Wireless Pers Commun (2017) 96:323–339
DOI 10.1007/s11277-017-4169-4

Interference Management Strategy for 5G Femtocell Clusters

Christos Bouras[1,2] · **Georgios Diles**[2]

Abstract With the next generation of mobile networks closing in, its main characteristics have already been proposed and adapted. Ultra-dense heterogeneous networks seem to be one of the main drivers to answer the need for larger device connectivity and increased data rate. Multiple Base Stations with different specifications will be deployed to achieve these targets. Femtocells are a type of Base Station that is expected to dominate, due to their low cost and easy deployment and maintenance. However, trying to increase spectral efficiency with the use of femtocells, by multiple base stations utilizing the same spectrum will lead to severe interference phenomena. This can be tackled by sharing spectrum strategies and power control techniques. In this manuscript, we propose a full scheme of resource management that can be applied in instances of femtocell deployments of increased density. The mechanism is based on coordination among the femtocells to achieve better spectrum usage, on power control and on hybrid access configuration aiming to fairness in resource allocation and to the improvement of overall capacity. Conducted simulations showed that our algorithm increases the overall capacity, protects non-subscribed users and balances the hybrid access effect on subscribers.

Keywords Femtocells · Hybrid access · Resource allocation

1 Introduction

Femtocells and small cells in general are a major characteristic of next generation networks. The densification of future networks through the deployment of multiple base stations (BS) of small radius, scattered along the umbrella of macrocell infrastructure is

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✉ Christos Bouras
bouras@cti.gr

Georgios Diles
diles@ceid.upatras.gr

[1] Computer Technology Institute and Press “Diophantus”, N. Kazantzaki, 26504 Patras, Greece

[2] Computer Engineering and Informatics Department, University of Patras, 26504 Patras, Greece

considered a prerequisite in order to meet the extreme increase in data rate demand and in number of connected devices [1]. The usage of millimeter wave spectrum with the significant penetration losses that characterizes it, makes the limited radius of small cells even more useful. Femtocells in particular, with their flexibility, capability for mobility, their user-friendly deployment and their cost effective features, present an attractive solution for the heterogeneity requirements of 5G networks.

However, there is also a downside, originating from the same characteristics that make femtocells attractive. Their ad-hoc deployment is hard to be controlled centrally [2]. The densification of the network by many BS, often deployed in the same building and utilizing the same spectrum can be devastating to users which may experience interference from multiple sources. Thus, while femtocells provide the means and resources for achieving next generation performance targets, a great consideration must be taken regarding the most efficient utilization of these resources in order to maximize the advantages and minimize the disadvantages.

Spectrum sharing and power control are some of the most useful fields that have been researched towards interference mitigation. Hybrid access also is a major technique that is used by femtocells towards these goals providing a solid compromise between open access where femtocells serve users within their range indiscriminately, and closed access where they serve only a list of subscribers called Closed Subscriber Group (CSG). Hybrid access allows limited access to nearby non-subscribed users, hence avoiding the large interference of the latter case (close access) while respecting private resources by enforcing priorities compared to the former case (open access).

In this manuscript, we utilize the possibilities provided by the hybrid access mode for femtocells and the opportunities for coordination provided by the dense nature of these networks and we propose a complete mechanism that determines spectrum sharing, user redistribution among base stations and power control for every femtocell and every user in the range of these networks. More specifically, we propose an enhanced version of hybrid access that is extended to cover the users of nearby femtocells, and distinguish them from other non-subscribers. This concept allows us to define and combine spectrum-sharing strategies with redistribution of the users, providing greater capacity and protecting non-subscribers from the accumulative interference of the multiple base stations. In addition, we enforce power control to balance the negative impact of spectrum sharing to subscribers by distributing it to multiple base stations.

Conducted simulations showed that our algorithm provides greater capacity by the femtocell tier compared to the CSG approach, reduces the load on the macrocell tier, restores the performance of non-subscribers, improves the worst case performance reduction due to spectrum sharing and provides a fairer resource allocation among subscribed users. Finally, while the number of users served by the femtocells is greatly increased, the impact on subscribed users becomes negligible.

The structure of the paper is as follows. The next section presents the state of the art for the subject. In Sect. 3, we describe the system model and the assumptions we were based on. Section 4 presents a detailed description of our proposed mechanism. Section 5 includes the simulation results conducted to evaluate the performance of our mechanism. Finally, in Sects. 6 and 7, we draw our conclusions and we suggest future research steps, respectively.

2 Related Work

Resource allocation is a field that has attracted great attention for the next generation networks. Multiple spectrum utilization and power control strategies have been proposed to face the challenges of heterogeneous networks and two-tier macrocell/femtocell networks in particular.

On spectrum sharing, the work in [3] proposes a self-organizing femtocell network that employs an opportunistic smart frequency reuse technique that exploits the frequency and polarization diversity to mitigate interference femtocell/macrocell networks. The authors combine reverse frequency allocation and orthogonal polarized transmission to maximize spectral efficiency and minimize downlink interference. The authors in [4] propose a mechanism in resource partitioning for hybrid access femtocells that takes into account the pre-experienced Signal to Interference plus Noise Ratio (SINR) value of the non-CSG users, to determine the upper and lower bound of spectrum regions. The authors in [5] search for the optimal allocation of channels in open access 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. Multichannel hybrid access femtocells are the focus of the work in [6]. 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.

