

# Joint User Association, Power Control and Scheduling in Multi-Cell 5G Networks

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**Abstract**—The focus of this paper is targeted towards multi-cell 5G networks composed of High Power Node (HPNs) and of simplified Low Power Node (LPNs) co-existing in the same operating area and sharing the scarce radio resources. Consequently, high emphasis is given to Inter-Cell Interference Coordination (ICIC) based on multi-resource management techniques that take into account user association to cells. Beside user association, this paper takes also power control and scheduling into consideration. This complex problem is remained largely unsolved, mainly due to its non-convex nature, which makes the global optimal solution difficult to obtain. We address the user association challenge according to the two broadly adopted approaches in wireless networks: the network-centric approach where user association is allocated efficiently in a centralized fashion; and the user-centric approach where distributed allocation is used for reduced complexity. The scheduling and ICIC power control are solved in a centralized fashion, in order to reach an optimal solution of the joint optimization problem.

**Keywords**-5G; ICIC; Game Theory; convex optimization.

## I. INTRODUCTION

5G networks are currently facing significant challenges in terms of signaling load. Compared to its predecessors, 5G results in a significantly higher signaling requirement per subscriber. While a portion of this new signaling is required for new services and new device types, the majority of the signaling burden is related to mobility and paging. This increase is in part due to architectural changes such as heterogeneous networks and greater node density. Consequently, one of the objectives of 5G networks is to enhance the capabilities of HPNs and simplify LPNs through offloading some of their functions to a *signal processing cloud* connected through high-speed optical fibers. The signal processing cloud is, in fact, a pool of Base Band Units (BBUs). For a simplified architecture, all control signaling and system broadcasting information are delivered by HPNs to UEs. This paper addresses the issue of UE association to HPNs in 5G networks. Further, as multiple HPNs use the same radio resources in a given operating area, ensuing interference harms radio transmissions and degrades the performances. Hence, a certain degree of coordination between the HPNs belonging to the same baseband unit (BBU) pool is required to minimize the interference level through power control. We consider Orthogonal Frequency Division Multiple Access (OFDMA) as the multi access

scheme for the downlink. As the same Resource Block (RB) is used in neighboring cells, interference may occur and degrade the channel quality of serviced UEs. Hence, efficient Inter-Cell Interference Coordination (ICIC) techniques [1] are still-considered among the key building blocks of 5G networks, in particular, ICIC through power control. Multi-Resource management based on joint power allocation, scheduling and UE association is a primary key to achieve good global performance.

Accordingly, the aim of this paper is threefold:

1. UE association to HPNs:
  - Decide the UE association to the adequate HPN for the signaling plan; this decision is operated in a centralized fashion by the advanced cloud computing processing techniques in the BBU pool.
  - Decide the UE association to the adequate HPN for the data plan; this decision is operated by UEs in a distributed fashion.
2. Interference mitigation among HPNs through power control:
  - The joint HPN/UE association and HPN power control is solved in an iterative fashion until convergence involving the following steps:
    - Fixing the association of UEs, the power levels are cooperatively updated by HPNs to alleviate inter-cell interference and thereby improving network utility.
    - Fixing the HPN power allocation, the association of UEs to each HPNs is again done by solving the resulting optimization problem for UE association.
3. Fair scheduling of resources among UEs.

We propose a unified framework to study the interplay of UE association and power allocation, in conjunction with fair scheduling. For that, we strive to optimize a network utility function that ensures proportional fairness among all served UEs.

### A. Related Work

The joint UE association (i.e. HPN selection), scheduling and power control is a relevant problem in many wireless communications systems. However, despite its importance, it still largely unsolved, mainly due to its non-convex and combinatorial nature that makes the global optimal solution difficult to obtain. In OFDMA networks, many articles have addressed the subject of joint UE association and power control ([2]-[6]). An intuitive idea is to optimize UE

association and power levels in an iterative fashion, as suggested in ([2]-[4]). In [3], the authors propose an iterative method for power control and UE association: the power control is modeled as a non-cooperative game while the UE association relies on a signaling-based heuristic. The work in [4] considers a pricing-based UE association scheme for heterogeneous networks and proposes a distributed price update strategy based on a coordinate descent algorithm in the dual domain. The proposed UE association scheme is incorporated with power control and beamforming and solved iteratively. The work in ([5]-[6]) strives to obtain global optimality for the joint UE association and power control problem. In [5], the joint problem is addressed using duality theory, but only for a relaxed version of the problem where the discrete constraints are eliminated. Finally, authors in [6] propose a novel algorithm based on Benders decomposition to solve the joint non-convex problem optimally.

