

Copyright Notice

©2011 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

This document was downloaded from Chalmers Publication Library (<http://publications.lib.chalmers.se/>), where it is available in accordance with the IEEE PSPB Operations Manual, amended 19 Nov. 2010, Sec. 8.1.9 (<http://www.ieee.org/documents/opsmanual.pdf>)

(Article begins on next page)

Joint Scheduling and Power Control in Coordinated Multi-Point Clusters

Jingya Li[†], Tommy Svensson[†], Carmen Botella[†], Thomas Eriksson[†], Xiaodong Xu^{††}, Xin Chen^{††}

[†]Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden.

{jingya.li, tommy.svensson, carmenb, thomase}@chalmers.se

^{††}WTI Lab, Key Lab of UWC, Ministry of Education, Beijing University of Posts and Telecommunications, Beijing, China
xuxiaodong@bupt.edu.cn, chenxin@mail.wtilabs.cn

Abstract—In this paper, we address the problem of designing a joint scheduling and power control algorithm in a downlink coordinated multi-point (CoMP) cluster supporting CoMP joint transmission. The objective is to maximize the cell-edge throughput under per-point power constraints. By an analytical derivation, binary power control is proved to be the optimal solution for any given selected user group. Utilizing this analytical result, a centralized and a semi-distributed version of joint user selection and power control algorithms are proposed. Compared to algorithms without considering joint transmission and algorithms without considering power control, simulation results show that the proposed algorithms achieve a good trade-off between joint transmission and interference coordination, which helps to improve the cell-edge performance.

I. INTRODUCTION

Coordinated multi-point (CoMP) joint transmission has emerged as a means to further improve the cell-edge performance [1]-[2]. In CoMP systems, coordinated base stations (BSs) are inter-connected via a high-speed backbone. In the case of joint transmission, the coordinated BSs share not only channel state information (CSI) but also the data of all users. Hence, the inter-cell interference is reduced by using the signals transmitted from other cells to assist the transmission instead of acting as interference. Global coordination requires an enormous amount of feedback and backhaul overhead. In order to make the inter-BS communication overhead affordable, user grouping, e.g., serving only subsets of terminals with CoMP joint transmission [3], and clustering of BSs, i.e., dividing the network into small subsystems or clusters of BSs [4], have been considered.

Clearly, radio resource management (RRM) plays an important role in optimizing the system performance of a CoMP cluster. Currently, RRM schemes for CoMP systems assume that the user can only communicate with a single BS, which is called the anchor (or serving) cell, and the inter-cell interference is controlled by coordinating scheduling and power control with the rest of the BSs in the cluster [5]-[8]. In [5], a fast multi-cell RRM algorithm is proposed and evaluated for the uplink of a coordinated cluster, which shows that RRM coordination can provide significant performance gains compared to traditional single-cell configurations. A capacity-maximizing coordinated power control is derived for the downlink of a two-cell cluster in [6], where binary power control is proved to be the optimal power allocation, i.e., in any

given time slot, the cell either transmits with full power (turned on) or does not transmit (turned off). Based on [6], it is shown in [7] and [8] that the binary power control can be extended to the multi-cell environment with negligible performance loss compared to the optimal solution. The main limitation of [6]-[8] is, however, that no CoMP joint transmission is supported. In [9], the authors consider a system model with CoMP joint transmission and the user scheduling problem is treated assuming that all BSs always transmit on full power, i.e., no joint power control across multiple BSs is considered.

In this paper, the problem of designing a joint scheduling and power control algorithm supporting CoMP joint transmission is addressed. We focus on the downlink of a CoMP cluster, consisting of three base station sectors (BSSs). The objective is to maximize the cell-edge sum throughput under a per-BSS power constraint. Based on the assumption of a flat fading channel, the scheduling problem becomes a user selection problem, which selects the best user group for each scheduling time slot. Through analytical derivation, binary power control is proved to be the optimal power control solution for any given selected user group. Using this analytical result, a centralized joint scheduling and power control algorithm is proposed. Then, a low-complexity semi-distributed algorithm is proposed for practical use. Compared with the algorithms proposed in [8] and [9], system level simulation results demonstrate that the proposed algorithms achieve a good trade-off between joint transmission and interference coordination, which helps to improve the cell-edge performance.