A dynamic algorithm for spectrum shared hybrid access femtocells is proposed in [7], that determines resource allocation based on femtocell users' satisfaction and depending on the level of congestion in the network. The authors in [8] 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 femtocells transmission parameters by predicting the demand of the macrocell tier users. Similarly regarding the effort to offer femtocell owners motivation to share their resources, the authors in [9] are based on profit sharing among the macrocell and femtocell owners, trying to optimize macrocells benefit by deciding the ratio of revenue distribution to femtocell owners.

On power control, the work in [10] tackles the accumulative interference when femtocell clusters exist, by centrally determining which members of the cluster will operate and which won't, in favor of the overall network performance. It is considered that femtocells work in closed access and the decision is based on which femtocell inflicts more interference to their surroundings. The authors in [11] utilize a combination of power control and beamforming when perfect channel information is not available. Specifically, analyzing the effect of channel uncertainty parameters on the performance, it determines the transmit power level to provide the desired SINR of the indoor cell edge femtocell user and the beam weight to maximize the output SINR of both tier users by mitigating interference in a collaborate manner. The authors in [12] formulate a Stackelberg game to address uplink interference in a spectrum-sharing femtocell network. The macrocell BS sets an interference cap for femtocell users and power allocation tries to maximize the utility of the macrocell BS and the individual utility of femctocell users. A pricing mechanism is used in [13] to price the transmit power of dense femtocell networks and construct the utility function and proposes a power self-optimization algorithm with guaranteed convergence for the established non-cooperative game framework. As a result, increase in network throughput and reduction in average transmit power is achieved.

Finally, another model is proposed in [14] where a combination of power control and optimal base station selection leads to reduction of bandwidth usage per user and increases user satisfaction, though its applicability as mentioned is limited in non-dense femtocells deployments.

While the above papers present interesting and efficient ways to utilize resources in femtocells, they either concentrate on one method (i.e. power control or spectrum reuse), or they do not investigate the matter from the perspective of the distributed coordination between several femtocells closely deployed, forming a femtocell cluster. In this manuscript, we propose a complete scheme covering all basic aspects: power control, spectrum division and user redistribution among femtocells base stations acting complementary to each other. In addition, we focus on scenarios of next generation networks exploiting their dense nature. Finally, while most papers focus on improving the capacity or individual performance, our work intends to increase capacity in a way that increases fairness among all type of users and in favor of most negatively affected ones.

3 System Model

In this section we describe the system model and the assumptions made for formulating and testing our mechanism. We consider working under the assumption of the Orthogonal Frequency Division Multiplexing (OFDM) system model. We follow the Orthogonal Frequency-Division Multiple Access scheme (OFDMA) used by Long Term Evolution Advanced (LTE-A), with 12 subcarriers per physical resource block. For the evaluation of the performance we are based on SINR calculation, through the power received by the user from the serving station, versus the interfering power received by the proximal macro BSs and femto BSs. Specifically, the SINR of a macrocell user is provided by the following equation [15]:

$$SINR_{m,k} = \frac{H_{M,k}}{\sigma^2 + \sum_{M'} \mathrm{H}_{M',k} + \sum_{F} \mathrm{H}_{F,k}} \tag{1}$$

where $H_{M,k} = P_{M,k} G_{m,M,k}$ 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. $\sigma^2 = N_0 \Delta_f$ is the white noise power spectral density multiplied by the sub-carrier spacing. $\mathrm{H}_{M',k} = P_{M',k} G_{m,M',k}$ the transmit power of neighboring macrocell base station M' on subcarrier k, multiplied by the channel gain between user m and macrocell M' on sub-carrier k. Similarly, $\mathrm{H}_{F,k} = P_{F,k} G_{m,F,k}$ is the transmit power of femtocell base station F on subcarrier k, multiplied by the channel gain between user m and femtocell F on subcarrier k.

Upon deployment, and before the power control mechanism of Sect. 4 takes place, the pilot power transmission $P_{F,k}$ of the femtocell is determined in a way to achieve a constant radius of coverage independently of where it is located in the macrocell. This means that each femtocell must set 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 P_{max}. Thus, the pilot femtocell transmit power can be calculated in decibels through [16]:

$$P_f = \min\left(P_m + G_\theta - PL_m(d) + PL_f(r), P_{max}\right) \tag{2}$$

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_θ is the macrocell antenna gain. $PL_m(d)$ denotes the average macrocell path loss at the femtocell distance d (excluding any additional wall losses).

The calculation of the SINR for a femtocell user follows the same logic, taking into account the received power from the macro BSs and any adjacent femtocell. Thus, for a user f on subcarrier k interfered by all macrocells and adjacent femtocells, this yields to:

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

where $H_{F,k} = P_{F,k} G_{f,F,k}$, $H_{M,k} = P_{M,k} G_{f,MF,k}$ and $H_{F',k} = P_{F',k} G_{f,F,k}$ and following notation as before. Based on the calculated SINR, the practical capacity of a user $x(f\, or\, m)$ on subcarrier k is given by [15]:

$$C_{x,k} = \Delta f \cdot \log_2\left(1 + aSINR_{x,k}\right) \tag{4}$$

where *alpha* is defined by $a = -1.5/\ln(5\mathrm{BER})$, with BER being the Bit Error Rate equal to 10^{-6}. The overall throughput of serving base station B (macrocell or femtocell) can then be expressed as [18]:

$$T_B = \sum_x \sum_k \beta_{x,k} C_{x,k} \tag{5}$$

where $\beta_{x,\mathrm{k}}$ notifies the sub-carrier assignment for users. When $\beta_{\mathrm{x,k}} = 1$, the sub-carrier k is assigned to user x. Otherwise, $\beta_{\mathrm{x,k}} = 0$.

