FCRA: Femtocell Cluster-based Resource Allocation Scheme for OFDMA Networks

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***Abstract*—Recently, operators have resorted to femtocell networks in order to enhance indoor coverage and quality of service since macro-antennas fail to reach these objectives. Nevertheless, they are confronted to many challenges to make a success of femtocells deployment. In this paper, we address the issue of resources allocation in femtocell networks using OFDMA technology (e.g., WiMAX, LTE). Specifically, we propose a hybrid centralized/distributed resource allocation strategy namely *Femtocell Cluster-based Resource Allocation* (`FCRA`). Firstly, `FCRA` builds disjoint femtocell clusters. Then, within a cluster the optimal resource allocation for each femtocell is performed by its cluster-head. Finally, the contingent collisions among different clusters are fixed. To achieve this, we formulate the problem mathematically as Min-Max optimization problem. Performance analysis shows that `FCRA` converges to the optimal solution in small-sized networks and outperforms two prominent related schemes (`C-DFP` and `DRA`) in large-sized ones. The results concern the throughput satisfaction rate, the spectrum spatial reuse, and the convergence time metrics.**

***Index Terms*—Femtocells, OFDMA, resource allocation, clustering.**

I. INTRODUCTION

Since the introduction of third generation services, customers demand more and more data while exacting high quality of service (QoS). In fact, mobile phone data traffic is forecast to increase 10 to 30 times between 2010 and 2013 [1]. On the other hand, most of the traffic takes place inside buildings where the macro antennas' coverage is quite poor [2]. To fend off this weakness, operators make use of femtocells (a.k.a. home base stations) to enhance indoor coverage and network capacity [3].

Femtocells are small wireless access points deployed inside buildings and connected to an operator's network commonly through a digital subscriber line (DSL) connection or fiber. Femtocells Access Points (FAP) are administered by operators and make use of licensed spectrum technology (e.g. UMTS, LTE, WiMAX). Thanks to FAPs, indoor coverage and quality of service in terms of bandwidth are significantly improved. Nonetheless, due to the high density of FAPs, many new challenges have not been sufficiently addressed such as resources allocation and interference management. Finding the optimal resource allocation between FAPs in such highly dynamic and dense environment is, in general, a non-linear non-convex NP-hard optimization problem [4]. Hence, an optimal solution cannot be generated in large-sized networks and even in small-sized network with large set of constraints. Consequently, several heuristics have been proposed in the literature, which can be classified as either centralized or distributed.

In this paper, we propose a new scalable resource allocation algorithm called *Femtocell Cluster-based Resource Allocation* (`FCRA`) for OFDMA based femtocells. Our motivation stems from the fact that next generation networks (e.g. 3GPP Long Term Evolution) make use of OFDMA technology. Our objective is to associate the best spectrum set of frequency/time resources with each FAP in order to deliver the users data, while minimizing the gap between the required and allocated tiles and at the same time minimizing interference between FAPs. To achieve this, we formulate the resource allocation as a Min-Max optimization problem and propose a hybrid centralized/distributed scheme, namely `FCRA`, involving three main phases: *(i) Cluster formation*, *(ii) Cluster-head resource allocation* and *(iii) Resource contention resolution*. First, `FCRA` makes use of a distributed algorithm to build disjoint femtocell clusters. Then within each cluster, a Cluster-Head (CH) is elected, which assigns resources to all FAPs in its cluster taking into account their required bandwidth. Accordingly, each CH resolves the Min-Max optimization problem and converges to the optimal solution in a timely manner, as shown in this paper. However, users at the edge of two neighboring clusters might still interfere with each other when operating on the same resources. To handle such interference case, a simple algorithm is also proposed and allows to enhance the overall satisfaction rate of FAPs.

To evaluate the efficiency of our proposal, we compare the `FCRA` algorithm with two prominent ones from the literature: Centralized-Dynamic Frequency Planning (`C-DFP` [5]) and Distributed Random Access (`DRA` [6]). Evaluation and comparison metrics include the satisfaction rate of the required throughput, spectrum spatial reuse, and convergence time. The obtained results show that `FCRA` converges to the optimal solution in small-sized networks and outperforms both `C-DFP` and `DRA` in large-sized ones.