The rest of the paper is organized as follows. In Section II, we present the system model and formulate the maximum cell-edge throughput problem. In Section III, the optimal power control scheme in a CoMP cluster is analyzed for any given selected user set. Algorithms for joint scheduling and power control are proposed in Section IV. Section V presents the simulation results. Conclusions and future work are presented in section VI.

II. SYSTEM MODEL

We consider the downlink of a static cluster, in which the neighboring BSSs are connected to a central unit (CU) that is responsible for the joint user scheduling and power control of the cluster; see Fig. 1. In the cluster, users are divided into two classes, namely cell-center users (CCUs) and cell-edge users (CEUs), according to the path loss gain. CoMP joint

This work has been supported by The Swedish Agency for Innovation Systems (VINNOVA). The work has been performed in the framework of the Sino-Swedish program on 'IMT Advanced and beyond'.

transmission is only intended for the CEUs. In this study, we focus only on the CEUs in the cluster. Each CEU has a cooperative transmission set (CTS), which is formed by the BSSs of the cluster that provide data transmission service to this CEU. Hence, for each CEU, its cooperative transmission set may include zero, one, or multiple BSSs. The BSSs and the CEUs are assumed to have one transmit antenna and one receive antenna, respectively. The three transmit antennas have the same maximum power constraint P_{\max} and share the same cell-edge frequency bandwidth B .

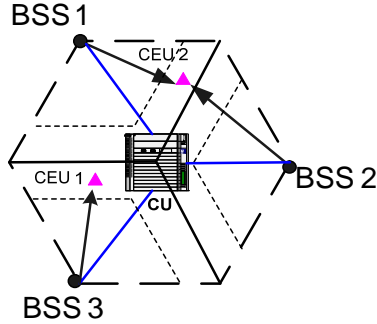


Fig. 1. System model for downlink joint transmission in one cluster

Let $\mathcal{N} = \{1, \dots, N\}$ and $\mathcal{M} = \{1, \dots, M\}$ denote the set of BSSs and CEUs in the cluster, respectively. Note that $N = |\mathcal{N}|$ and $M = |\mathcal{M}|$, where $|\cdot|$ is the cardinality of the set. Let $\mathbf{X}(t) = [x_{nm}(t)]$ denote a user selection indicator matrix of size $N \times M$, where $x_{nm}(t)$ is interpreted as

$$x_{nm}(t) = \begin{cases} 1, & \text{if BSS } n \text{ transmits to CEU } m \text{ in time slot } t \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Denote by $S_m(t)$ the CTS of CEU m in time slot t , that is

$$S_m(t) = \{n \mid x_{nm}(t) = 1, n \in \mathcal{N}\}. \quad (2)$$

From now on, we suppress the time slot index, and concentrate on one arbitrary given time slot. It is assumed that a BSS can transmit data to at most one CEU in any given time slot. Then, only one single element in each row of \mathbf{X} is non-zero. Let $\mathbf{P} = [P_n]$ denote the $N \times 1$ sized transmit power vector, where $P_n \leq P_{\max}$ denotes the transmit power of BSS n . Let G_{nm} denote the channel gain between BSS n and CEU m , consisting of path loss, large-scale fading, and small-scale fading. Then, the signal to interference and noise ratio (SINR) value of the CEU m based on non-coherent reception becomes

$$\text{SINR}_m(\mathbf{X}, \mathbf{P}) = \frac{\sum_{n=1}^N P_n G_{nm} x_{nm}}{\sum_{j=1}^N P_j G_{jm} (1 - x_{jm}) + N_0} = \frac{\sum_{i \in S_m} P_i G_{im}}{\sum_{j \in \bar{S}_m} P_j G_{jm} + N_0}, \quad (3)$$

where N_0 denotes the power of the additive white Gaussian noise (AWGN), and \bar{S}_m denotes the complement set of S_m . Based on Shannon theorem, we calculate the achievable data rate of CEU m as

$$R_m(\mathbf{X}, \mathbf{P}) = B \log_2 (1 + \text{SINR}_m(\mathbf{X}, \mathbf{P})). \quad (4)$$