### B. Our Contribution

In our work, we show that proportional fairness among UEs boils down to time fairness in section III-A. The power control is solved in centralized fashion in section III-C, where for a fixed UE association, the power levels are updated by computing the resulting non-convex optimization problem for power control. The latter is transformed to a convex problem through geometric transformation. Such a solution allows multiple cells to coordinate with the objective of alleviating inter-cell interference, and improving overall network utility. The UE association in section IV is solved according to the network-centric approach for the control plane and the user-centric approach for the data plane.

In the network-centric approach, the assignment of UEs to each HPN is done in a centralized fashion by solving the resulting optimization problem for UE association.

In the user-centric approach, the UE association scheme for the data plane is portrayed as non-cooperative game. In our case, HPNs and UEs optimize their local parameters by using signaling messages already present in the network. A distributed algorithm for the UE association scheme based on Best-response algorithm will be applied by UEs to attain the Nash Equilibriums (NE) of the game.

We have used an iterative optimization approach involving a centralized ICIC power control for a fixed UE association and UE assignment for a fixed power allocation. The above two steps will be iterated to reach a (local) optimal solution of the joint power control and user association problem. The centralized UE association scheme is stable but is highly computational complex. In fact, it requires a central controller that collects information from HPNs and UEs, and sends signaling messages back to HPNs and UEs which can be cumbersome. However, it is particularly suited for the UE association to the control plane. As for the data plane, it requires more frequent updates in association and it is better handled in a distributed fashion by the end-user.

The remainder of this paper is organized as follows. Section II presents the network model. Our approach is put forward in Section III. The scheduling problem is presented in Section III-A, the joint UE association and power control is explained in section III-B and the centralized power control is detailed in section III-C. The User association approach is explained in section IV where the network-centric UE association is presented in Section IV-A and the user-centric UE association approach is presented in Section IV-B. Section V discusses simulation setup and displays quantitative results along with the discussion. Section VI concludes the paper.

## II. NETWORK MODEL

We consider the downlink of an OFDMA Single Input Single Output (SISO) cellular network, where a radio Resource Block (RB) is the smallest radio resource unit [7] that can be scheduled to a UE. A permanent downlink traffic scenario is considered, and all RBs are assigned at each scheduling period to a given UE. The variables and parameters used within this paper are defined in Table 1.

TABLE I. MATHEMATICAL NOTATIONS, VARIABLES AND PARAMETERS IN THE DOCUMENT.

$J$	Set of HPNs.	$I$	Total set of UEs.
$K$	Set of RBs.	$K(j)$	Set of RBs used by HPN $j$
$G_{ijk}$	Channel power gain of UE $i$ on RB $k$ associated to HPN $j$ .		
$\rho_{ijk}$	SINR of user $i$ associated HPN $j$ served on RB $k$ .		
$\beta_{jk}$	Interference impact of all HPNs among UEs of HPN $j$ .		
$N_0$	Noise power.		
$\pi_{jk}$	downlink power devoted by HPN $j$ to RB $k$ .		
$\alpha_{ij}$	The proportion of time that UE $i$ is scheduled on the downlink by HPN $j$ .		
$p_j^{max}$	Maximum downlink transmission power per HPN.		
$p^{min}$	Minimum downlink transmission power per RB.		

The Signal-to-interference-plus-noise-ratio (SINR) of UE  $i$  associated to HPN  $j$  and allocated RB  $k$  is given by:

$$\rho_{ijk} = \frac{\pi_{jk} G_{ijk}}{N_0 + \sum_{j' \neq j} \pi_{j'k} G_{ij'k}}. \quad (1)$$

We assume that there is a mapping function  $f(\cdot)$  that maps  $\rho_{ijk}$  to its corresponding bit rate  $r_{ijk}$  (bit/s) realized by UE  $i$  associated with HPN  $j$  served on RB  $k$ , i.e.,  $r_{ijk} = f(\rho_{ijk})$ .