The rest of this paper is organized as follows. Next section discusses the related work. Section III presents the network model and formulate the OFDMA resource allocation problem mathematically. Section IV introduces the `FCRA` algorithm followed by a characterization of the metrics used for the evaluation of the system's performance in Section V. Simulation results are provided in Section VI. Finally, Section VII concludes this paper.

II. RELATED WORK

Resource management in OFDMA-based femtocell networks is an ongoing research area. In the following, we describe some of the main related schemes proposed in the literature.

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In [5], the authors proposed three resource allocation algorithms in OFDMA femtocells. The objective was to avoid interference between femtocells and macrocells in order to maximize the global network throughput. The first method is called orthogonal assignment algorithm. It divides the spectrum into two independent sets S_M and S_F used by the macrocells and femtocells, respectively. The problem is to find the best split that maximizes the satisfaction of the required QoS. However, this scheme does not take into account the femto-to-femto interference, which remains an important issue for indoor performance, especially when femtocells are densely deployed. The second method is called co-channel assignment algorithm $\texttt{FRS}_x$. Here macrocells can use the entire spectrum, but each femtocell uses only one random fragment. The interference between femtocells are indeed reduced by a factor of x. However, no details are given to find its optimal value. The last method is called Centralized-Dynamic Frequency Planning `C-DFP`. In this method, femtocells send their request to a centralized node in the backhaul to find the best resource allocation for each femtocell. This scheme can easily converge to the optimum. However, it is practicable only for small-sized femtocell networks.

The authors in [6] proposed a distributed resource allocation algorithm namely Distributed Random Access (`DRA`), which is more appropriate for medium-wide networks. The resources, represented as time-frequency slots (tiles) are orthogonalized between macrocells and femtocells based on the gradient ascent/descent heuristic. Once the resource set dedicated to femtocells is determined, each femtocell runs locally `DRA` to reserve a set of tiles, while avoiding interference with its neighbors using a randomized hashing function. To do so, each femtocell divides the resources into blocks. The block's size is equal to the femtocells interfering neighbors. Then, `DRA` reserves randomly one tile in each block by applying the randomized hashing function. It is shown that this algorithm is fully distributed with an acceptable worst-case performance guarantee. However, due to its pseudo-random nature, such an approach cannot guarantee any level of QoS. Moreover and as opposed to our work, the throughput satisfaction rate of femtocells has not been considered in the analysis.

In [4], the authors proposed a fully distributed and scalable algorithm for interference management in LTE-Advanced environments. The proposal called Autonomous Component Carrier Selection (`ACCS`) is executed locally in each femtocell. Each femtocell has always one active component carrier, called the Primary Component Carrier (PCC), and selected according to the computed path loss. If the offered QoS in terms of bandwidth is not sufficient, a femtocell tries to reserve more carrier components called Secondary Component Carrier (SCC) without deteriorating the QoS of neighboring femtocells. It has been shown that `ACCS` improves the experience of all users without compromising the overall cell capacity. However, the scheme is highly correlated with the environmental sensing since it mainly relies on measurement reports. In addition, `ACCS` does not allocate time-frequency slots but only subcarriers, which can be expensive and penalizing in terms of bandwidth.

In [7], the authors propose a decentralized `F-ALOHA` spectrum allocation strategy for two-tier cellular networks. The proposal is based on a partition of the spectrum between the macrocell and femtocells. Once computed, each femtocell accesses a random subset of the candidate frequency sub-channels. The probability to reserve a sub-channel depends on the set of its interfering femtocells. The main limitation of this scheme is that `F-ALOHA` cannot guarantee any level of QoS since it is based on a pseudo-random algorithm. In addition, this scheme does not consider time-frequency slots as resources. Instead, it focuses on sub-carriers allocation.