Path loss estimation follows LTE-A specification for urban environments [17], and for the case of a macrocell user in distance R from its serving antenna and L_{ow} denoting penetration loss due to external wall, is calculated by:

$$PL(\mathrm{db}) = 15.3 + 37.6 \log_{10} R + L_{ow} \tag{6}$$

While for a femtocell user, path loss in urban environment according to LTE-A is given through:

$$PL(\mathrm{db}) = 38.46 + 20 \log_{10} R + L_{ow} \tag{7}$$

4 Proposed Scheme

In this section, we introduce the mechanism that dictates the allocation of resources among the femtocells that have been characterized as members of the same cluster. First, we define the requirements for a cluster to be formed. Then we categorize users to classes of different priority upon the available resources. Finally, we describe how we determine the spectrum sharing directives for users and the power levels of the femtocell's base stations, considering both the effect of spectrum allocation on the performance, and the change in interference that these power levels will cause to any affected users. The mechanism takes into account any user that moves under the range of the femtocells that belong to the cluster.

4.1 Femtocell Clusters

We first, need to define the conditions upon the mechanism operates. In order for the algorithm to be applied, a femtocell cluster has to be formed, which is when multiple femtocells are deployed in a small area. Specifically, we define a femtocell to be qualified as a member of a cluster, when it is deployed at a distance of <25 m of at least two other femtocell-cluster members. Beyond 25 m, the impact of a femtocell to another becomes quite small to be included into the cluster. Of course, the condition for the first two members is their distance to be <25 m.

4.2 User Classes

Next we categorize the users in three levels of significance. The first level and most important is the user group defined by CSG. Thus for each femtocell, the first class is consisted by its subscribers. These users have rightfully the utmost priority, since the femtocell is considered a private property. Their performance is the first goal of the femtocell when it determines spectrum and power levels. We will refer to these as Class A users.

The second class/level of users is consisted of the subscribers (CSG) again, but the ones of neighboring femtocells, that have been attributed the term cluster member of the same cluster the femtocell in question belongs to. This group is introduced to facilitate the user redistribution among base stations, and to define an intermediate class in significance between the first class and the one that follows. It is evident that the users of this class (Class B users) can easily be transformed in Class A users if they finally get admitted by their origin femtocell (and vice versa). The level (and the station) that each such user belongs to, is determined by the optimal user assignment of users among the base stations as described later.

In the bottom of the hierarchy of user classification, there are all the other users that are in the area but do not qualify to any of the previous classes. This includes both any users belonging to a femtocell CSG but this femtocell is not a cluster member and any user that is simply served by the macrocell antenna. The users of this class are also granted the least priority in the hierarchy, affecting the portion of the resources allocated compared to Class A and Class B users. We will refer to these as Class C users or macrocell users for simplicity (even if as mentioned they may belong to the CSG of a non-cluster femtocell). The significance of each class determines the priority on the spectrum allocation for the users as seen in Fig. 1 and as explained below.

4.3 Spectrum Allocation and Power Control

Following the formulation of the cluster and the categorization of users involved, the mechanism determines the spectrum allocation among the users and the power level of every member of the cluster, under the following directives:

1. Spectrum allocation to Class A users must retain advantage of owing the femtocell by experiencing better performance than without it.
2. Class A users are eligible to fall in Class B by finding a neighbor BS to be admitted if such action improves their performance. Thus, they are allocated at least the spectrum required to increase their throughput compared to connecting to their origin femtocell.
3. Necessary condition for the admission of a Class B user by another cluster member is the increase of the overall capacity offered by the two femtocells involved (target and origin). If this condition is not met, the femtocell is not admitted and the user either remains in Class A or searches for another neighboring femtocell. This protects the reduction of overall capacity in favor of a single user's performance.
4. Spectrum for Class C users is allocated based on the principle that a newly deployed femtocell has to have the minimum impact on the existing network. Thus, a Class C user is granted the spectrum required to achieve the performance he/she experienced before the deployment (and the interference) of the femtocell. These users are the main victims of a femtocell cluster situation, since they experience the accumulative interference of multiple base stations. In our work, we consider scenarios where both femtocells and users are located indoors hence, recreating the prior performance can be achieved with little resources from the femtocell part, since prior performance is already degraded by the attenuation.
5. The power levels of each femtocell are determined in order to avoid extensive decrease on the performance of individual femtocells because of the aforementioned hybrid access operation for the admission of Class C users. Thus, power control

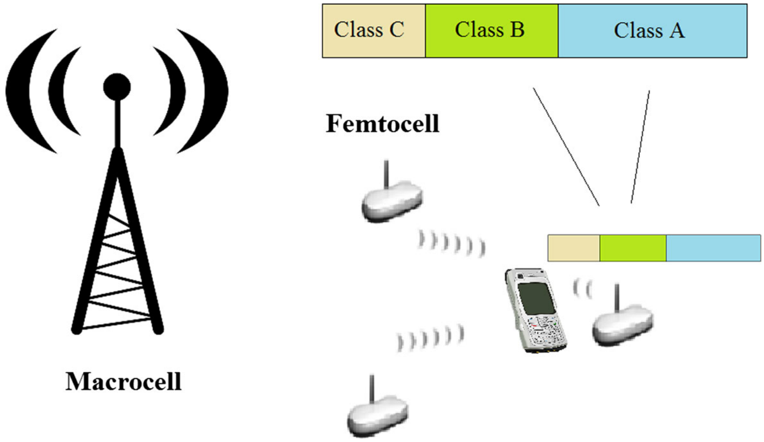

Fig. 1 The class of a user determines the portion of resources the user is allocated by the femtocell

compensates for the decrease of less spectrum utilization by Class A and Class B users (that belong to the CSGs), by balancing power levels in favor of femto BSs that have allocated significant resources to Class C users, and at the expense of BS that have allocated little or not at all.