Conventional UE association uses the max-SINR rule. It is evident from a network utility maximization perspective that max-SINR is inappropriate as it may deprive bad channel quality UEs from accessing radio resources. Hence, in this paper, we consider the network utility maximization problem under proportional fairness. Hence, we privilege users' interest by using the proportional equity incarnated by the logarithmic function [8]. To reach this objective we maximize  $\sum_{i \in I} \log(r_i)$  where  $r_i$  is the mean bit rate of UE  $i$ :

$$r_i = \sum_{j \in J} \theta_{ij} \alpha_{ij} \sum_{k \in K(j)} f(\rho_{ijk}), \quad (2)$$

with  $\theta_{ij}$  is the association variable:

$$\theta_{ij} = \begin{cases} 1 & \text{if UE } i \text{ is associated with HPN } j \\ 0 & \text{otherwise.} \end{cases} \quad (3)$$

Hence, the joint multi-resource management problem based on power control, UE association and proportional fair scheduling is defined as:

$$\underset{\theta, \alpha, \pi}{\text{maximize}} \sum_{i \in I} \log \left( \sum_{j \in J} \theta_{ij} \alpha_{ij} \sum_{k \in K(j)} f(\rho_{ijk}) \right). \quad (4a)$$

$$\text{subject to:} \quad \sum_{j \in J} \theta_{ij} = 1, \forall i \in I, \quad (4b)$$

$$\sum_{i \in I(j)} \alpha_{ij} = 1, \forall j \in J \quad (4c)$$

$$\sum_{k \in K(j)} \pi_{jk} \leq P_j^{\max}, \forall j \in J, \quad (4d)$$

$$\theta_{ij} \in \{0, 1\}, \forall i \in I, \forall j \in J, \quad (4e)$$

$$0 \leq \alpha_{ij} \leq 1, \forall i \in I, \forall j \in J, \quad (4f)$$

$$\pi_{jk} \geq P_j^{\min}, \forall j \in J, \forall k \in K(j). \quad (4g)$$

Constraint (4c) ensures that a UE is served at most 100% of the time by a given HPN. Constraints (4d-4g) guarantee the maximum total power consumed per HPN and the minimum power allocated per RB respectively. The utility function in (4a) can be re-written as:

$$\begin{aligned} U &= \sum_{i \in I} \log \left( \sum_{j \in J} \theta_{ij} \alpha_{ij} \sum_{k \in K(j)} f(\rho_{ijk}) \right) \quad (5) \\ &= \sum_{i \in I} \sum_{j \in J} \theta_{ij} \log(\alpha_{ij}) + \sum_{i \in I} \sum_{j \in J} \theta_{ij} \log(r_{ij}). \end{aligned}$$

where  $r_{ij} = \sum_{k \in K(j)} \rho_{ijk}$  represents the mean bit rate obtained by UE  $i$  connected to HPN  $j$ . In this paper, we consider that the function  $f(\cdot)$  is the identity function. Accordingly, the utility formulation is technology-agnostic: the mapping between the throughput and the SINR of each UE can be derived in respect to the appropriate coding and modulation scheme in wireless networks. Inevitably, improving this network utility amounts to improving the UE throughput.

### III. PROBLEM FORMULATION

We show that proportional fairness among UEs boils down to time fairness in Section III-A. The resulting joint UE association and power control problem will be presented in Section III-B. The centralized power control problem will be described in Section III-C.

#### A. The Scheduling Problem

The utility function in (5) contains in its first term the per cell scheduling problem that we intend to solve in this section (by computing  $\alpha_{ij}$  which is the percentage of time UE  $i$  is served in HPN  $j$ ).

Assuming that UE  $i$  has chosen HPN  $l$  (i.e.  $\theta_{il} = 1$ ;  $\theta_{ij} = 0, \forall j \neq l$ ), we have what follows:

$$\sum_{i \in I, j \in J} \theta_{ij} \log(\alpha_{ij}) = \sum_{i \in I(l)} \log(\alpha_{il})$$

where  $I(l)$  is the set of UEs associated to HPN  $l$ . Consequently, the scheduling problem for HPN  $l$  is as follows:

$$\underset{\alpha}{\text{maximize}} \quad \sum_{i \in I(l)} \log(\alpha_{il}) \quad (6a)$$