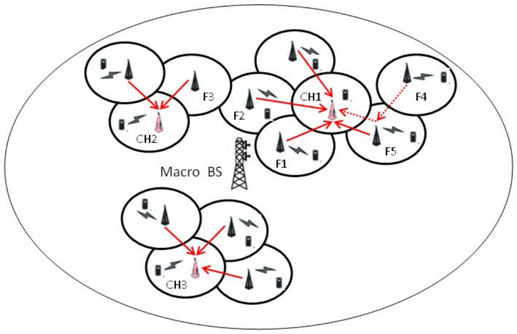


Fig. 1. Network Model

In this paper, we propose `FCRA` a new scalable resource allocation strategy based on clustering. There are indeed several clustering algorithms that have been proposed in the literature, especially in the context of ad-hoc networks and more recently in sensor and wireless mesh networks [8]–[13]. However, clustering in ad-hoc networks mostly focus on efficient handle of the frequent network topological changes due to ad-hoc nodes mobility. The main objective has therefore been to adapt quickly to topological changes, which occurs only occasionally in femtocell networks, due to their relatively static topologies. In our work, we use a distributed clustering algorithm to form disjoint femtocell clusters, as described in Section IV. Our objective is to subdivide the resource allocation problem into subproblems by means of clustering and the use of optimum centralized spectrum allocation inside each cluster to handle more efficiently the available resources.

III. SYSTEM DESCRIPTION

A. Network model

We consider a macrocell embedded with a set F of femtocells (FAPs) that represent residential or enterprise networks, as shown in Fig. 1. Both FAPs and the macrocell are assumed to operate using the same OFDMA technology. Similar to [6], we consider an OFDMA frame structure that is populated with time-frequency slots, so-called tiles.

In our study, we focus on the downlink communications. As in [5] [6], we assume that resources are split between the macrocell and femtocells, eliminating thus interference between femto/macro users. This kind of spectrum partition aims at maximizing the throughput and fairness within the macrocell and femtocells [5] [6]. Our objective is then to find the optimal allocation of resources dedicated for femtocells to deliver the users data, while minimizing the interference between femto/femto and at the same time ensuring the required QoS.

Problem 1 Min-Max femtocells resource allocation problem

$$\forall \mathcal{F}_a \in \mathcal{F}: \qquad \min \left[\max_a \left(\frac{\mathcal{R}_a - \sum_{i,j} \Delta_a(i,j)}{|\mathcal{F}| \times \mathcal{R}_a} \right) \right]$$

`subject to:`

$$(a) \quad \forall \mathcal{F}_a \in \mathcal{F}: \qquad \sum_{i,j} \Delta_a(i,j) \leq \mathcal{R}_a$$

$$(b) \quad \forall i,j, \quad \forall \mathcal{F}_a \in \mathcal{F}, \forall \mathcal{F}_b \in \mathcal{I}_a: \qquad \Delta_a(i,j) + \Delta_b(i,j) \leq 1$$

$$(c) \quad \forall i,j, \quad \forall \mathcal{F}_a \in \mathcal{F}: \qquad \Delta_a(i,j) \in \{0,1\}$$

For each femtocell $F_a \in F$, we define the set of interfering femtocells, denoted by I_a. This set depends on the minimum required Signal to Interference plus Noise Ratio (SINR) values and the indoor path loss model. As in [4], the latter is modeled based on A1-type generalized path loss models for the frequency range 2-6 GHz developed in WINNER [14].

In addition, we define for each femtocell F_a the binary resource allocation matrix denoted by Δ_a, with 1 or 0 in position (i,j) according to whether the tile (i,j) is used or not.

To represent the users' demands, we introduce a vector V_a whose elements correspond to the bandwidth required by users associated with the femtocell F_a. We denote by R_a the total number of tiles required by the femtocell F_a to fulfill the attached users' demands (i.e., $R_a = \sum_{i=1}^{n_a} V_a(i)$, where n_a is the total number of users belonging to femtocell F_a). Obviously, R_a is not constant and depends on the arrival/departure process of end users. Hence, we assume that R_a is updated periodically every epoch δ_t.

The number of end users that can be associated with each femtocell follows a random uniform distribution with a maximum value of 4 per femto. Moreover, we assume that femtocells adopt the Round Robin strategy to serve the associated users [4] [6].

