [1,C]\}] = \sum_{n=1}^{C}(-1)^{n-1} \sum_{E \in \mathcal{E}_n} \prod_{j \in E} \beta_j \quad (7)$$

where β_j is now the probability of conflict between cell j and user of class $c \neq 0$ in cell 0, calculated by:

$$\beta_j = \begin{cases} p_0^c \frac{n_0^c}{n^c} + \frac{n^c - n_0^c - n_{\bar{c}}^c}{n^c}, & n^c > 0 \& j = c \\ \frac{n_0^j}{n^j}, & n^j > 0 \& j \neq c, \bar{c} \\ 0, & \text{otherwise} \end{cases} \quad (8)$$

Remains the probability of having no secondary scheduling in the slave cell, calculated by:

$$Pr[B_c] = \begin{cases} 1, & n^{\bar{c}} > 0 \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

IV. Flow level performance evaluation

In the previous two sections, we discussed the impact of CoMP schemes on both PHY and MAC layers. In particular, we derived the throughput knowing that there is a coordination between cells (PHY layer), and the throughput knowing the number of users in each of the cells. However, this is not sufficient to describe the performance in a dynamic setting when users arrive to the network and depart after bringing a certain workload to the system. This is the aim of this section, dedicated to the flow level performance knowing the PHY/MAC throughputs.

A. Markovian analysis

When we want to calculate the user-perceived QoS knowing an offered traffic, we have to derive the stationary distribution of the number of users in the target cell. Let $\bar{T}_c^0$ be the throughput of class-c users in this case.

We consider that customers of class c arrive to cell j following a Poisson process of intensity λ_c^j and stay active until downloading files of i.i.d. exponential sizes of mean F. The evolution of $\vec{n}^0$, the state of cell 0, is governed by a Markov chain with transitions driven by the following events:

1) Arrival of a call of class c, which happens with rate λ_c^0.
2) Class c call termination, which happens with rate: $\mu_c^0 = n_c^0 \frac{\bar{T}_c^0}{F}$.

The transition matrix is thus built and the steady-state probabilities can be obtained by solving $\vec{\Pi}.Q = 0$ with the normalizing condition $\vec{\Pi}.\vec{e} = 1$, where $\vec{e}$ is a vector of ones.

B. Average impact between cells

In the Markovian analysis presented above, the departure rates depend not only on the state of cell, but also on the states of neighboring cells. Indeed, the departure rate of class-c calls can be written as:

$$\mu_c^0(\{\vec{n}^j; j \in [0, C]\}) = n_c^0 \frac{\bar{T}_c^0(\{\vec{n}^j; j \in [0, C]\})}{F}$$

The number of cells of which this rate depends is different following the class. In particular, the departure rate of cell center users depends on the states of all neighboring cells. As of class $c \neq 0$ departure rate, it depends on the states of cells 0 and c.

Solving the balance equations for the target cells is then impossible independently from the other cells. An exact analysis is thus unfeasible as it involves a large number of user classes. It is however possible to calculate the average probabilities of the events A_c^j that we will use in the general case for the throughput calculation. Let us call I_c^j the set of cells interfering with class c of cell j, then we have

$$E[Pr[A_c^j]] = \sum_{x \in I_c^j} \sum_{n^x \neq 0} Pr[A_c^j] \Pi(\vec{n}^x)$$

C. Fixed point analysis

Thanks to the simulation of CoMP on PHY/MAC layers explained in the next section, we obtain values for average user throughput when served in the different cells. With these values, we build a first transition matrix Q representing the evolution of the number of users in cell 0 and supposing that the neighboring cells are empty. Solving $\vec{\Pi}.Q = 0$, we obtain the steady-state probabilities $\Pi(\vec{n}^j)$, then the average probabilities of events A_c^j. We can now calculate throughputs $\bar{T}_c^j(\vec{n}^j)$, and start again the process with these new values for the throughput and so on. We consider that we are in a stable state when the average probabilities of events A_c^j converge, that is when every difference between 2 successive values of $E[Pr[A_x^j]]$ is less than a small ϵ. With the last obtained values, we calculate the flow throughput for each class c of cell 0:

$$\tilde{T}_c^j = \frac{\sum_{\vec{n}^j} n_c^j \bar{T}_c^j \Pi(\vec{n}^j)}{\sum_{\vec{n}^j} n_c^j \Pi(\vec{n}^j)} \quad (10)$$