6. Finally, the users of the same class served by the same base station are considered equal regarding their rights upon their base station's resources. For example, subscribers of the same femtocell will share the spectrum provided by the femtocell equally.

These goals define the context of resource management by respecting femtocell owners, redistributing subscribers optimally among the BSs and admitting non-subscribers with the least individual cost. Expressing the above formally, for the spectrum allocated to the first class $SP_{A,X}$, the second class $SP_{B,X}$ and the third class user $SP_{C,X}$, where X denotes the base station the user connects to (M for macrocell and F for femtocell), we get:

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

based on the system model of the previous section and coming from the fact that we want $THR_{BEF} = THR_{AFT}$ (restriction 4), with THR_{BEF} denoting 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.

The above activates the restriction (5), with the power control balancing the loss of a portion of that femtocell's spectrum to a Class C user and distributing it to the rest members of the cluster. This means that the power adjustment downwards will be greater for femtocells with small decrease on their subscribers' SINR, in order to decrease interference to their neighbors that have allocate larger spectrum to hybrid access. Thus the power adjustment for femtocell i is:

$$PC_i = \sum \left(SINR_{d,i} - SINR_{d,j}\right) \cdot a \cdot \frac{P_{i,k} G_{x,i,k}}{N_0 \Delta_f + \sum_M P_{M,k} G_{x,M,k} + \sum_f P_{f,k} G_{x,f,k}}, f \neq j \tag{9}$$

The first term makes sure that reduction depends on the femtocell's SINR reduction compared to the rest members' of the cluster SINR reduction. The second term a makes sure that any power reduction will take place only for femtocells experiencing greater reduction. Thus:

$$a = \begin{cases} 1, & if\, SINR_{d,i} - SINR_{d,j} < 0 \\ 0, & otherwise \end{cases} \tag{10}$$

Finally, the third term represents the effect that the adjustment will have to its neighbors, based on the model described in Sect. 2. The latter protects from unnecessary power reduction (and ultimately capacity reduction) when no benefit is expected. Under the assumption that as a member of the cluster, the dictating sources of interference are nearby femtocells, we easily evaluate the resulting power transmission of femtocells through:

$$Pnew_i = (1 + PC_i) \cdot Pcurr_i \tag{11}$$

with $\mathrm{Pnew_i}$ and $\mathrm{Pcurr_i}$ denoting the new and the current power level transmission of the femto BS, respectively. Restrictions (1), (2), (3) help defining the spectrum allocation for Class B users (and as a result for Class A users). Thus, minimum and maximum boundaries for spectrum can be expressed by:

$$min : SP_{B,B} \frac{\log(1 + SINR_{B,B})}{log(1 + SINR_{B,A})} \tag{12}$$

$$max : \min\left(\frac{SP_{TOT}}{\#users}, SP_{TOT} - \frac{SP_{A,M} \cdot \log\left(1 + SINR_{A,M}\right)}{log\left(1 + SINR_{A,F}\right)}\right) \tag{13}$$

with $\mathrm{SP_{B,B}}$ denoting the spectrum the user of the second class utilized when served by its origin femtocell, $\mathrm{SINR_{B,A}}$ and $\mathrm{SINR_{B,B}}$ the same user's SINR when connected to its neighboring and origin femtocell, respectively, $\mathrm{SINR_{A,M}}$ and $\mathrm{SINR_{A,F}}$ the first class user' SINR when connected to its macrocell and the femtocell, respectively and $\mathrm{SP_{TOT}}$ the available femtocell spectrum.

Finally, when the user allocation on the base stations (hence their class) and the power and spectrum resources per base station have been determined, spectrum dedicated to each

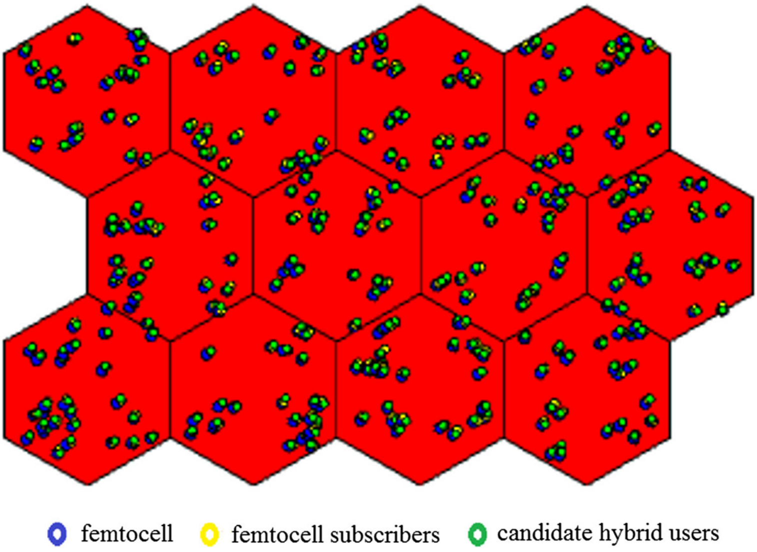

Fig. 2 Instance of the topology during the simulations

class of a femtocell, is divided equally to the users of this class, that are served by that BS following restriction (6). Any change on the topology may trigger re-evaluation of the above restrictions. Algorithm 1 summarizes the steps of the mechanism.