The CU can jointly determine the group of CEUs selected for data transmission and the transmitted power of each BSS to maximize the cell-edge sum throughput subject to per-BSS

antenna power constraint. The optimization problem can be formulated as

$$\begin{aligned} \max_{\mathbf{X}, \mathbf{P}} \quad & R(\mathbf{X}, \mathbf{P}) = \sum_{m=1}^M R_m(\mathbf{X}, \mathbf{P}) \\ \text{s.t.} \quad & 1) \sum_{m=1}^M x_{nm} \leq 1, \forall n \in \mathcal{N} \\ & 2) x_{nm} \in \{0, 1\}, \forall m \in \mathcal{M}, \forall n \in \mathcal{N}. \\ & 3) 0 \leq P_n \leq P_{\max}, \forall n \in \mathcal{N}. \end{aligned} \quad (5)$$

Note that the formation of the CTS for each user is included in the optimization problem. The constraint 1) guarantees that a BSS transmits to at most one CEU.

III. POWER CONTROL ANALYSIS

For any given user selection indicator matrix, let $\hat{\mathcal{M}}$ denote the set of selected CEUs, which is given by

$$\hat{\mathcal{M}} = \{m \mid x_{nm} = 1, n \in \mathcal{N}, m \in \mathcal{M}\}. \quad (6)$$

Then, the solution to (5) comes from the optimal power allocation for the given user set $\hat{\mathcal{M}}$, that is

$$\mathbf{P}^* = \arg \max_{\mathbf{P}} \sum_{m \in \hat{\mathcal{M}}} R_m(\mathbf{P}). \quad (7)$$

The constraints 1) and 2) in (5) can be transformed as $|\hat{\mathcal{M}}| \leq N$. According to the system model considered in this paper (see Fig. 1), the cluster consists of three BSSs, i.e., $N = 3$. Hence, we have $|\hat{\mathcal{M}}| \leq 3$ and the selected user set $\hat{\mathcal{M}}$ may include one, two, or three users. Below, the power control optimization problem is analyzed for these three cases separately.

A. One Selected User Case

When only one CEU m is selected to be served by the three BSSs during a given time slot, the cell-edge throughput $\sum_{m \in \hat{\mathcal{M}}} R_m(\mathbf{P})$ in (7) is given by

$$\sum_{m \in \hat{\mathcal{M}}} R_m(\mathbf{P}) = R_m(\mathbf{P}) = B \log_2 \left(1 + \frac{P_1 G_{1m} + P_2 G_{2m} + P_3 G_{3m}}{N_0} \right). \quad (8)$$

It is straightforward to notice that the optimization solution of (7) for the case $|\hat{\mathcal{M}}| = 1$ is $[P_1^*, P_2^*, P_3^*] = [P_{\max}, P_{\max}, P_{\max}]$, i.e., all BSSs transmit data to the selected CEU with full power, and the CTS of this CEU includes the three BSSs.

B. Two Selected Users Case

Without loss of generality, let m_1 denote a CEU served by BSS n_1 and BSS n_2 . Let m_2 denote a CEU served by BSS n_3 . Note that $m_1, m_2 \in \hat{\mathcal{M}}$, and $n_1, n_2, n_3 \in \mathcal{N}$. Then, we have

$$\sum_{m \in \hat{\mathcal{M}}} R_m(\mathbf{P}) = B \log_2 (J(\mathbf{P})), \quad (9)$$

where

$$J(\mathbf{P}) = \left(1 + \frac{P_{n_1} G_{n_1 m_1} + P_{n_2} G_{n_2 m_1}}{P_{n_3} G_{n_3 m_1} + N_0} \right) \left(1 + \frac{P_{n_3} G_{n_3 m_2}}{P_{n_1} G_{n_1 m_2} + P_{n_2} G_{n_2 m_2} + N_0} \right). \quad (10)$$