V. Numerical results

A. CoMP Simulator

The network is composed of 19 base stations, each one creating 3 cells with directive 120° antenna pattern, which makes 57 cells. We consider a MIMO system with 4 antennas at the transmission side, and 2 at the reception one. Users are randomly generated in the 21 inner cells at the beginning of each run of the simulation (the total number of users being a parameter). Outer cells are only considered for interferences. Each user then sorts all the received signals by power descending in order to know its serving cell (the first one), and its most interfering cell (the second). The received power P_r in dBm at the user is obtained by :

$$P_r = P_e + GdB + \gamma - Ploss \quad (11)$$

where P_e is the transmit power at the base station, Gdb the emission antenna gain, γ the shadowing (modeled by Gaussian variable), and $Ploss$ the path loss depending on the distance between the user and the base station. Users are classified as cell edge users if their received power is less than a given threshold (defined as a parameter).

At each TTI, the fast fading channel (modeled by a Rayleigh random variable) is updated. Then, the channel matrices coefficients $H_{i,j} (1 \leq i \leq 2, 1 \leq j \leq 4)$ are calculated for each couple user/cell. We can notice that the model used to describe the channel is basic. Beams are next sorted according to the maximization of $\|H_i v_i\|^2$, v_i being the weight vector from the LTE codebook. Thus, the user is able to know both most and least impacting beams from each cell, and report them to the base station. Probabilities p_x^j are calculated here counting the number of users in the center of a cell served by impacting beams for users in neighboring cells.

B. Performance without taking into account the dynamics of arrivals and departures

Table I groups together the gains in percentage for the average user throughputs obtained by the CoMP simulator. These are gains relative gains compared to the baseline model with no cooperation. when served for the 4 types of CoMP studied in this paper compared to the average user throughput when served without CoMP. We have separated the results according to the position of the user in order to see the benefits of CoMP. This is an exact separation: the cell edge average user throughput when served is calculated as the mean of user throughputs for all cell edge users, likewise the center average user throughput when served is the mean for center users.

	SU-JP	MUJP(MIB)	MUJP(LIB)
Center	-0.69	-1.79	-0.54
Edge	14.24	0.79	15.75
Overall	2.76	-1.18	3.28

TABLE I
AVERAGE USER THROUGHPUT GAINS EVALUATED BY THE CoMP SIMULATOR.

The aim of CoMP is to increase throughput in cell edge, therefore we will not focus on the minor losses for the center. We can see that SUJP and MUJP(LIB) have better results than the MUJP(MIB). We will see next that the flow level throughput evaluation will further differentiate the JP schemes.

C. Flow level performance

Thanks to the Markovian model developed above, we calculate the performance metrics for the different CoMP schemes. We consider FTP-like calls with files to be downloaded of average size 1 Mbyte. We vary the arrival rate in order to illustrate the impact of

We plot four different performance measures. The flow throughput for cell center and cell edge users, in addition to the overall flow throughput, indicate the user perceived QoS. The blocking rate illustrates the Erlang-like capacity of the cell and indicates whether the cell is saturated or not.

Figures 3-5 illustrate the cell edge flow throughput, the cell center flow throughput and the overall flow throughput, respectively, for the four schemes: baseline, SUJP, MUJP(MIB) and MUJP(LIB), for an offered traffic ranging from 4 to 24 Mbps. The first observation is that the flow throughput always decreases when traffic increases.

Enhancing the performance of cell edge users is the main motivation of CoMP schemes. Figure 3 shows that MUJP(MIB) never brings a gain. This is due to the large interference generated by secondary scheduling as close beams are permitted. On the other hand, for low traffic, both SUJP and MUJP(LIB) can enhance the cell edge throughput. However, MUJP(LIB) is the best option for medium traffic. For large traffic, however, all JP schemes bring losses. These results are interesting, as SUJP and MUJP(LIB) have comparable performance on PHY/MAC layers. This difference is due to the fact that there is no user scheduled in the slave cell that is silent half the time.

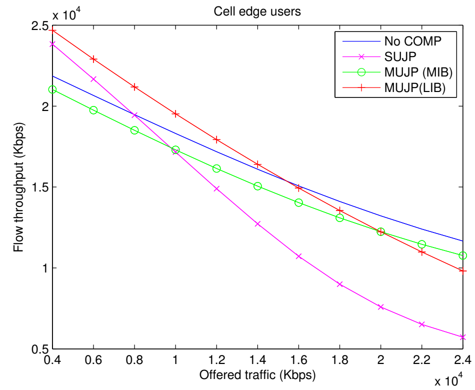

Fig. 3. Flow throughputs at cell edge.