B. Problem Formulation

As stated earlier, our objective is to find the optimal resource allocation of a set of tiles in each femtocell to deliver the users data, while minimizing the interference between femto/femto and at the same time ensuring the required QoS. To do so, we introduce a new metric, called throughput satisfaction rate per femtocell, which is defined as the ratio of the received number of allocated tiles to the total requested ones for each femtocell. Our aim is then to maximize this metric. In other words, our objective function will be to minimize the maximum gap between the number of allocated and required tiles in each FAP (i.e., the worst case is optimized). Given the set of interferer femtocells $I_a, \forall F_a \in F$ and for every epoch δ_t, our problem can be formulated as illustrated in Problem 1. Condition (a) denotes that the resource scheduler must guarantee that femtocells cannot obtain more than the required spectrum, and inequality (b) ensures that two interfering femtocells cannot use the same tiles.

Note that Problem 1 has been proved to be NP-hard [15]. To solve it, we propose to subdivide it into subproblems by means of clustering. A detailed description of our proposal is given in the next section.

IV. PROPOSAL: `FCRA` ALGORITHM

In this section, we present our hybrid `FCRA` algorithm for OFDMA femtocell networks. Our proposal is based on three main components: (i) Cluster formation, (ii) Cluster-head resource allocation and (iii) Resource contention resolution. First, `FCRA` builds disjoint clusters within the network. Then, a cluster-head allocates resources for all femtocells within its cluster by resolving the above problem (Problem 1). Each cluster may interfere with its neighbors and the cluster-head resolution does not consider the neighbor clusters allocation. Hence, a resource contention avoidance is also considered to resolve collision in subsequent frames. In the following, we detail these three stages.

A. Cluster formation stage

Each femtocell starts by creating its one-hop neighbor list containing the identity of its interfering femtocells (i.e., causing interference to its users). This can be reached by sensing the environment exploiting users' measurement reports. The list is then transmitted and shared with the corresponding one-hop neighbors. Therefore, every FAP can compute the number of interfering femtocells (i.e., interference degree) of each of its one-hop neighbors. Based on this information, a cluster-Head (CH) needs to be elected as the one deciding on the resource allocation, which is then notified to the other Cluster-Members (CMs). To do so, each FAP will determine whether it can act as CH or CM. Indeed, a femtocell is elected as CH if it has the highest interference degree among its one-hop neighbors. In this case, all associated one-hop neighbors will act as CMs and are attached to the elected CH. Otherwise, the femtocell is considered as CM and will be attached to the elected CH among its immediate neighbors (if it exists). If more than one unique CH is chosen by the neighborhood's femtocells, the one with the highest interference degree is considered as CH in order to minimize the tiles' collision between femtocells (if equal degrees, a random tie-break is used). However, if no CH is chosen by the neighborhood's femtocells (i.e., all neighbors act as CMs and are associated to other clusters), the FAP is attached to the cluster of the neighbor with the highest interference degree. More formally, the cluster formation stage is described by the pseudocode in Algorithm 1.

B. Cluster-head resource allocation stage

Once the femtocell network partitioned in clusters, the second step is to jointly allocate resources to all femtocells within each cluster. The objective is to satisfy as much as possible the femtocells' requirement in terms of tiles while avoiding interference within the cluster. To achieve this, each CH resolves individually the above resource allocation problem (Problem 1) every epoch δ_t. It is worth noting that, since the obtained clusters' size is not large, the CH resolution using a solver such as ILOG CPLEX [16], would still converge within a short time period T_{conv}. This allows femtocells to serve their attached users in a timely manner (as will be shown in Section VI).