Algorithm 1

```
Define clusters
for each femtocell f and femtocells f1,f2 ∈ c
  If distance(f-f1)< 20 m AND distance(f-f2)< 20 m
    f ∈ c
  end if
end for
categorize users
-Class A: Subscribers
-Class B: Same cluster's femtocells' subscribers
-Class C: Others
for each user ∈ Class C then
  {calculate required spectrum for Class C user}
  $SP_{C,F} = SP_{C,M} \frac{(\log(1+SINR_{C,M}))}{(log(1+SINR_{C,F}))}$
end if
Power control for all femtocells in the cluster to distribute hybrid access impact
for femtocells i,u ∈ cluster and j u's user do
  {Power adjustment = (SINR negative reduction difference) _ (Impact on j by i)=(Impact by all)}
  $P_{adj}(i) = \sum\left(SINR_{d,i} - SINR_{d,j}\right) \cdot a \cdot \frac{P_{i,k}G_{x,i,k}}{N_0 \Delta_f + \sum_M P_{M,k}G_{x,M,k} + \sum_F P_{F,k}G_{x,F,k}}, f \neq j$
  where $a = \begin{cases} 1, & if\ SINR_{d,i} - SINR_{d,j} < 0 \\ 0, & otherwise \end{cases}$
  {calculate power transmission}
  $P_{new}(i) = (1 + P_{adj}(i)) \cdot P_{curr}(i)$
end for
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
  $min: SP_{B,B} \frac{\log(1+SINR_{B,B})}{log(1+SINR_{B,A})}$
  $max: \min(\frac{SP_{TOT}}{\#users}, SP_{TOT} - \frac{SP_{A,M} \cdot \log(1+SINR_{A,M})}{log(1+SINR_{A,F})})$
  $CAP_{BEF} = CAP_{AFT}$
end if
divide calculated spectrum for each user class and BS equally to users of this BS and this class
```

5 Performance Evaluation

In this section, we present the results obtained during the evaluation of the proposed scheme with the help of simulations. First, we describe the test bed parameters and secondly, we present and discuss the results.

5.1 Simulation Parameters

For the simulations, we built a system level simulator, based on the model described in Sect. 3. We considered a network comprised of 12 macrocells where the macrocell BS is located at the center of each cell, transmitting at a constant 46 dBm. 250 femtocells were deployed randomly among the cells, with their pilot power defined in Sect. 2. Maximum allowed power was set at 21 dBm. Following, users that were considered subscribers were deployed in the proximity of their respective femtocells. For each femtocell, the number of subscribers was determined randomly ranging from 1 up to 3 users, and their position and distance from the femtocell was also decided randomly ranging from 1 up to 15 m from the BS. In addition, 250 non-subscribed users were deployed in the area to represent candidate users for hybrid access. All users were considered static, the traffic model was full buffer and the environment was considered urban. An instance of the topology is seen in Fig. 2. As explained in Sect. 2, we considered OFDMA access scheme and path loss calculation based on LTE-A specification [17] with available spectrum of 10 MHz. Experiments depicting cdfs were conducted 20 times and the average results are presented. In the figures depicting cdfs, the lines represent hundreds of points, therefore the markers appearing on these lines have only been placed scarcely to facilitate distinction between the lines. A summary of the simulation parameters is given in Table 1. The selection of the values was based on 3GPP specifications and [19].

5.2 Performance Results

In order to evaluate the mechanism, we first present the effect that each step of the algorithm has on the performance of the users and then its overall impact. Starting from the resource allocation for the Class C users, Fig. 3 depicts the performance of these users on

Table 1 Simulation parameters

Parameter	Value
Number of macro BSs	12
Macrocell radius	250 m
Number of femto BS	250
Number of subscribers/ femtocell	1–3
Number of non-subscribers	250
Carrier frequency	2 GHz
Macro BS TX power	46 dBm
Femto BS max TX power	20 dBm
Path loss (macrocell user)	$PL(\text{db}) = 15.3 + 37.6 \log_{10} R + L_{ow}$
Path loss (femtocell user)	$PL(\text{db}) = 38.46 + 20 \log_{10} R + L_{ow}$
Subcarrier spacing	15 kHz
White noise power density	−174 dBm/Hz

three instances: if there would be no femtocell in their proximity, when the femtocell is deployed under CSG operation mode and when the user gets admitted to it according to the scheme.

We can observe two important things from the figure. First, we note the significant impact of interference from the femtocell that can have on nearby non-subscribers. The decrease when comparing with their initial data rate is significant and discouraging. Secondly, we can see that the mechanism's goal was achieved. Specifically, with the help of the femtocell operating in hybrid access, the performance of these users was restored successfully to their previous levels, since the two 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. 4 shows the cumulative distribution function (CDF) of the spectrum percentage required by the femtocells to devote to Class C users. As it can be seen from the graph, in 98% of the cases, <20% of available resources is adequeate. This can be explained from the fact that we focus on indoors femtocell scenarios.