In order to find the optimal solution, similar to the one in ref. [6], by calculating the derivative of $J(\mathbf{P})$ w. r. t. P_{n_1} , we have

$$f(\mathbf{P}) = \frac{\partial J(\mathbf{P})}{\partial P_{n_1}} = \frac{A(P_{n_1} + C)^2 + D}{E}, \quad (11)$$

where

$$A = G_{n_1 m_1} G_{n_1 m_2}^2 > 0,$$

$$C = (P_{n_2} G_{n_2 m_2} + N_0) / G_{n_1 m_2} > 0,$$

$$D = G_{n_1 m_1} (P_{n_2} G_{n_2 m_2} + N_0) (P_{n_2} G_{n_2 m_2} + N_0 + P_{n_3} G_{n_3 m_2}) - P_{n_3} G_{n_1 m_2} G_{n_3 m_2} (P_{n_3} G_{n_3 m_1} + N_0 + P_{n_2} G_{n_2 m_1}) - G_{n_1 m_1} (P_{n_2} G_{n_2 m_2} + N_0)^2,$$

$$E = (P_{n_3} G_{n_3 m_1} + N_0) (P_{n_1} G_{n_1 m_2} + P_{n_2} G_{n_2 m_2} + N_0)^2 > 0.$$

Since $E > 0$, the solution of $f(\mathbf{P}) = 0$ comes from the solution of $A(P_{n_1} + C)^2 + D = 0$. Note that $A, C > 0$. Hence, if $D \geq 0$, no P_{n_1} can be found in the domain of $[0, P_{\max}]$ such that $A(P_{n_1} + C)^2 + D = 0$, i.e., there is no extreme point for $J(\mathbf{P})$ w. r. t. P_{n_1} . Otherwise, $A(P_{n_1} + C)^2 + D$ has one zero for $P_{n_1} \in [0, P_{\max}]$ and changes from negative to positive for increasing P_{n_1} , i.e., there is a minimum point for $J(\mathbf{P})$. In either case, the maximum value of $J(\mathbf{P})$ is obtained at the boundary point of P_{n_1} , i.e., 0 or P_{\max} . Using the same method, the above analysis also holds for P_{n_2} and P_{n_3} . Hence, binary power control is the optimal solution for the two selected users case.

C. Three Selected Users Case

If $|\hat{\mathcal{M}}| = 3$, each of the three BSSs in the cluster transmits data to different CEUs, which means the CTS of each selected CEU includes at most one BSS. Let i denote the user served by BSS i . The cell-edge throughput can be rewritten by

$$\sum_{m \in \hat{\mathcal{M}}} R_m(\mathbf{P}) = \sum_{i=1}^3 B \log_2 \left(1 + \frac{P_i G_{ii}}{\sum_{j \neq i} P_j G_{ji} + N_0} \right), \quad (12)$$

which is the same problem formulation of a coordinated power control without considering joint transmission [7]. Note that in this case, signals transmitted from other BSSs are acting as interference. Hence, the SINR values for the selected CEUs are low, and the cell-edge throughput can be approximated by the Taylor expansion, $\log_2(1 + \text{SINR}) \approx \text{SINR} / \ln 2$. Thus, we have

$$\sum_{m \in \hat{\mathcal{M}}} R_m(\mathbf{P}) = \frac{B}{\ln 2} \sum_{i=1}^3 \frac{P_i G_{ii}}{\sum_{j \neq i} P_j G_{ji} + N_0}. \quad (13)$$

By calculating the second order of the derivative w. r. t. each P_i , we have

$$\frac{\partial^2 \left(\sum_{m \in \hat{\mathcal{M}}} R_m(\mathbf{P}) \right)}{\partial P_i^2} = \frac{B}{\ln 2} \sum_{j \neq i} \frac{2P_j G_{ji} G_{ij}^2}{\left(\sum_{k \neq j} P_k G_{kj} + N_0 \right)^3} \geq 0. \quad (14)$$

Hence, the cell-edge throughput is a convex function with respect to each P_i , and the optimal power control in the three selected users case is binary, i.e., 0 or P_{\max} .

Based on the above analysis, we can conclude that the optimal power control for the considered system model and any given selected user set is binary power control.

IV. JOINT SCHEDULING AND POWER CONTROL

In this section, two algorithms are proposed for joint scheduling and power control in a CoMP cluster. First we

present a centralized algorithm in subsection A, then, a low-complexity semi-distributed algorithm is proposed for practical implementation in subsection B.