$$\text{subject to} \quad \sum_{i \in I(l)} \alpha_{il} = 1, \forall l \in J, \quad (6b)$$

$$0 \leq \alpha_{il} \leq 1, \forall i \in I(l), \forall l \in J. \quad (6c)$$

*Proposition 3.1:* the optimal solution of the scheduling problem is given by what follows:

$$\alpha_{il}^* = 1/|I(l)|, \forall l \in J, \forall i \in I(l). \quad (7)$$

**Proof:** Problem (6) is a convex optimization as the utility function (6a) is concave (sum of concave functions) and all constraints are linear. Let us express the KKT conditions that provide a first-order optimality condition for the problem:

$$-1/\alpha_{il} + \mu_l = 0, \quad \forall l \in J, \forall i \in I(l), \quad (8a)$$

$$\sum_{i \in I(l)} \alpha_{il} \leq 1, \quad \forall l \in J, \quad (8b)$$

$$\mu_l \left( \sum_{i \in I(l)} \alpha_{il} - 1 \right) = 0, \quad \forall l \in J. \quad (8c)$$

From constraints (8a), we know that  $\mu_l \neq 0$ , otherwise  $1/\alpha_{il} = 0$  which is not possible. Hence, we deduce from constraint (8c) that  $\sum_{i \in I(l)} \alpha_{il} = 1$ . Furthermore, the utility function in (6a) can be re-written as:

$$\log \left( \prod_{i \in I(l)} \alpha_{il} \right) \quad (9)$$

As the sum of the  $\alpha_{il}$  variables is constant, the product of these variables is maximized for  $\alpha_{il} = \frac{1}{|I(l)|}, \forall l \in J, \forall i \in I(l)$ .

#### B. The Joint UE Association and Power Control Problem

As  $\alpha_{ij} = \frac{1}{|I(j)|} = \frac{1}{\sum_{i \in I(j)} \theta_{ij}}, \forall j \in J$ , the utility function in (5) can be re-written such as:

$$U = \sum_{i \in I} \log \left( \sum_{j \in J} \frac{\theta_{ij}}{\sum_{i' \in I(j)} \theta_{i'j}} \sum_{k \in K(j)} \rho_{ijk} \right) \quad (10)$$

As the  $\theta_{ij}$  variables are binary and  $\sum_{j \in J} \theta_{ij} = 1$  for all UEs, there exists only one HPN  $j$  for which  $\theta_{ij} = 1$  ( $\theta_{i'j} = 0, \forall j' \neq j \in J$ ). Hence, the utility function can be re-casted as:

$$U = \sum_{i \in I} \sum_{j \in J} \theta_{ij} \log \left( \frac{\sum_{k \in K(j)} \rho_{ijk}}{1 + \sum_{i' \neq i} \theta_{i'j}} \right) \quad (11)$$

Given Jensen's inequality and the concavity of the log function, we have:

$$\log \left( \frac{\sum_{k \in K(j)} \frac{\rho_{ijk}}{1 + \sum_{i' \neq i} \theta_{i'j}}}{|K(j)|} \right) \geq \frac{\sum_{k \in K(j)} \log \left( \frac{\rho_{ijk}}{1 + \sum_{i' \neq i} \theta_{i'j}} \right)}{|K(j)|}$$

Thus, the utility function can be re-casted as follows:

$$\begin{aligned} U &= \sum_{i \in I} \sum_{j \in J} \theta_{ij} \log \left( \sum_{k \in K(j)} \frac{\rho_{ijk}}{1 + \sum_{i' \neq i} \theta_{i'j}} \right) \\ &\geq \sum_{i \in I} \sum_{j \in J} \sum_{k \in K(j)} \log \left( \frac{\rho_{ijk}}{1 + \sum_{i' \neq i} \theta_{i'j}} \right) \end{aligned} \quad (12)$$

We denote by  $\bar{U}$  the upper bound on the utility function, given by:

$$\bar{U} = \sum_{i \in I} \sum_{j \in J} \sum_{k \in K(j)} \log \left( \frac{\rho_{ijk}}{1 + \sum_{i' \neq i} \theta_{i'j}} \right) \quad (13)$$

Henceforward, we adopt this newly defined utility function  $\bar{U}$ . The ensuing joint UE association and power control will be solved according to a centralized power control in section III-C and two UE association approaches in section IV.