Next we examine the impact of the above user admissions by the femtocells on their subscribers and how the power control attempts to eliminate part of it by distribution among the members of the cluster. Figure 5 depicts an instance of a cluster containing 7 femtocells. For each femtocell we present three states (columns) of the performance of their subscribers (Class A, B users): when the femtocell operate in CSG, when hybrid access is established to admit Class C users and when the power control is in effect.

The first column of each member is always the largest since it represents the CSG case where all resources are utilized by the subscribers. The second makes obvious the uneven decrease on the performance between the members depending on the resources required to be allocated in hybrid access. The third column shows how the power control balances this effect by increasing data rate for femtocells 1, 2, 4 and 5 that had suffered greater decrease at expense of femtocells 3, 6 and 7 that had experience smaller decrease (as a percentage). While the example depicted is extreme showing large reduction due to hybrid access (which is possible but less often), it helps illustrating clearly the balancing act of the power control between uneven reductions. Thus, the impact of power control depends on how much uneven the hybrid access is among the members and how much the topology allows it without significant loss in overall capacity.

Then we examine the effect of users' redistribution. Figure 6 presents an instance of two femtocells that initially serve 1 (User 1) and 3 users (Users 2, 3 and 4), respectively. The figure shows their performance before and after the admission of User 2 by its neighboring femtocell. This leads to the performance increase of Users 2, 3 and 4 at expense of User 1. The way the mechanism is structured allows User 1 to still experience adequate data rate, while increasing the one of users with the worst performance, and improving the overall capacity these two femtocells provide collectively to their subscribers. The increase of the overall capacity can be more clearly observed in Fig. 7, where we can see the overall capacity provided by femtocells that participate in the redistribution of the users, before and after the algorithm takes place.

Finally, Fig. 8 presents the capacity of every Class A and B user before and after the entire algorithm takes place. These users are subscribers thus we compare the algorithm with the performance they had initially under CSG mode. It is interesting to note that the reduction of their performance is quite insignificant if we consider that at the end of the algorithm hundreds of non-subscribers have also been admitted by their serving femtocells. It is the power control and the optimal redistribution of the users that makes the mechanism compensate almost completely for the loss of resources due to hybrid access.

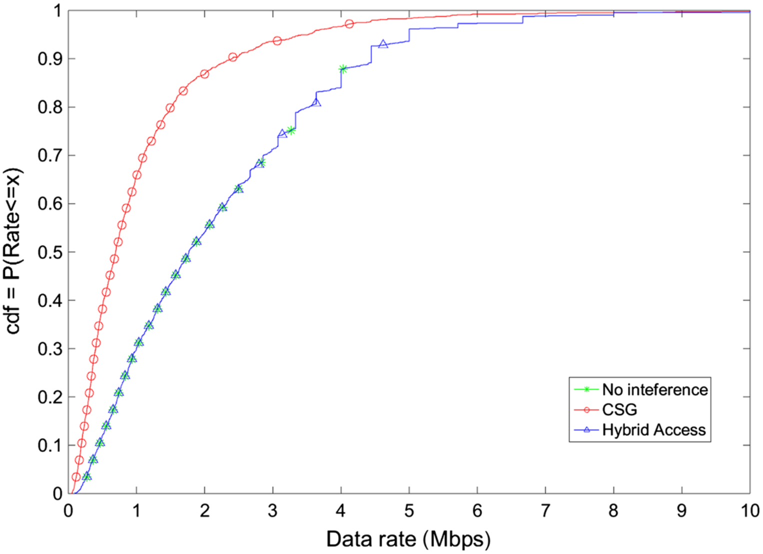

Fig. 3 Class C users' data rate before and after the interference from nearby femtocell and when connected to it. The latter restores fully the initial performance, therefore the No interference line coincide with Hybrid Access case

While the simulations parameters selected were generic enough to prove the advantages of the proposed algorithm, there are some limitations that dictate its applicability and the degree of its usefulness. Since our mechanism is based on femtocell clustering, it is evident that its usefulness is dependent on the density of femtocells deployment. In scarce deployment scenarios where no clusters are formed, the proposed power control and the re-association of femtocell users does not make sense. However, the determination of spectrum threshold for hybrid access can still apply. Ultra-dense small cell deployment in the upcoming networks makes sure that clusters will be a usual phenomenon, especially since the deployment does not follow the random pattern that we adopted above, instead has the tendency to form clusters, following the same tendency that population "deployment" has

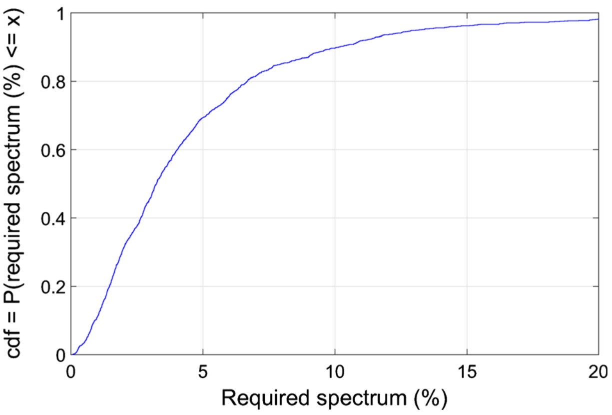

Fig. 4 Required allocated spectrum to compensate for non-subscribers data rate decrease