A. Centralized Scheduling and Power Control

Assume the CU has perfect CSI of all the CEUs in the cluster. Based on the analytical result obtained in Section III, the optimization solution becomes an exhaustive binary search. The CU searches all the possible values of the user selection indicator matrix \mathbf{X} and all feasible boundary point sets for the binary power control. The chosen matrix \mathbf{X}^* and transmit power vector \mathbf{P}^* will be the ones that achieve the highest cell-edge throughput. Hence, the optimal joint scheduling and power control to maximize the cell-edge throughput is composed of three steps:

- 1) For each matrix \mathbf{X} , obtain the set of selected CEUs $\hat{\mathcal{M}}$ using (6).
- 2) Based on the cardinality of $\hat{\mathcal{M}}$, find the optimal binary power allocation $\mathbf{P}(\hat{\mathcal{M}})$ based on (7), (8), (9), (13) for each $\hat{\mathcal{M}}$. Then, store the corresponding cell-edge throughput $R(\mathbf{P}(\hat{\mathcal{M}}), \hat{\mathcal{M}})$ and the optimal power allocation $\mathbf{P}(\hat{\mathcal{M}})$.
- 3) Find the user group $\hat{\mathcal{M}}^*$ that achieves the maximum cell-edge throughput. Choose the user scheduling matrix \mathbf{X}^* according to $\hat{\mathcal{M}}^*$. Let the BSSs in the CoMP cluster transmit with power $\mathbf{P}^* = \mathbf{P}(\hat{\mathcal{M}}^*)$.

Note that the number of the feasible selected user sets is M^N . For each selected user set, in the binary power control step, the number of the feasible boundary points set is 2^N . Therefore, the complexity is $O(2^N M^N)$. For a system with a large number of users in the cluster, the centralized scheduling and power control algorithm is prohibitively complex.

B. Semi-distributed Scheduling and Power Control

In single cell multi-user MIMO systems, low-complexity user scheduling methods based on the idea of greedy user selection (GUS) are widely accepted. GUS is a successive procedure by selecting the user with best channel quality, and then iteratively adds a new user from the remaining users until adding one more user reduces the cell throughput [10]. Inspired by GUS, a low-complexity semi-distributed algorithm is proposed for joint scheduling and power allocation in a CoMP cluster, where each BSS successively performs a greedy user selection combined with transmit power decision based on decisions made by the previous BSSs. This algorithm is performed based on the objective function (8) to maximize the cell-edge throughput. Note that a similar GUS based scheduling scheme is proposed in [9] without considering power control. We assume that all BSSs in the cluster know the perfect CSI of all the CEUs. Let $\hat{\mathcal{M}}^{(n)}$, $\mathbf{P}^{(n)}$, and $R^{(n)}$ denote the set of selected CEUs, the power allocation vector, and the cell-edge throughput achieved in the n^{th} iteration, respectively. The proposed algorithm is listed in Table I.

The algorithm starts with an empty user set, and the transmit power of each BSSs is assigned to be zero. Then, in each iteration n , based on the decision made by previous steps, the selected user set $\hat{\mathcal{M}}$ and the transmit power vector \mathbf{P} are jointly updated by the BSS n , and then forwarded to the next BSS. Hence, compared with the GUS based scheduling scheme

in [9], a CU is not needed for collecting and distributing the user selection matrix \mathbf{X} in each iteration, which reduces the backhaul overhead. After finishing all BSSs in the cluster, $\hat{\mathcal{M}}^{(N)}$ and $\mathbf{P}^{(N)}$ will be the final selected user set and power control vector, respectively. The proposed algorithm requires N iterations, and the optimization problem in line 4 is solved with complexity $O(M)$ in each iteration. Hence, the complexity of this algorithm is $O(NM)$, achieving a significant reduction compared to the centralized algorithm.

