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Resource management in 5G femtocell networks

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***Abstract*—Small cells are expected to contribute to the targets of next generation mobile networks. Ultra dense networks through the form of heterogeneous structures of multiple RAT technologies and small cells present a flexible, economical way for better coverage and data rates. In this paper, we investigate particularly how femtocells may best utilize their available resources in order to increase their provided capacity when neighbouring femtocells are present. We propose a spectrum policy, according to which femtocell deployments are forming clusters and the femtocells adopt hybrid access policy versus users subscribed to other femtocells members of the same cluster. We also determine the spectrum allocation for non-subscribed users in the range of the femtocell. We evaluate the performance of the set up through simulations showing that the mechanism offers better overall capacity.**

***Keywords*—femtocells, hybrid access, clusters, resource allocation**

I. INTRODUCTION

Femtocells and small cells in general are a cornerstone of next generation networks. From its concept, future networks are designed with the consideration that the extreme demand in data rates can only be met by utilizing multiple base stations of small radius, scattered along the umbrella of macrocell infrastructure [1]. The usage of millimetre wave spectrum with the significant penetration losses that characterizes it, makes the limited radius of small cells even more useful. Added with their flexibility, capability for mobility, their user-friendly deployment and their cost effective features, small cells in the form of micro-, pico- and femtocells are an integral part of what will comprise the next generation networks.

However, their strengths can easily turn into vulnerabilities if no careful preparation is made. Their ad-hoc nature, especially in the case of femtocells, makes the centralized control of the network difficult, if not impossible. In addition, their deployment will result to a heterogeneous network, which will include several base stations, often by multi-vendors, probably implementing several different Radio Access Technologies (RAT), that will require to optimally share the available resources, to work without disturbing one another, and fulfilling the increased demands of the expected data rates of the future. Issues such as interference, distributed coordination among Base Stations (BS) and resources allocation rise as significant concerns that should be addressed.

Hybrid access, where femtocells' resources are allocated to every user in the range of the femtocell but under certain rules, has been a candidate approach towards mitigating interference. The work on the subject is significant. In [2], a power control algorithm is proposed that can provide QoS support in minimum signal-to-interference-plus-noise ratios (SINRs) for all users while exploiting differentiated channel conditions. The algorithm uses non-cooperative game theory and applies it to a hybrid access scheme through a distributed load-award association for macro users, which enables flexible user association to BSs of either tier.

Multichannel hybrid access femtocells are the focus of the work in [3]. Specifically, it considers a randomized channel assignment strategy, and using stochastic geometry, it models the distribution of femtocells as Poisson point or Neyman-Scott cluster process to derive the distributions of SINR, and mean achievable rates. In [4], the authors search for the optimal allocation of channels for the macro users, based on an activity profile created to compute the maximum achievable throughput and the consumed energy per successfully transmitted data bit by the macro users.

A traffic-aware Orthogonal Frequency-Division Multiple Access (OFDMA) hybrid small-cell deployment for Quality of Service (QoS) provisioning and an optimal admission control strategy are proposed in [5]. The authors in [6] propose a pricing mechanism that decides for the hybrid access of femtocells non-subscribers. In order to provide greater motivation for femtocells to share resources, the mechanism considers environments where multiple femtocells by different providers may serve the user, and they must compete for the profit gained by the service. In addition, an online learning algorithm adjusts the femtocell's transmission parameters by predicting the demand of the macrocell tier users. Similarly regarding the effort to offer hybrid access femtocell owners motivation to share their resources, [7] is based on profit sharing among the macrocell and femtocell owners, trying to optimize macrocell's benefit by deciding the ratio of revenue distribution femtocell owners.

In this paper, we propose an algorithm that determines the resource allocation in femtocell clusters, that is multiple deployments of femtocells in proximity. We apply hybrid access policy and we perceive three classes of users that can be admitted by a femtocell. The users that are in the subscriber list of the femtocell, the users non-subscribed to it but are registered to another femtocell that belongs to the same cluster and finally all the other users. We then set the rules according to which the resources of the femtocells are allocated to the three types of users.

The division of the spectrum is based on three principles. First, to increase the capacity of the cluster. Second, to compensate for the interference to non-subscribers caused by femtocells. Third, for the subscribed user to maintain benefit by owning the femtocell. We evaluate the mechanism through simulations and showcase that our scheme performs well in several scenarios.