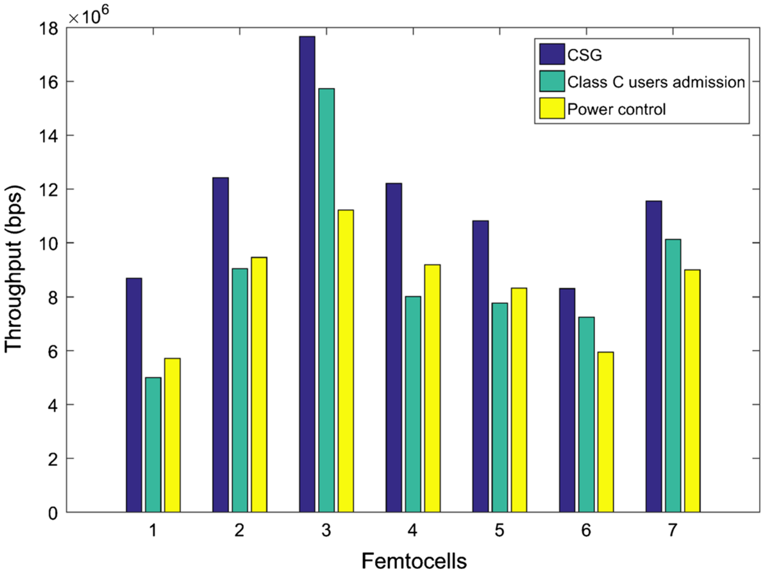

Fig. 5 Data rate of the subscribers of 7 femtocells-members of a cluster in three states: operating in CSG mode, after hybrid access mode (less spectrum) and after power control

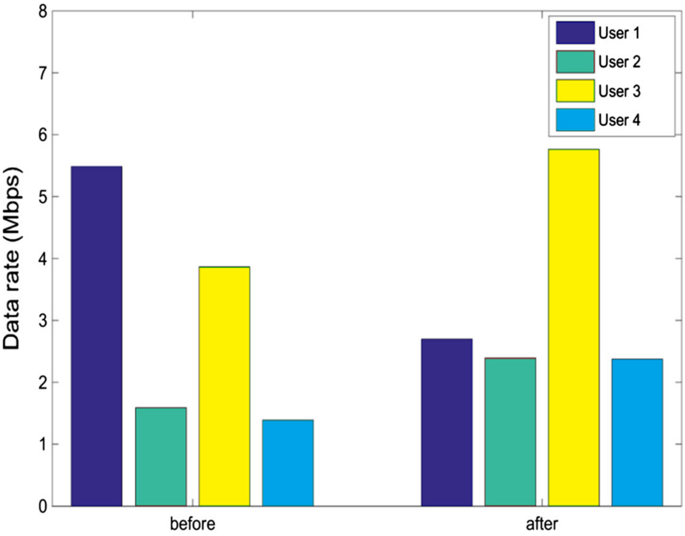

Fig. 6 Throughput of 4 subscribed users served by two femtocells before and after user redistribution. Initial distribution of 1 and 3 users to each femtocell leads to 2 users to each femtocell with fairer throughput and increased overall capacity

(i.e. large residence blocks or company buildings). Therefore, we consider the above results conservative, given that when the deployment density increases, so does the probability of beneficially re-associating users and the need for balance through power control.

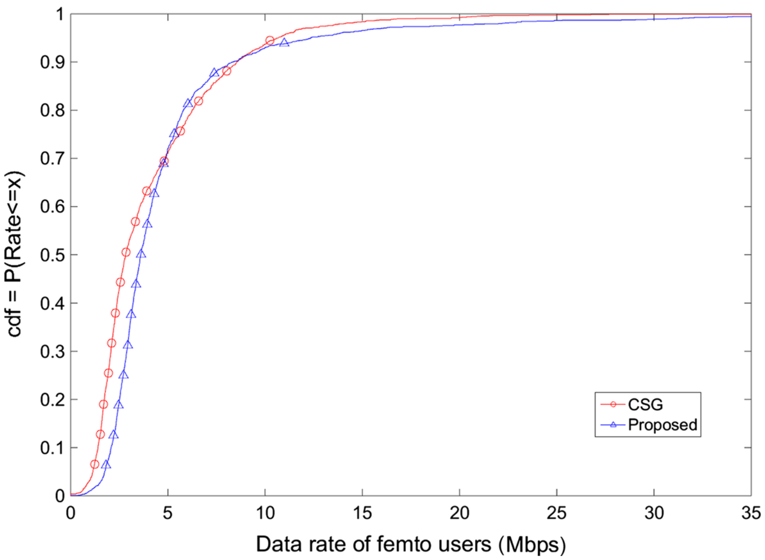

Fig. 7 Cdf of the capacity provided by the femtocells whose users were affected by the redistribution. Overall provided capacity was improved