However, we note that users at the edge of two neighboring clusters might still interfere when they operate on the same

Algorithm 1 Cluster Formation Algorithm - Femtocell $\mathcal{F}_a$

```
$\mathcal{F}_a$ creates the 1-hop neighbouring interfering femtocells list
$\mathcal{F}_a$ sends the associated interfering list to its 1-hop neighbours
if $\mathcal{F}_a$ has the highest degree of interfering neighbours then
    $\mathcal{F}_a$ elects itself as a cluster-head
else
    if $\mathcal{F}_a$ is interfering with cluster-heads then
        $\mathcal{F}_a$ attaches itself to the cluster administered by its highest interfered neighbour cluster-head
    else
        $\mathcal{F}_a$ selects the highest interfering neighbour femtocell $\mathcal{F}_b$
        $\mathcal{F}_a$ attaches itself to the $\mathcal{F}_b$'s cluster
    end if
end if
```

resources. This could indeed happen since each CH resolves the above mentioned problem independently from its neighboring clusters. Consequently, two interfering femtocells attached to different clusters could use the same allocated tile. To resolve such collision, a simple coordination mechanism can be realized and detailed in the next subsection.

C. Resource contention resolution stage

As stated earlier, two femtocells associated with different CHs, but interfering with each other, may have been assigned the same tiles from their respective CHs. Thus, interference occurs between their associated end users. In this case, each user suffering from contention will send a feedback report to its associated femtocell to notify about the collision on the selected tile. Then, each femtocell tries to resolve contention on the collided tiles by sampling a Bernoulli distribution. Accordingly, it decides whether the attached user would keep using the tile or would remove it from the allocated resources.

It is worth noting that if collision occurs, FCRA converges to a stationary allocation within a small number of frames, as will be shown in Section VI. This makes our solution practically feasible.

V. PERFORMANCE METRICS

Building on the output of the above optimization problem resolution for each constructed cluster, the performance of our proposal can now be evaluated. Three QoS metrics are considered: Throughput Satisfaction Rate (TSR), Spectrum Spatial Reuse (SSR) and convergence time.

A. Throughput Satisfaction Rate (TSR)

TSR denotes the average degree of satisfaction of a femtocell with respect to the requested resources. For each femtocell $\mathcal{F}_a$, $TSR(\mathcal{F}_a)$ is defined as the ratio of the received number of allocated tiles to the total requested ones and can be expressed as follows:

$$\forall \mathcal{F}_a \in \mathcal{F} : \qquad TSR(\mathcal{F}_a) = \Big(\sum_{i,j} \Delta_a\,(i,j) \Big) / \mathcal{R}_a$$

The TSR metric can be thus given by:

$$TSR = \sum_{\mathcal{F}_a \in \mathcal{F}} TSR(\mathcal{F}_a)/|\mathcal{F}|$$

B. Spectrum Spatial Reuse (SSR)

SSR denotes the average portion of femtocells using the same elementary resource block (tile) within the network. Therefore, it is defined as the mean value of tiles' spatial reuse . The SSR metric can be thus expressed as follows:

$$SSR = \frac{1}{M \times |F|} \sum_{i,j} \sum_{\mathcal{F}_a \in \mathcal{F}} \Delta_a\,(i,j)$$

where M is equal to the length of OFDMA frame (downlink) in terms of tiles (time-frequency slots).

C. Convergence Time

This is the time needed by our scheme to converge to a stationary allocation (i.e., no resource contention). This metric depends on the network topology and size as well as the SINR threshold fixed in the transceiver.