### C. The Centralized Power control

In this section, we resort to a centralized power control for ICIC scheme by fixing the UE association, the corresponding Power Control (PC) problem is given by:

$$\text{maximize}_{\pi} U^{PC}(\pi) = \quad (14a)$$

$$\sum_{j \in J} \sum_{i \in I(j)} \sum_{k \in K(j)} \log \left( \frac{1}{n_j} \times \frac{\pi_{jk} G_{ijk}}{N_0 + \sum_{j' \neq j} \pi_{j'k} G_{ij'k}} \right)$$

subject to:  $\sum_{k \in K(j)} \pi_{jk} \leq P_j^{max}, \forall j \in J$  (14b)

$$\pi_{jk} \geq P_j^{min}, \forall j \in J, \forall k \in K(j). \quad (14c)$$

where  $n_j$  is the number of UEs associated to HPN  $j$ , i.e.  $|I(j)|$ . Problem (14) is a non-convex optimization problem. However, it can be rendered convex through geometric programming by performing a variable change  $\hat{\pi}_{jk} = \log(\pi_{jk})$  and defining the following  $\hat{N}_0 = \log(N_0)$ ,  $\hat{G}_{ijk} = \log(G_{ijk})$  and  $\hat{n}_j = \log(n_j)$ . The resulting optimization problem deemed  $P(\hat{\pi})$  is given by the following:

$$\text{maximize}_{\hat{\pi}} U^{PC}(\hat{\pi}) = \quad (15a)$$

$$\sum_{j \in J} \sum_{i \in I(j)} \sum_{k \in K(j)} (\hat{\pi}_{jk} + \hat{G}_{ijk} - \log(\exp(\hat{N}_0) + \sum_{j' \neq j} \exp(\hat{\pi}_{j'k} + \hat{G}_{ij'k}))) - \sum_{j \in J} K \cdot n_j \cdot \hat{n}_j$$

subject to:

$$\log \left( \sum_{k \in K(j)} \exp(\hat{\pi}_{jk}) \right) - \log(p_j^{max}) \leq 0. \quad (15b)$$

$$-\hat{\pi}_{jk} + \log(p_j^{min}) < 0, \forall j \in J, \forall k \in K(j). \quad (15c)$$

*Proposition 4.1: The optimization problem  $P(\hat{\pi})$  is convex.*

**Proof:** The first part of the utility function is linear thus concave. The second part includes the log-sum-exp expressions which are convex and hence their opposite is concave. Further, the new constraints in (15b) are convex owing to the properties of the log-sum-exp expression, while the constraints in (15c) are linear and hence convex.

## IV. THE USER ASSOCIATION APPROACHES

We present in this section the UE association schemes. Each scheme will be run iteratively with the ICIC power control explained in section III-C, until convergence.

For the network-centric approach, the convergence to a local optimum is guaranteed as, at each iteration, and iteratively, both the power control scheme and the centralized UE association scheme will monotonically improve the value of the utility function.

For the user-centric approach we resort to a distributed UE association scheme based on Best-response algorithm and run by UEs. The convergence of the centralized power control and the distributed UE association is assessed through extensive simulations.

### A. Network-centric UE Association

For fixed power levels, The UE Association (UA) problem is given by:

$$\text{maximize}_{\theta} U^{UA}(\pi) = \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} \theta_{ij} \log \left( \frac{\rho_{ijk}}{n_j} \right) \quad (16a)$$

$$\text{Subject to: } \sum_{j \in J} \theta_{ij} = 1, \forall i \in I. \quad (16b)$$

$$\theta_{ij} \in \{0,1\}, \forall i \in I(j) \quad (16c)$$

$$n_j = \sum_{i \in I} \theta_{ij}, \forall j \in J. \quad (16d)$$

The problem in (16) is combinatorial due to the binary variable  $\theta_{ij}, \forall j \in J, \forall i \in I$  and the complexity of the brute force algorithm (in  $O(|J|^{|I|})$ ) is exponential in the number of UEs. A workaround is to allow UEs to be associated to more than one HPNs, i.e., the UE association becomes a load balancing scheme. The relaxed problem, that we deem *optimal load balancing*, is convex (for  $0 \leq \theta_{ij} \leq 1$ ), and provides an upper bound to the original problem in (16). However, in a practical system, it is much more difficult to implement a load balancing algorithm that allows costly recurrent shifts between HPNs than a UE association algorithm (single HPN selection). Thus, we adopt a rounding method to revert back to the original UE association and we deem it *Network-centric UE Association*.