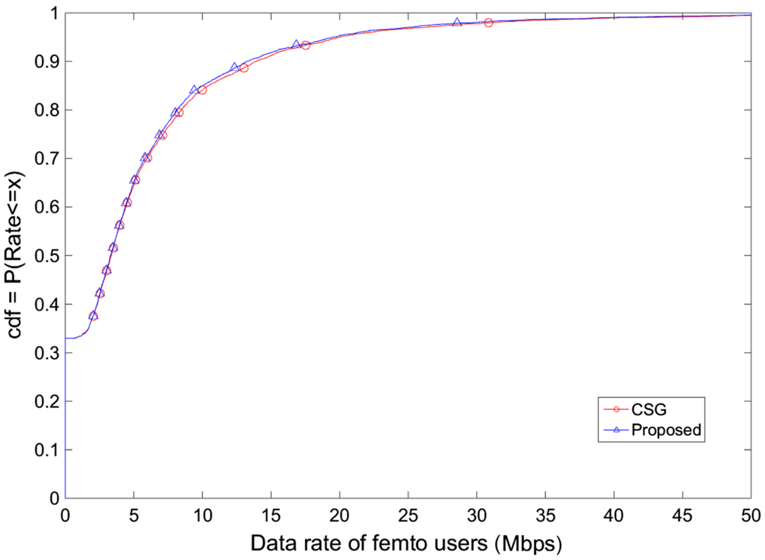

Fig. 8 Cdf of the capacity provided by the entirety of femtocells in the network before and after the proposed algorithm. Power control and user redistribution made the decrease due to hybrid access negligible

The power control is also dependent on the initial imbalance in hybrid access. If most of the femtocells have dedicated a similar amount of resources to non-subscribers, power control has not any impact on the femtocells' transmission and it results only to unnecessary computational burden. Instead, it best applies to scenarios where some femtocells have allocated large portion of spectrum and some have not allocated any, at all. As seen in Fig. 4, our hybrid access policy leads to cases where the allocated resources range from zero to over 20%, therefore covering all cases.

Finally, a major difficulty in distributed femtocell mechanisms is the computational capabilities of femtocells and the large signaling overhead involved. Communication between femtocells is supported in LTE-A through X2 [20, 21], making coordination possible. Still, femtocells can be burdened severely by the extra computational and signaling requirements. There are, however, novel suggested approaches that could be adapted to overcome or mitigate this problem [22].

6 Conclusions

In this work, we have presented a complete scheme of resource management that extends hybrid access mode in femtocells. The algorithm is based on femto BS clustering and user classification, and defines in detail the context for resource allocation. Specifically, it combines femtocells' hybrid access capability and user classification to achieve user redistribution among femtocell users that belong to the same cluster and provide adequate service to macrocell users avoiding the increased interference of dense networks. It also utilizes power control in order to mitigate the impact of spectrum sharing for subscribed users.

Based on the evaluation, the introduced algorithm was found to have multiple advantages. It restores non-subscribers performance through hybrid access operation mitigating the interference and causing the load of the macrocell tier to decrease. In addition, it distributes the burden of non-subscribers admission to multiple BSs improving the fairness and reducing the extreme deterioration on individual base stations. Finally, it increases the utilization of resources through redistribution of users optimizing the capacity provided by the femtocell in the cluster, improving the performance of the worst case users and respecting the priority of the main users of the femtocell.

The algorithm's approach can be very beneficial for scenarios where most or all femtocell cluster members belong to the same entity (i.e. a company or a multi-apartment building), thus allowing full or increased service for their primary users (i.e. employees in a company or residents), while offering a limited service to non-associated users (i.e. customers or passing by users). These scenarios provide the necessary incentive for primary users to willingly participate in a greater group with colleagues or other residents (formed by Class A and B users) and share their femtocell's resources.

On the downside, power control and nonsubscribers' admission have a small negative impact on the performance experienced by the subscribed users.

7 Future Work

The future steps for this work can be made in several directions. One possible extension is adjusting and increasing the robustness of the scheme taking under consideration the mobility of the users. Mobility patterns can by identified in users and their behavior can be predicted and integrated in the algorithm to achieve more efficient resource allocation.

Another step may be the investigation of resource allocation and base station selection for scenarios where users are given the opportunity to be served by two base stations concurrently. This interesting field provides an extra degree of both freedom in the parameters under consideration, but it also adds an extra complexity layer.

Finally, a direction worth mentioning is expanding the examined networks to include more types of small cells, such as picocells and microcells. That way, the networks will better reflect the complete heterogeneity expected by the upcoming networks. It will also require spectrum-sharing, power control and base station selection strategies of greater scale and complexity.

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Christos Bouras is Professor in the University of Patras, Department of Computer Engineering and Informatics. Also he is a scientific advisor of Research Unit 6 in Computer Technology Institute and Press—Diophantus, Patras, Greece. His research interests include Analysis of Performance of Networking and Computer Systems, Computer Networks and Protocols, Mobile and Wireless Communications, Telematics and New Services, QoS and Pricing for Networks and Services, e-learning, Networked Virtual Environments and WWW Issues. He has extended professional experience in Design and Analysis of Networks, Protocols, Telematics and New Services. He has published more than 400 papers in various well-known refereed books, conferences and journals. He is a co-author of 9 books in Greek and editor of 1 in English. He has been member of editorial board for international journals and PC member and referee in various international journals and conferences. He has participated in R&D projects.

Georgios Diles was born in Athens, Greece in 1982. He obtained his Diploma from the Electronic and Computer Engineering Department of Technical University of Crete, Greece in 2010. He was accepted in the postgraduate program Computer Science and Engineering in Computer Engineering and Informatics Department of Patras University, Greece in 2011. He works in the Research Unit 6 of Computer Technology Institute and Press "Diophantus" and he has published one research paper. He has obtained the Cambridge Proficiency in English. His main interests include Mobile Telecommunications networks and heterogeneous, femtocell-overlaid cellular networks.