TABLE I. SEMI-DISTRIBUTED ALGORITHM

1:	Initialize $P_n = 0, \forall n \in \{1, \dots, N\}; R^{(0)} = 0; \hat{\mathcal{M}}^{(0)} = \phi$
2:	for $n = 1$ to N
3:	$P_n = P_{\max}, \mathbf{P}^{(n)} = [P_1, \dots, P_n]$
4:	$m^* = \arg \max_{m \in \mathcal{M}} \sum_{i \in \hat{\mathcal{M}}^{(n-1)} \cup \{m\}} R_i(\mathbf{P}^{(n)})$
5:	if $\sum_{i \in \hat{\mathcal{M}}^{(n-1)} \cup \{m^*\}} R_i(\mathbf{P}^{(n)}) < R^{(n-1)}$
6:	$R^{(n)} = R^{(n-1)}, P_n = 0, \mathbf{P}^{(n)} = [P_1, \dots, P_n]$
7:	else
8:	$R^{(n)} = \sum_{i \in \hat{\mathcal{M}}^{(n-1)} \cup \{m^*\}} R_i(\mathbf{P}^{(n)}), \hat{\mathcal{M}}^{(n)} = \hat{\mathcal{M}}^{(n-1)} \cup \{m^*\}$
9:	end if
10:	end for

V. SIMULATION RESULTS

The performance of the cell-edge average throughput, the average transmit power, and the probability of joint transmission are evaluated for the proposed centralized and semi-distributed joint scheduling and power control algorithms, named as C-JSPC and D-JSPC, respectively. In addition, two algorithms are used for comparison purposes:

1) Coordinated user scheduling without power control [9]: All the BSSs in the cluster transmit with full power P_{\max} , i.e., no power control is considered. However, the selected user set is jointly designed and CoMP joint transmission is supported. One centralized and one semi-distributed version of the scheduling algorithms are considered, named as C-NPC and D-NPC, respectively, since no power control (NPC) is considered.

2) Joint scheduling and power control without joint transmission: To make the coordinated binary power control algorithm in [8] comparable, we generalize it to consider user selection algorithms similar to the schemes proposed in this paper. However, due to the assumption that each CEU can only be served by its serving BSS in [8], multi-BSS joint transmission is not supported. One centralized and one semi-distributed version of the scheduling algorithms are considered, named as C-NJT and D-NJT, respectively, since no joint transmission (NJT) is considered.

Consider a cluster of three BSSs with one transmit antenna each and a cell radius of 500m. Users are uniformly dropped in each BSS. CCUs and CEUs are divided by a path loss window [11], where the threshold is predefined as 7dB. The path loss model is set as $L(d) = 128.1 + 37.6 \log_{10}(d)$ in dB. Shadowing standard deviation is 8dB. Only CEUs are considered in the simulation. The AWGN power is -125dBW . The performance

of the above mentioned six algorithms is evaluated under various transmission power constraints per BSS. 10000 independent trials are evaluated by Monte-Carlo simulation for each fixed maximum power constraint.

Fig. 2 shows the cell-edge average throughput for the six different algorithms considered in this paper. It can be seen that the semi-distributed versions of the algorithms achieve more than 97% of the cell-edge average throughput from the centralized solutions. The proposed C-JSPC algorithm achieves the highest cell-edge throughput performance. Even the semi-distributed D-JSPC algorithm with much lower complexity outperforms the centralized C-NPC and C-NJT algorithms. This is because the proposed C-JSPC and D-JSPC algorithms support CoMP joint transmission, at the same time, there is a parameter to control the CTS of each user that comes from the binary power control. Note that binary power control without joint transmission can be considered as one simplified approach performing dynamic inter-cell interference coordination (ICIC), which has been proposed in 3GPP LTE [12]. Hence, the improved cell-edge performance for the C-JSPC and D-JSPC algorithms is yielded by a better trade-off between joint transmission and interference coordination.

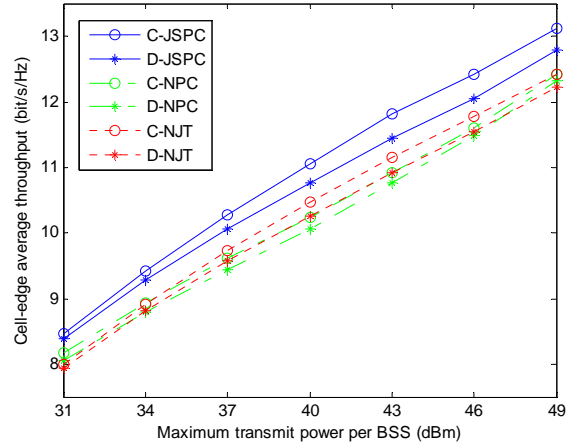


Fig. 2. Cell-edge average throughput vs. the maximum transmit power constraint per BSS