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The rest of the paper is structured as follows: In Section two, we present the design that we base our assumptions. In Section three, we describe the aspects of our proposed mechanism. In Section four, we present the results of the simulation and evaluate the algorithm. Finally, in the last section, we draw our conclusions and suggest future steps.

II. SYSTEM MODEL

We consider working under the assumption of the Orthogonal Frequency Division Multiplexing (OFDM) system model. The access scheme is based for simplicity on downlink OFDMA, with 12 subcarriers per physical resource block.

Femtocells' power transmission is set to ensure a constant coverage femtocell radius. Thus, each femtocell sets its power to a value that on average is equal to the power received from the closest macrocell at a target femtocell radius r, subject to a maximum power of $Pmax$. The femtocell transmit power can be calculated in decibels through [8]:

$$P_f = min(P_m + G - PL_m(d) + PL_f(r), Pmax) \tag{1}$$

where $PL_f(r)$ is the line of sight path loss at the target cell radius r and P_m is the transmit power of the macrocell in which the femtocell is located and G is the antenna gain. $PL_m(d)$ denotes the average macrocell path loss at the femtocell distance d (excluding any additional wall losses).

SINR is calculated through the power received by the user from the serving station, versus the interfering power received by the proximal macro BSs and femto BSs. As mentioned in [9] the SINR of a macrocell user is provided by the following equation:

$$SINR_{m,k} = \frac{H_{M,k}}{\sigma^2 + \sum\limits_{M'} H_{M',k} + \sum\limits_{F} H_{F,k}} \tag{2}$$

where $H_{M,k} = P_{M,k} * G_{m,M,k}$ that is the transmit power of serving macrocell base station M on subcarrier k, multiplied by the channel gain between user m and macrocell M on sub-carrier k. $\sigma^2 = N_0 \mathit{\Delta} f$ is the white noise power spectral density multiplied by the sub-carrier spacing. $H_{M',k} = P_{M',k} G_{m,M',k}$ the transmit power of neighbouring macrocell base station M' on subcarrier k, multiplied by the channel gain between user m and macrocell M' on sub-carrier k. $H_{F,k} = P_{F,k} G_{m,F,k}$ the transmit power of femtocell base station F on subcarrier k, multiplied by the channel gain between user m and femtocell F on sub-carrier k.

The expression of a femtocell user is similarly derived, this time considering as interference the received power from the macro BSs and any adjacent femtocell. Specifically, for a user f on subcarrier k interfered by all macrocells and adjacent femtocells, the received SINR is given by:

$$SINR_{f,k} = \frac{H_{F,k}}{\sigma^2 + \sum\limits_{M} H_{M,k} + \sum\limits_{F'} H_{F',k}} \tag{3}$$

Path loss heavily depends on the environment of the network. Regarding this paper, an urban environment is considered, thus for a macrocell user in distance R from the transmitter, it is given by [10]:

$$PL(db) = 15.3 + 37.6 log_{10} R + L_{ow} \tag{4}$$

where the term L_{ow} is added for the case of indoor users to denote the penetration loss of the external wall.

Similarly, the suggested model according to [10] for the case of an indoor femtocell user is estimated, taking into account the penetration loss due to exterior walls:

$$PL(db) = 38.46 + 20 log_{10} R + L_{ow} \tag{5}$$

The practical capacity of macro-user m on sub-carrier k is given by [9]:

$$C_{m,k} = \mathit{\Delta} f \cdot log_2(1 + \alpha SINR_{m,k}) \tag{6}$$

where α is defined by $\alpha = -1.5/ln(5BER)$. The overall throughput of serving macrocell M can then be expressed as [11]:

$$T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \tag{7}$$

where, $\beta_{m,k}$ notifies the sub-carrier assignment for macrocell users. When $\beta_{m,k} = 1$, the subcarrier k is assigned to user m. Otherwise, $\beta_{m,k} = 0$. Similar expression can be derived for femtocell users, related to the practical capacity and the overall throughput [11].

III. PROPOSED SCHEME

In this section we describe the mechanism that dictates the spectrum allocation of the femtocells.

A. Femtocell clusters

Expected ultra dense networks will be comprised by multiple deployed BSs, such as femtocells, leading to the formation of areas with many femtocells close to each other. We define the femtocell cluster to be a collection of close by deployed femtocells. For a femto BS to be considered member of the cluster must be in maximum distance of 30 m from atleast two other members of the cluster.