VI. PERFORMANCE EVALUATION

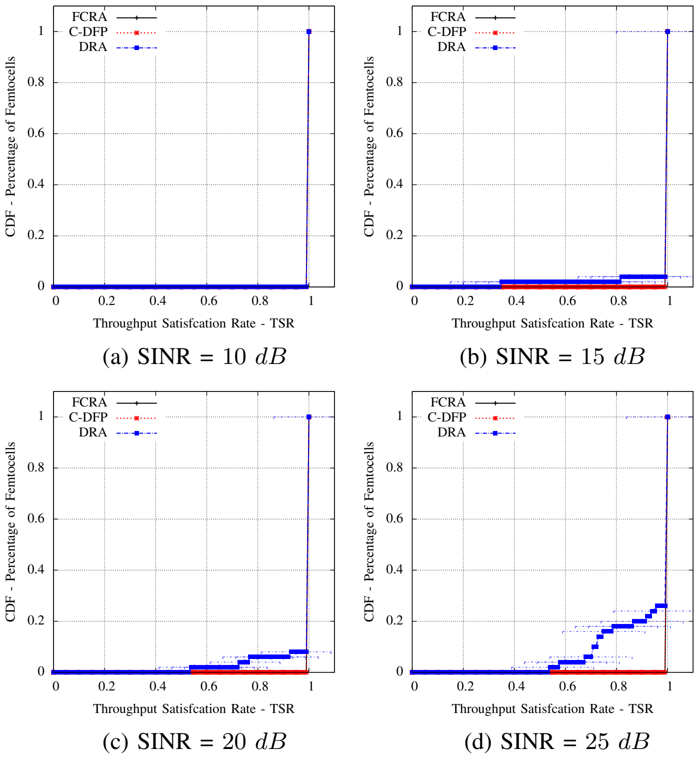
In this section, we evaluate the efficiency of our proposal. Both centralized optimal (`C-DFP` [5]) and distributed resource allocation (`DRA` [6]) schemes are used as benchmarks to which the `FCRA` potential benefits are compared. We study the gain of `FCRA` when the users are static using several arbitrary FAPs topologies and under various interference level scenarios. The reported results are obtained using the solver "ILOG CPLEX" [16]. We run 31 simulations and we calculate the mean value and its confidence level fixed to 99.70%. Note that in each simulation, we vary the number of mobile nodes attached to each femtocell and their traffic demands.

The analysis is achieved using a typical OFDMA frame (downlink LTE frame) consisting of $M = 100$ tiles (time-frequency slots), as in [6]. Users are distributed uniformly within the femtocells with a maximum value of 4 per FAP. Each user uniformly generates its traffic demand (required bandwidth), which is translated into a certain number of tiles V_a ($0 \leq V_a \leq 25$). We considered different network sizes: 50 and 200 FAPs, which are representative of small and large femtocell networks, respectively. The N femtocells are distributed randomly in a 2-D $400m \times 400m$ area, with one FAP randomly placed in each $10m \times 10m$ residence. Then, based on the SINR values and the path loss model [14], the interference matrix I_a for every femtocell $\mathcal{F}_a$ is derived. In our simulations, we considered different SINR thresholds: 10, 15, 20 and 25 dB to show the impact of the interference degree on the evaluated metrics. Recall that in our `FCRA` algorithm, we used a Bernoulli distribution to resolve the resource contention problem. Hence in our experiments, we set the mean of Bernoulli to 0.5. Consequently, femtocells have the same chance to use or discard the collided tile.

In what follows, we present the simulation results. Before discussing the results, let us start by comparing the computation time of both `FCRA` and `C-DFP` methods. We set the SINR value to 10 dB. As shown in Table I, we can see that, while `FCRA` always converges in few milliseconds, `C-DFP`'s computation time

TABLE I
COMPUTATION TIME (IN MSEC) OF FCRA AND C-DFP METHODS

Network size	50	100	200
FCRA	8	10.2	11.2
C-DFP	40	1804	6000



(a) SINR = 10 dB
(b) SINR = 15 dB
(c) SINR = 20 dB
(d) SINR = 25 dB

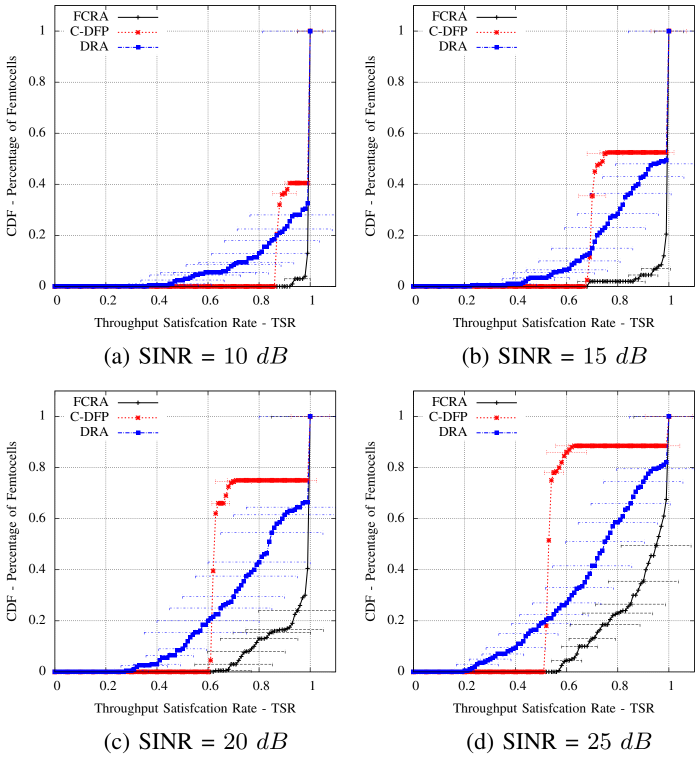
Fig. 2. CDF of throughput satisfaction rate in small-sized femtocell networks