To improve further our understanding of joint transmission and interference coordination in the six algorithms considered in this paper, in Fig. 3 and Fig. 4, we plot the probability of the joint transmission and the probability of the interference coordination, respectively. For a fixed maximum transmit power per BSS constraint, the joint transmission probability is calculated as the number of joint transmission trials divided by the total number of trials evaluated in the simulation. We define an interference coordination trial as the trial in which at least one BSS is turned off and no joint transmission occurs. Then, the interference coordination probability can be derived in the same way as the joint transmission probability, i.e., the number of interference coordination trials divided by the total number of evaluated trials.

As seen from Fig. 3 and Fig. 4, compared to the corresponding centralized algorithms, the corresponding semi-distributed algorithms achieve higher joint transmission probability and lower interference coordination probability. Note that the joint transmission probability of both the C-NJT and D-NJT algorithms is always zero, since joint transmission is not supported in the C-NJT and D-NJT algorithms; the

interference coordination probability of the C-NPC and D-NPC algorithms is always zero, since all BSS are always turned on in the C-NPC and NPC algorithms, i.e., interference coordination is not considered. The C-JSPC and D-JSPC algorithms achieve a better trade-off between joint transmission and interference coordination, which helps to improve the cell-edge performance.

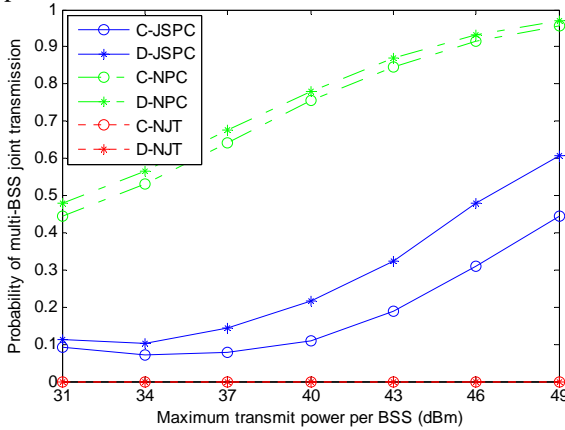


Fig. 3. Joint transmission probability vs. the maximum transmit power constraint per BSS

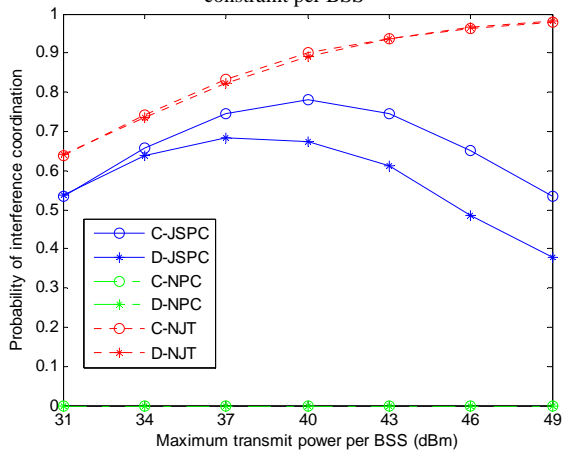


Fig. 4. Interference coordination probability vs. the maximum transmit power constraint per BSS

Fig. 5 shows the average number of BSS turned on as a function of the maximum power constraint per BSS. For the C-NPC and D-NPC algorithms, where all BSSs always transmit with full power, the average number of BSSs turned on is always three, i.e., no power savings. For the C-NJT and D-NJT algorithms, the average number of BSSs turned on decreases as the maximum power constraint increases; and for the C-JSPC and D-JSPC algorithms, the average number first decreases and then increases. This can be explained by the tendency of the coordination probability as shown in Fig. 4.

VI. CONCLUSION

In this paper, we consider the downlink of a coordinated cluster with 3 neighboring base station sectors. Two joint scheduling and power control algorithms are presented in order to maximize the cell-edge sum throughput under a per base station sector power constraint. First, we prove that binary power control algorithm is the optimal power allocation for any given selected user group. Then, a centralized joint scheduling and power control is proposed under the assumption that the CU can get access to perfect channel state information and data

of all the users. A low-complexity semi-distributed algorithm is proposed for practical implementation. It is demonstrated by the simulation results that the proposed algorithms can offer a good balance between CoMP joint transmission and interference coordination, which provides a substantial cell-edge performance improvement.