In the area defined by the range of the cluster femtocells, there are users that can be either subscribers (belong to a femtocell's Close Subscriber Group - CSG) or unsubscribers (served by the macro BS) . The latter are potential users if are admitted by any of the femto base stations. Each time interval, the choice of what user will be admitted can change based on the decision policy we describe below.

B. User classes

As stated above, the femtocell may decide to serve any user that is within its range. The resources available to them is decided based on what type of user is. Thus, first, we categorize the users, by defining three classes. The first class is the users subscribed to the femtocell. Usually, these are the owners of the femtocell, thus rightfully expecting a resource allocation in their favor.

Then we introduce the second class, with the users belonging to it, are the users who are not registered to the particular femtocell's CSG, but are subscribers of a femtocell that is also a member of the cluster the first femtocell belongs to. These users although not equal to the first class's users, are also considered important having intermediate significance between the first class and the third that it is described below.

The third class is every user that does not fall to the aforementioned two. Either subscribers of a femtocell at a great distance from the femto BS, or most probably non-subscribers that are served by the macro BS. These users are considered the less significant since there is no immediate association with any of the close by femtocells.

They also are the most unfortunate ones, since being inside the area of the cluster, they are victims of the accumulative interference from all members of the femtocell cluster. Since most femtocells are located indoors, the addition of the weak macro BS signal due to wall attenuation degrades even more their connection, making their protection by a hybrid access scheme necessary.

C. Spectrum allocation

The allocation of the spectrum is determined based on the users present and eager to connect to the femtocell and their corresponding classes. First Class C users are allocated resources in order to be compensated for the impact on its performance. The mechanism takes into account the throughput achieved by the user before the deployment of the nearby femtocell and it will try to reproduce it, by its own right. It is noted that this approach tries to ensure that the allocated spectrum will compensate for the impact to the user by this femtocell, and this femtocell only, and not by any other sources of interference, such as other femtocells in the area.

Thus, if THR_{BEF} denotes the throughput of the non-subscriber before the deployment of femtocell, and THR_{AFT} is the target throughput of the user under the service of the femtocell, then we want $THR_{BEF} = THR_{AFT}$ which, based on the model described in Section 2, yields to:

$$\frac{SP_{C,F}}{SP_{C,M}} = \frac{(log(1 + SINR_{C,M}))}{(log(1 + SINR_{C,F}))} \tag{8}$$

$SP_{C,F}$ represents the required spectrum that must be allocated by the femto BS to the user, in order to reach earlier level of performance and $SP_{C,M}$ being the spectrum the user used to utilize when he was connected to the macrocell. $SINR_{C,M}$ and $SINR_{C,F}$ are the SINR experienced by the user, when he is connected to the macrocell and femtocell, respectively. We stress again the fact that $SINR_{C,M}$ is calculated disregarding the interference of the femtocell that the user will eventually connect to (since it represents the state before the femtocell deployment in the area). However, it takes into account the presence of neighbouring femtocells that might contribute to the interference.

Next the allocation among Class A and Class B users is determined under the following rules:

i. The maximum portion of the spectrum allocated to the Class B user must not exceed the portion allocated to Class A user. Since we examine full buffer scenarios, the above ensures that the subscriber is not surpassed by the class B user.

ii. The portion allocated to Class B user is also limited by the fact that Class A user experiences significant gain from the femtocell's ownership relative to the throughput experience without it. Thus:

$$DR_{A,A} > DR_{A,M} \tag{9}$$

where $DR_{A,A}$ and $DR_{A,M}$ denote the data rate of Class A user when served by its femtocell and the macrocell respectively.

iii. Class B user is admitted only if his performance is improved compared to the case where served by its origin femtocell and the overall resulting capacity provided by the involved femtocells (Class B and Class A origin femtocells) is greater than the capacity without its admission. This ensures that the cluster overall capacity to its subscribers is increased. Therefore:

$$DR_{B,A} > DR_{B,B} \tag{10}$$

where $DR_{B,A}$ and $DR_{B,B}$ the data rate the Class B user experiences when he is served by its neighboring and origin femtocell, respectively.