grows exponentially with the network size, which illustrates the efficiency of our method. In fact, with FCRA, the constructed clusters are not large in size. Hence, a centralized resolution within each cluster will be indeed feasible. Note here that for FCRA, the reported computation time in Table I corresponds to the mean value of the computation time of all constructed clusters.

Let us now focus on the comparison among the different strategies based on the throughput satisfaction rate, the spectrum spatial reuse and the convergence time.

Fig. 2 shows the cumulative distributed function (CDF) of the throughput satisfaction rate of different strategies (i.e., FCRA, DRA, and C-DFP) for the 50-node network case using different values of SINR. We can see that FCRA converges to the optimal centralized solution (C-DFP) since both of them satisfy all the users traffic demands regardless of the interference level (SINR). The reason is that in small-sized networks, where interference is not high, the clusters constructed by our FCRA approach often contain a small number of nodes (one or two FAPs). Hence, each FAP can use the whole spectrum satisfying the users demand. However in DRA, due to the use of a random hash function, some users are not fully satisfied especially when the SINR threshold is high. Indeed, 20% of femtocells have their $TSR \leq 0.9 \pm 0.16$, as depicted in Fig. 2(d).

This observation is shown clearly in Fig. 3, where we plot the CDF of the same metric (i.e., throughput satisfaction rate) for the 200-node network case. Two main observations can be made here. First, our FCRA scheme outperforms the other schemes for all interference levels. The median satisfaction rate (i.e., for 50% of the femtocells) when $SINR = 20\ dB$ for example is 1 ± 0.15 for FCRA, 0.84 ± 0.2 for DRA, and 0.63 ± 0.03 for C-DFP (see Fig. 3(c)). This means that FCRA, DRA and C-DFP often satisfy the users demand at 100%, 84% and 63%, respectively. Moreover, increasing the interference level decreases the satisfaction rate of all underlying schemes. Indeed, as shown in Fig. 3(a), the median TSR for all schemes is equal to 1 when the interference is low. However, for high values of SINR, this metric evaluates to 0.96 ± 0.13 for FCRA, 0.75 ± 0.15 for DRA and 0.53 ± 0.02 for C-DFP (see Fig. 3(d)). It is worth noting that C-DFP is not scalable and cannot converge to the optimal allocation in large-sized network, as shown in Table I. Indeed in our simulations, the solver is stopped after 6 seconds.



(a) SINR = 10 dB
(b) SINR = 15 dB
(c) SINR = 20 dB
(d) SINR = 25 dB

Fig. 3. CDF of throughput satisfaction rate in large-sized femtocell networks

Fig. 4 plots the spectrum spatial reuse (SSR) of the underlying schemes as function of SINR for both small and large-sized networks. Two main observations can be made. First, FCRA and C-DFP offers the highest SSR values in small-sized network. Indeed, C-DFP has a global view of the network and converges to the optimal solution. However, this happens at the cost of a high computation time, as shown in Table I. We notice that our proposal FCRA has the same performance as the optimal solution in small-sized network. On the other hand, in large-sized networks, the performance of FCRA are the best compared with C-DFP and DRA. However, the performance of DRA degrades, notably at high interference level. Moreover, C-DFP has the worst performance since it cannot converge to the optimal solution. This indicates that our approach is an efficient,