### B. User-centric UE Association

We propose to solve the distributed UE association problem by having recourse to non-cooperative game theory. Non-Cooperative game theory models the interactions between players competing for a common resource. Hence, it is well adapted to model the HPN selection scheme. Here UEs are the decision makers or players of the game. We define a multiplayer game  $G_{UA}$  between the  $|I|$  UEs, assumed to make their decisions without knowing the decisions of each other.

The formulation of this non-cooperative game  $G_{UA} = (I, S, U^{UA})$  can be described as follows:

- A finite set of UEs  $i = \{1, \dots, |I|\}$ .
- The space of pure strategies  $S$  formed by the Cartesian product of each set of pure strategies  $S = S_1 \times S_2 \times \dots \times S_{|I|}$ , where the strategy space of any UE  $i$  is  $S_i = \{HPN_j^i, HPN_{j'}^i\}$  with  $j, j' \in J$ .
- If the UE  $i$  is finally associated with  $eNB_j^i$  (this is an outcome of the pure strategies played by UE  $i$ ), then  $\theta_{ij} = 1$ , else  $\theta_{ij'} = 1$ .
- We denote by  $a_i \in S_i$  the action taken by UE  $i$ .
- A set of utility functions

$$U^{UA} = (U_1^{UA}(\theta), U_2^{UA}(\theta), \dots, U_{|I|}^{UA}(\theta))$$

That quantify UEs' utility for a given strategy profile  $\theta$ , where the utility function of any UE  $i$  is given by:

$$U^{UA} = \sum_{j \in J} \sum_{k \in K} \theta_{ij} \log \left( \frac{\rho_{ijk}}{1 + \sum_{i \neq i} \theta_{ij}} \right) \quad (17)$$

The game  $G_{UA}$  is an unweighted crowding game as it is a normal-form game in which the UEs share a common set of actions and the payoff a particular UE  $i$  receives for choosing a particular action (selecting one of the available HPNs) is player specific and a non-increasing function of the total number of UEs choosing that same action. Unweighted crowding games have PNE (Pure NE). Furthermore, when players have only two strategies (choosing between  $HPN_j^i$  and  $HPN_{j'}^i$  for any UE  $i$ ), the game has the Finite Improvement Path (FIP) property [9] and hence a Best-Response algorithm permits attaining the PNE of the game. In fact, according to the optimal UE association as investigated in the performance evaluation Section VI, the large majority of UEs will be only associated to a single HPN and very few UEs will load balance their traffic among two HPNs solely. Hence, in the user-centric approach deemed distributed approach, it is largely enough to give each UE a choice among the two strategies denoted  $(\theta_i, 1 - \theta_i)$ . Accordingly, the utility function in (17) can be re-written as:

$$U_i^{UA} = \theta_i \log \left( \frac{\rho_{ij}}{1 + \sum_{i' \neq i} \theta_{i'}} \right) + (1 - \theta_i) \log \left( \frac{\rho_{ij'}}{|I| - \sum_{i' \neq i} \theta_{i'}} \right) = \theta_i \log \left( \frac{\rho_{ij}}{\rho_{ij'} / (1 + \sum_{i' \neq i} \theta_{i'})} \right) + \log \left( \frac{\rho_{ij'}}{|I| - \sum_{i' \neq i} \theta_{i'}} \right) \quad (18)$$

where  $\rho_{ij} = \prod_{k \in K} \rho_{ijk}$ . Note that the second term in (18) is independent of the player strategy and does not intervene in the strategy updates given in algorithm 1. Further at each round of the Best-response algorithm, each UE  $i$  favors the HPN that endows it with the higher mean rate.

#### Algorithm 1 BR algorithm for UE Association

- 1) Initialization: set  $t=0$  and each UE  $i$  defines an initial strategy  $\theta_i(0)$ .
- 2) For each UE  $i, i=\{1, \dots, |I|\}$ , do if:

$$\frac{\rho_{ij}}{1 + \sum_{i' \neq i} \theta_{i'}} > \frac{\rho_{ij'}}{|I| - \sum_{i' \neq i} \theta_{i'}}$$

Then UE  $i$  associates with  $HPN_j^i$  ( $\theta_i(t) = 1$ ).