So we effectively set conditions to define minimum and maximum limits of Class B user spectrum allocation and also set a general requirement to be true. So, based on the model of section 2, we can write:

$$min : \frac{SP_{B,B} * log(1 + SINR_{B,B})}{log(1 + SINR_{B,A})} \tag{11}$$

$$max : min(\frac{SP_{TOT}}{\#users}, SP_{TOT} - \frac{SP_{A,M} * log(1 + SINR_{A,M})}{log(1 + SINR_{A,F})}) \tag{12}$$

with $SP_{B,B}$ denoting the spectrum the Class B user utilized when served by its origin femtocell, $SINR_{B,A}$ and $SINR_{B,B}$ the Class B user's SINR when connected to its neighboring and origin femtocell, respectively, $SINR_{A,M}$ and $SINR_{A,F}$ the Class A user' SINR when connected to its femtocell and the macrocell, respectively and SP_{TOT} the available femtocell spectrum. The mechanism is finally approved when the following condition must be met:

$$CAP_{BEF} < CAP_{AFT} \tag{13}$$

where CAP_{BEF} and CAP_{AFT} denote the overall capacity that involved femtocells provide to their users before and after

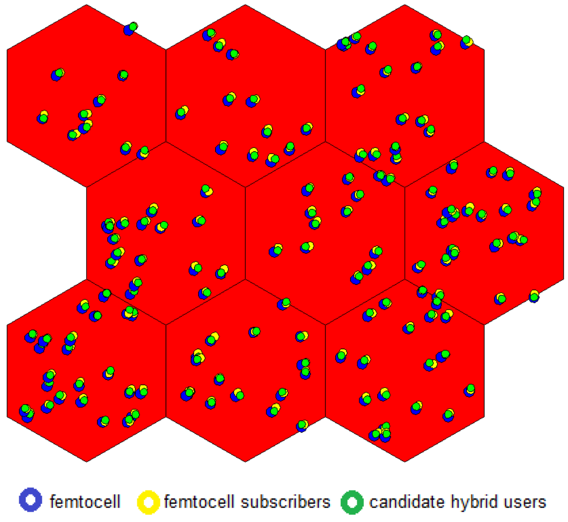

Fig. 1. An example of the topology used during the simulations

the mechanism application. We summarize the steps of the mechanism in Algorithm 1.

Algorithm 1 Resource allocation

```
Categorize users
-Class A: Subscribers
-Class B: Same cluster's femtocells' subscribers
-Class C: Others
if Class C then
    {calculate required spectrum for Class C}
    $SP_{C,F} = \frac{SP_{C,M}*(log(1+SINR_{C,M}))}{(log(1+SINR_{C,F}))}$
end if
if Class A OR Class B then
    allocate all available spectrum
end if
if Class A AND Class B then
    calculate min, max spectrum for Class B user as long as below rules apply
    $min : \frac{SP_{B,B}*log(1+SINR_{B,B})}{log(1+SINR_{B,A})}$
    $max : min(\frac{SP_{TOT}}{\#users}, SP_{TOT} - \frac{SP_{A,M}*log(1+SINR_{A,M})}{log(1+SINR_{A,F})})$
    $CAP_{BEF} < CAP_{AFT}$
end if
```

IV. PERFORMANCE EVALUATION

This section presents the configuration of the simulator and the results obtained through simulations.

A. Simulation parameters

Simulation network was comprised by 9 macrocells of intercell distance of 500 m (Fig. 1). Multiple femtocells were deployed randomly, with up to three users each. Power transmission was set at 46dBm for the macrocell and 20dBm for the maximum power of the femtocell. We considered urban environment following 3GPP 's respective calculation for path loss and wall attenuation. For each experiment, 30 repeated simulations were conducted and the average outcome was used for the results. Table I contains all parameters' values taken into account during simulation. The selection of the values is 3GPP compliant and according to [12].