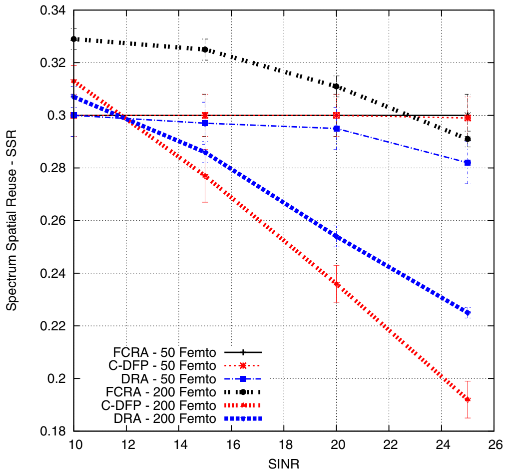


Fig. 4. Spectrum Spatial Reuse vs. SINR

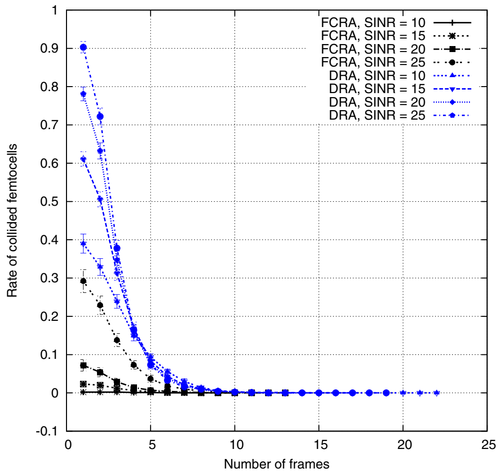


Fig. 5. Convergence time of `FCRA` and `DRA` methods in large-sized femtocell networks

scalable and feasible solution for practical FAPs deployment. Second, we can notice that the SSR metric decreases with the increase of SINR for all the strategies since the interference degree of each femtocell increases. In this case, according to our approach, a fewer number but more populated clusters are formed. This results in decreasing the possibility of reutilization of the same tile among the constructed clusters. Recall that our scheme does not allow the utilization of the same tile within the same cluster.

It is worth noting that the results shown in Figs. 2, 3 and 4 are obtained at the stationary allocation phase (i.e., after convergence). The convergence of both `FCRA` and `DRA` is illustrated in Fig. 5 for the large-sized network case (i.e., $N = 200$) and using different values of SINR. The X-axis represents the number of necessary control frames sent by the end users to their associated FAPs when collisions occur. The Y-axis represents the portion of femtocells that experienced a collision on one of their allocated tiles. Note that in each simulation, we vary the femtocell network topology, the number of mobile nodes attached to each femtocell and their traffic demands (in terms of requested tiles). From that figure, we can notice that `FCRA` converges to a stationary allocation within 6 and 10 frames when the SINR threshold is equal to 10 and 15 dB, respectively. On the other hand, `DRA` needs 13 and 15 frames to converge. For high interference levels (i.e., SINR $\geq 20\ dB$), both `FCRA` and `DRA` schemes need the same number of frames to converge ($11-12$ frames). However, we notice that `FCRA`'s rate of collided femtocells in each frame is less than the one obtained with `DRA`.

VII. CONCLUSION

In this paper, we studied the resource allocation problem in OFDMA-based femtocell networks and proposed a new allocation scheme called Femtocell Cluster-based Resource Allocation (`FCRA`). `FCRA` is based on a hybrid centralized/distributed approach and involves three main phases: (i) Construction of disjoint clusters; (ii) Optimal cluster-head resource allocation by resolving a Min-Max optimization problem; and (iii) Resource contention resolution. The obtained simulation results show that `FCRA` converges to the optimal centralized solution (i.e., `C-DFP`) in small-sized networks and outperforms the distributed solution `DRA` as well as `C-DFP` in large-sized ones. The results concern the throughput satisfaction rate, the spectrum spatial reuse and convergence time.

In the future, we plan to incorporate user mobility to study its impact on the proposed scheme. Specifically, we will study the dynamics of users' connections considering the variation in time of their positions, demands as well as the network load.

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