The results in this paper focus only on a single cluster with a flat fading channel. In future work, multi-cluster interference will be addressed in the algorithm design. In addition, joint resource allocation and power control problems in multiple sub-channel systems will be considered.

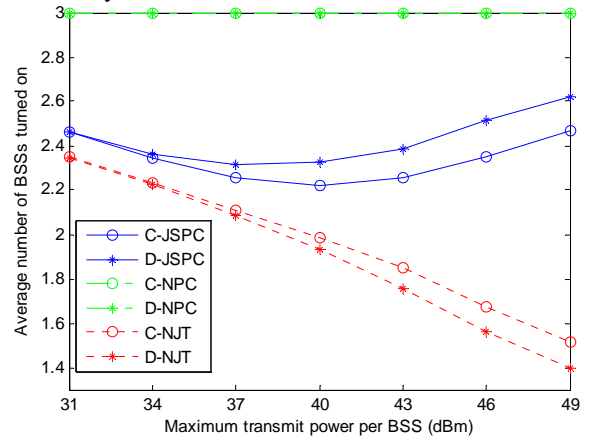


Fig. 5. Average number of BSSs turned on vs. the maximum transmit power constraint per BSS

REFERENCES

- [1] M. Sawahashi, Y. Kishiyama, A. Morimoto, D. Nishikawa, and M. Tannoi, "Coordinated multi-point transmission/reception techniques for LTE-Advanced," *IEEE Wireless Commun. Mag.*, pp.26-34, June 2010.
- [2] M. K. Karakayali, G. J. Foschini, and R. A. Valenzuela, "Network coordination for spectrally efficient communications in cellular systems," *IEEE Wireless Commun. Mag.*, vol. 13, no. 4, pp. 56–61, Aug. 2006.
- [3] J. Li, H. Zhang, X. Xu, X. Tao, T. Svensson, C. Botella, B. Liu, "A novel frequency reuse scheme for coordinated multi-point transmission," in *Proc. IEEE VTC'10*, 2010.
- [4] C. Botella, T. Svensson, X. Xu, H. Zhang, "On the performance of joint processing schemes over the cluster area," in *Proc. IEEE VTC'10*, 2010.
- [5] N. Reider, A. Racz, and G. Fodor, "On scheduling and power control in multi-cell coordinated clusters," in *Proc. IEEE GLOBECOM'09*, 2009.
- [6] A. Gjendemsj, D. Gesbert, G. Øien, and S. Kiani, "Optimal power allocation and scheduling for two-cell capacity maximization," in *Proc. Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks*, pp. 1-6, 2006.
- [7] J. Cho, J. Mo, and S. Chong, "Joint network-wide opportunistic scheduling and power control in multi-cell clusters," *IEEE Trans. on Wireless Commun.* Vol. 8, No. 3, March 2009.
- [8] A. Gjendemsj, D. Gesbert, G. Øien, and S. Kiani, "Binary power control for sum rate maximization over multiple interfering links," *IEEE Trans. on Wireless Commun.*, vol. 7, pp. 3164-3173, Aug. 2008.
- [9] H. Skjevling, D. Gesbert, and A. Hjørungnes, "Low-complexity distributed multibase transmission and scheduling," *EURASIP journal on Advances in Signal Proc.*, vol. 2008, pp. 1-8, 2008.
- [10] G. Dimic and N. D. Sidiropoulos, "On downlink beamforming with greedy user selection: performance analysis and a simple new algorithm," *IEEE Trans. on Signal Proc.*, vol. 53, pp. 3857-3868, Oct. 2005.
- [11] G. Piñero, C. Botella, A. González, M. de Diego, and N. Cardona, "Downlink power control and beamforming for a cooperative wireless system," in *Proc. IEEE PIMRC'04*, pp. 974-978, 2004.
- [12] 3GPP TR 25.814 v7.1.0, "Physical layer aspects for evolved UTRA (Release 7)," Sept. 2006.