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Inter-site distance	500 m
Bandwidth	20 MHz
Modulation Mode	64QAM
Subcarriers' bandwidth	15 KHz
Carrier frequency	2 GHz
Macrocell BS transmit power	46 dBm
Femtocell BS max transmit power	20 dBm
White noise power density	-174 dBm/Hz
Wall penetration loss	20 dB

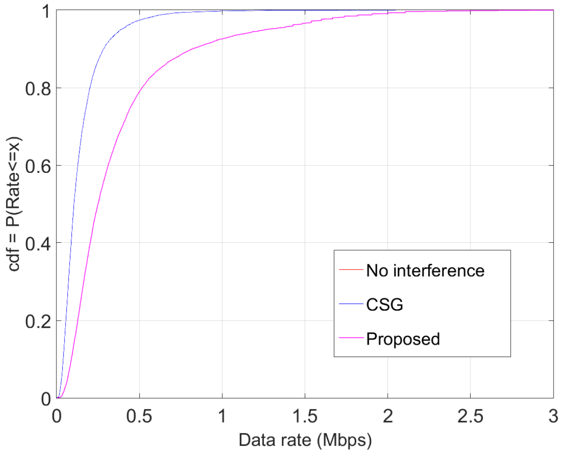

Fig. 2. CDF of Class C users' data rate before the deployment of the nearby femtocell, after the deployment in CSG mode and after users' admission by the femtocell.

B. Experimental results

Fig. 2 shows the results of the application of the algorithm on Class C users. The graph shows the performance of these users before and after the interference of the nearby femtocell, as well as when accepted to be served by the femtocell. It is evident from the figure that for those users that were finally accepted, the reproduction of their performance is successful, since the first and the third case lines coincide.

This was possible, because under the conditions of the mechanism and with femtocells' ability for increased data rates locally, requirements in resources by these users are low. More specifically, fig. 3 shows the cumulative distribution function (CDF) of the spectrum percentage required by the femtocell to devote to Class C users. As it can be seen from the graph, 90 % of the cases require less than 5 % of femtocells available spectrum, while almost all cases are less than 20 %. This can be explained from the fact that femtocell scenarios we examine

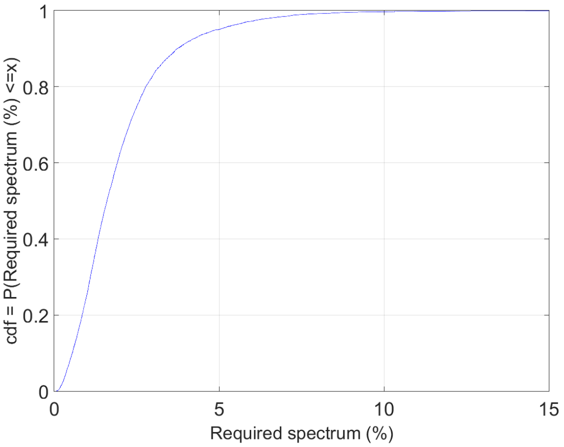

Fig. 3. CDF of the percentage of the spectrum calculated to be allocated to Class C users by the femtocells in hybrid access mode.

are indoors, thus wall attenuation makes the target throughput for the macro user relative low.

This small effect on the utilization of resources can be also depicted through the corresponding reduction of the Class A users' performance of these hybrid femtocells. After the admission of the Class C users, resources for the former decreased but since this reduction was low, it also leads to a small reduction on subscribers' performance as is seen in fig. 4.

Fig. 5 depicts the CDF of the users of classes A and B connected to the femtocells affected by the mechanism. Initially, users are connected based on the femtocells' CSG lists. Then the proposed mechanism applies and the users are redistributed to the femtocells based on the spectrum policy described in the previous section. It can be seen that a significant improvement has been witnessed in the overall capacity. The figure depicts only the difference witnessed to femtocells affected for clarity, which means the femtocells their users took part of the exchange. Keeping in mind, that the comparison shown is between the initial CSG mode and the case where femtocells users were redistributed including losses due to Class C users admission, the improvement is quite significant.

The denser the deployment of the femtocells, the higher the probability of users falling under the conditions of the mechanism for admission, hence the greater the improvement of the overall capacity.

Fig. 6 shows an indicative example of the mechanism application on an individual cluster. The figure shows the data rate of the users connected on two members of the cluster before and after the mechanism. Specifically the first column of each set (user 1) is the user served by the femtocell that admits user 2. As a result, due to sharing the available spectrum, user's 1 data rate significantly decreases. However, at his expense the data rate of the exchanged user as well as of his two former co-subscribers (user 3 and 4) are increased. The overall capacity was increased according to the requirements of the mechanism.