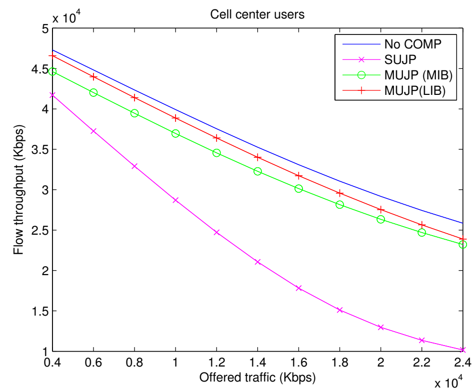

Fig. 4. Flow throughputs at cell center.

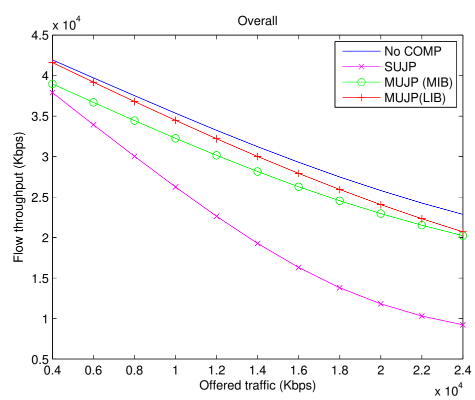

Fig. 5. Overall Flow throughputs.

As observed in Figures 4 and 5, there are losses for the center cell and the overall flow throughputs for all types of CoMP studied here. Indeed, because of the scheduling constraints in slave cells, a cell can be silenced, which is never the case (if there are users to be served) without CoMP. However, these losses remain acceptable for MUJP(LIB) in its area of operation (i.e. small to medium loads).

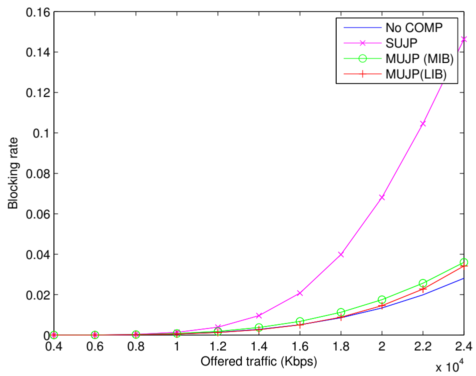

Fig. 6. Blocking rate.

Finally, we illustrate the blocking rate for the different schemes in Figure 6. We observe that the CoMP schemes do not enhance the capacity of the cell. However, the blocking rates of MUJP schemes remain acceptable (less than 2%) for operating traffics, and can thus be used for low or medium loads, as discussed above.

VI. Conclusion

In this paper, we propose a hybrid method, combining PHY/MAC simulations and flow level capacity analysis, in order to compare the performances of some CoMP schemes, namely single and Multi User Joint Processing. We make use of a realistic simulator that calculates the throughputs obtained for cell edge and cell center users with the different CoMP schemes. We then introduce the obtained values into a Markovian model that takes into account the interactions between cells and the dynamic behavior of users. Our results show that MUJP with Least Interfering Beam reporting achieves a good performance from low to medium loads, but is not beneficial for high traffic situations.

As of future works, we aim at studying other CoMP schemes like codebook based Coordinated Beamforming, but also non Codebook based schemes like Zero-forcing beamforming in order to see if these schemes can be used for large traffic loads.

References

[1] 3GPP TR 36.814 v0.4.1, ”Further Advancements for E-UTRA; Physical Layer Aspects”, Feb. 2009.

[2] P. Marsch and G. Fettweis, ”A Framework for Optimizing the Downlink Performance of Distributed Antenna Systems under a Constrained Backhaul”, in Proc. of EW, Apr. 2007.

[3] C. Botella, G. Pinero, A. Gonzalez and M. de Diego, ”Coordination in a multi-cell multi-antenna multi-user W-CDMA system: a beamforming approach”, IEEE Transactions on Wireless Communications, November 2008.

[4] F. Boccardi, E. Hardouin, H. Pennanen, A. Tölli, T. Svensson, C. Botella, M. Olsson, P. Rost, M. Boldi, V. D’Amico and V.Savin, ”D1.8 Intermediate Report on CoMP(Coordinated Multi-Point) and Relaying in the Framework of CoMP”, Version 1.0, pp.21-24, October 2009.