Else, UE  $i$  associates with  $HPN_{j'}^i$  ( $\theta_i(t) = 0$ ).

- 3) Set  $t \leftarrow t + 1$  and go to step 2 (until satisfying termination criterion :  $\theta_i(t + 1) = \theta_i(t)$  for all  $i \in I$ ).

## V. PERFORMANCE EVALUATION

We consider a network with a bandwidth of 5 MHz with 9 hexagonal cells. The physical layer parameters are based on 3GPP technical specifications TS 36.942 [10].

TABLE II. PHYSICAL LAYER AND SIMULATION PARAMETERS

<b>User noise figure (dB)</b>	7.0	<b>Number of RBs</b>	25
<b>Thermal noise (dBm)</b>	-104.5	<b><math>p_j^{max}</math> (dBm)</b>	43
<b>Frequency reuse</b>	1	<b><math>p_j^{min}</math> (dBm)</b>	15
<b>Number UE/HPN</b>	4 to 14	<b>Number HPNs</b>	9

The simulation parameters are displayed in Table 2. In this paper, we used matlab simulator, where various scenarios were tested to assess the performances of our control schemes. For each approach, 25 simulations were run where in each cell a predefined number of users is selected; users' positions were uniformly distributed in the cells.

### A. UE Association Schemes

We begin by comparing the UE association schemes after rounding (deemed network-centric UE Association) and the global optimum obtained by the relaxed problem deemed optimal Load balancing. We portray in Fig. 1 the total rate using the Shannon capacity:

$$\sum_{i \in I} \sum_{j \in J} \sum_{k \in K(j)} \frac{\theta_{ij}}{1 + \sum_{i' \neq i} \theta_{i'j}} W |K| \log_2 (1 + \rho_{ijk})$$

We run 25 simulations for each scenario with a random level for power allocation (the same power allocation is set for all UE association schemes).

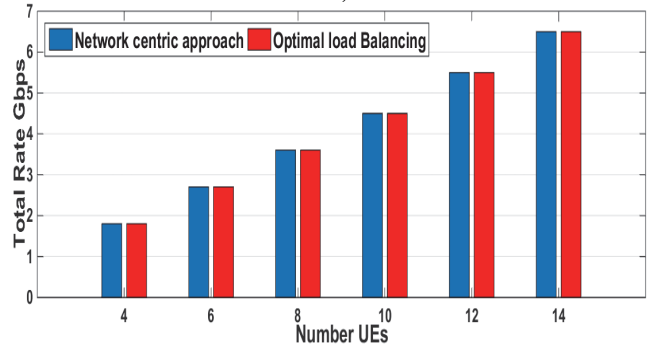


Figure 1. Total Mean Rate of optimal Load Balancing vs Network centric UE Association

The results of the network-centric UE Association are almost the same as the optimal Load balancing, showing the effectiveness of the rounding scheme. This occurs because in the optimal load balancing scheme, UEs have always a strong preference towards one of the HPNs as shown in Fig. 2. In fact, more than 99% of UEs are associated with exclusively a single HPN). The remaining UEs (less than 1%) make do with solely two HPNs.

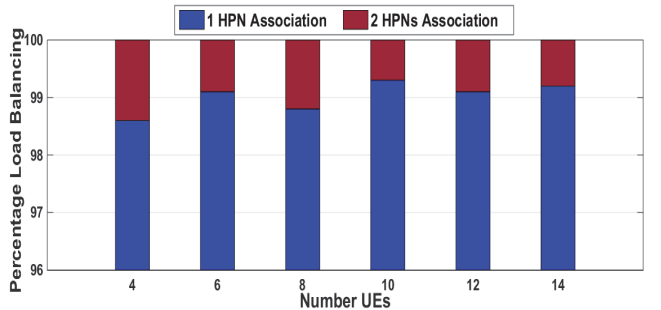


Figure 2. Percentage of Load Balancing

Therefore, and as stated earlier, it is relevant for the user-centric UE Association to choose among only two HPNs (best detected). Furthermore, we recorded, through the extensive simulations we performed, that the convergence of the BR Algorithm, is relatively fast, around 3 iterations, which is an undeniable asset of the distributed scheme.