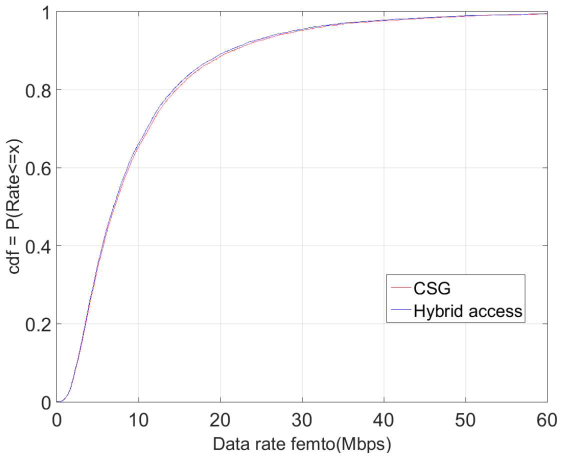

Fig. 4. CDF of Class A users' data rate before and after the admission of Class C users (not Class B).

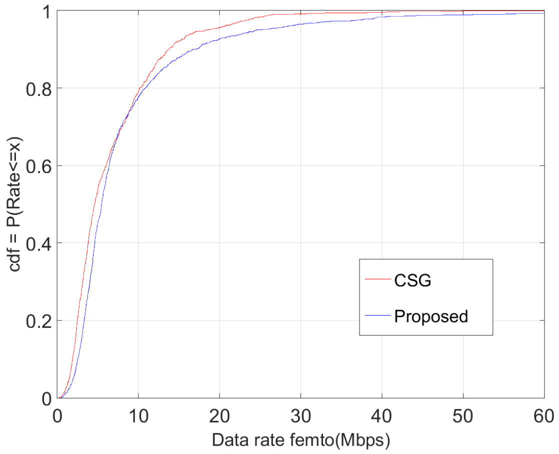

Fig. 5. CDF of all Class A and Class B users served by a femtocell affected by the application of the mechanism.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we propose a scheme for the femtocells to decide the portion of spectrum that may be allocated to non-subscribed users. In reality, we propose an implementation of hybrid access, where the rules determining its application were based on the categorization of the candidate users for admission. The set of rules were designed to apply on femtocells that are members of femtocell clusters.

First, we gave the definition of the cluster member. Then, the users likely to be admitted by a such a member were categorized in three classes of different rights and priority and a set of rules were introduced that determined spectrum allocation taking into account this categorization. Specifically, the goal was to prioritize the owners, then respect subscribers of neigboring femtocells and finally compensate if possible for femtocell's impact on passing by users.

In detail, the mechanism pursuits the compensation of macro users targeting if feasible their performance before the femtocell deployment. The rest of the spectrum is divided

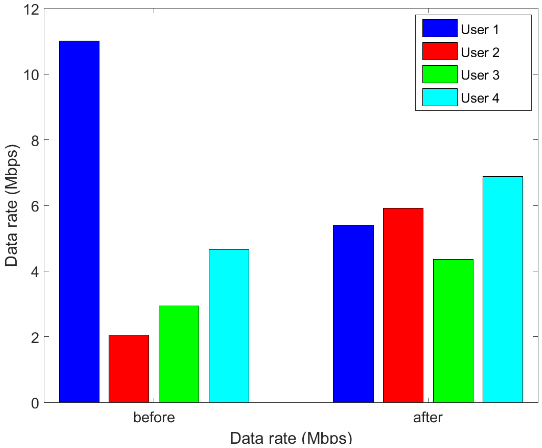

Fig. 6. Data rate of users connected to two femtocells affected by the application of the mechanism.

to owners and subscribers of neighboring users by allowing access under restrictions in order to increase the data rate of the users of the corresponding femtocells. Owners are protected by setting a minimum threshold of resources reserved for them, that is determined by the principle of maintaining a significant benefit of femtocell's ownership.

The approach can be very beneficial for scenarios where most or all femtocell cluster members belong to the same entity, thus allowing full or increase service for their primary users (i.e. employees in a company), while offering a limited service to non-associated users (i.e. customers or passing by users). The simulations showed that the mechanism performs well, increasing the total capacity offered by the femtocell cluster members collectively. At the same time it preserves non-subscribed users data rate, without the performance of the subscribed users to be significantly affected.

As a future research step, we believe coordination among the members of the cluster will also play a major role, when investigating the case where a user can utilize resources from two BS simultaneously. This interesting field will add flexibility and it will increase the utilization of available resources. However, it will also add complexity that will require methods to establish the proper coordination among the BSs, as well as more complex methods to determine its exact utilization.

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