## B. Global Performances

Here, we evaluate the performances of the global algorithm: the scheduling and HPN power allocation in conjunction with the user-centric and the network-centric UE Association (assessed in the previous subsection). This power control and UE associations will be run iteratively until convergence. The UEs distribution is displayed in Fig. 3, for the scenario with 10 UEs per HPN, where we see that the centralized and decentralized UE association schemes equilibrate uniformly the UE load among the various HPNs.

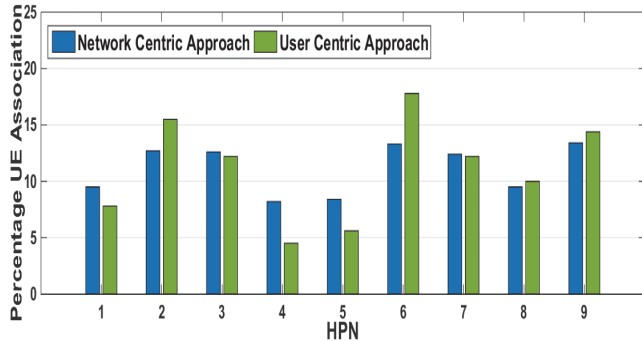


Figure 3. Percentage of UE Association

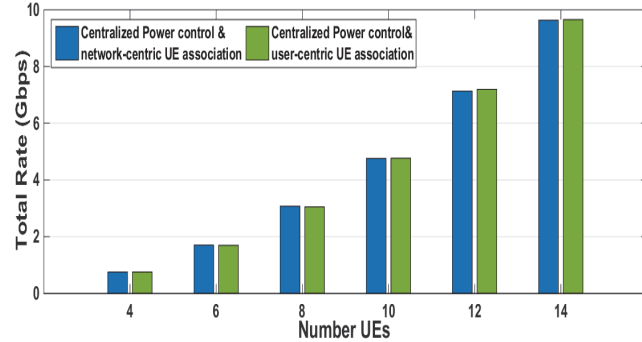


Figure 4. Global performances for the two proposed approach

In Fig. 4, we compare the global performances of the HPN power control and the UE association for the network-centric and user-centric approaches. We display the total mean rate as a function of the number of UEs, where we note a very low discrepancy among both approaches.

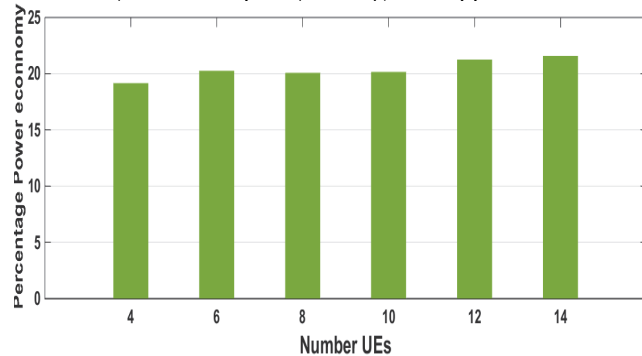


Figure 5. power economy of the network-centric approach vs the user-centric approach

However, due to their selfish behavior, the user-centric UE associations scheme consumes around 20% more power than the network-centric scheme, as we can see in Fig. 5,

where we illustrated the relative power economy of the network-centric approach in comparison with the user-centric approach. One more definite argument in favor of the user-centric approach is the very fast global convergence (around 4 iterations). Furthermore, note the signaling messages necessary for the user-centric UE Association algorithm are already present in actual wireless networks. Hence, the distributed scheme is a good compromise between complexity and efficiency.

## VI. CONCLUSION

The resource and power allocation problem is a challenging problem for present and future wireless networks. Several papers tackle this arduous task but rarely in a multi-cell network that accounts for the harmful impact of interference. In this work, we formulate the joint multi-cell scheduling, UE association and power allocation problem for 5G networks, where the objective is to maximize system throughput while guaranteeing fairness among UEs. The power control is addressed in a centralized fashion and the UE association is addressed in a centralized fashion by having recourse to convex optimization; and in a decentralized fashion by means of non-cooperative game theory. Extensive simulation results prove the significance of the user-centric schemes. In particular, it combine a low degree of system complexity and good performances in comparison with the network-centric schemes but with more power consumption.

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