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SPECIAL ISSUE - KEY TECH FOR 5G

Transmission optimizing on dense femtocell deployments in 5G

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SUMMARY

In the upcoming generation of mobile networks, femtocells will play a major role because they provide cost-efficient improvement in data rates and coverage. High penetration is expected in the upcoming ultra-dense 5G networks, increasing the probability of femtocells' clusters. This, in turn, will require interference mitigation techniques to protect nearby non-subscribed users, especially in weak macrocell signal areas. In this paper, we present a mechanism where multiple femtocells coordinate their transmission to serve multiple non-subscribed users through hybrid access. First, we introduce an algorithm that determines the spectrum allocation of femtocells' hybrid access. The algorithm aims to compensate for the performance reduction of subscribed users, due to reduced spectrum. For the second step of the mechanism, we introduce a power control algorithm that balances the impact of hybrid access among all the members of the femtocell cluster. First, we investigate the case where only one femtocell operates in hybrid access, and then we refine the power control algorithm by allowing multiple femtocells in the same cluster to operate in hybrid mode and by taking into account the effect that any change in power transmission will have on neighbouring femtocells. Simulations for the evaluation of the hybrid access algorithm compared with closed and other hybrid access schemes show improvement in the throughput of the non-subscribed users connected to femtocell and the most impacted subscribed users at weak macrocell signal areas and in the fairness of the hybrid access application scheme.

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KEY WORDS: hybrid access femtocells; heterogeneous networks; 5G; power control

1. INTRODUCTION

In mobile telecommunications, small cells appear to be an attractive solution for achieving higher spectral efficiency. Their lower cost against macrocell infrastructure has placed heterogeneous networks among the main characteristics of future generations' mobile networks [1]. Specifically, femtocells may present high efficiency due to their high flexibility and commercialization capability, in order to utilize unused spectrum and provide better data rates and coverage locally [2]. However, despite their advantages, the co-existence of multiple base stations (BSs) may create severe co-layer and cross-layer interference issues between users and BSs [3], making its mitigation one of the most important concerns for future networks. Because of the expected dense deployment of small cells in the near future, users served by the macro tier will struggle because of accumulative interference when deployed to multiple nearby femtocells. On the other hand, the random nature of femtocells' deployment makes their coordination a much more complex issue.

One way to avoid strong interference when deploying femtocells is to utilize their capability to be configured to operate in different access modes, open, closed and hybrid, or in combination of the aforementioned modes [4]. In close access, femtocells maintain a list of user equipments, known

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as closed subscriber group (CSG), which may be served by the femtocell when within its range. However, it may cause severe interference to non-subscribers in the vicinity of the femtocell's base station (FBS), requiring frequency reuse schemes and power control for its mitigation [5]. In open access instead, the femtocell may serve any user, thus avoiding interference but with the drawback of the exploitation of private resources by outsiders.

Hybrid access is a compromise between the previous two. Between open access where femtocells serve users within their range indiscriminately and closed access where they serve only a list of subscribers, hybrid access allows limited access to non-subscribed users. This means that when a user is within the femtocell's range and experiences high interference, the femtocell may decide to allocate a portion of available resources to serve the user. The resources can be allocated through spectrum management, scheduling or power control. The main characteristic that distinguishes open from hybrid access is that in the latter, there is always distinction between a subscriber and a non-subscriber, always prioritizing and favouring the former against the latter in resource allocation and scheduling [6].

In this work, we propose a mechanism that determines how the femtocell divides resources among subscribed and non-subscribed users. The mechanism is based on allocating enough spectrum for the non-subscribed user to reach, if possible, its levels of performance prior to the femtocell deployment. Next, we propose a coordinated power control mechanism that controls the power transmission of femtocells in a cluster, that is, when multiple femtocells have been closely deployed to each other. The mechanism controls the power of the members of the femtocell cluster when at least one of them operates in hybrid access. Specifically, it adjusts the power of the femtocells in order to relieve the hybrid access femtocells from the extra interference. This way, the mechanism tries to distribute the burden of hybrid access mode evenly among all femtocells in the cluster, taking into account the effect that any change in power transmission of a femtocell will have to its neighbours in order to prevent significant negative effects on the overall capacity of the cluster.

Simulation and comparison with close access (CSG) deployment and fixed hybrid access in terms of user throughput and network capacity show that the aforementioned mechanism achieves a balanced compromise among the cluster members. More specifically, it protects subscribed users from large performance decrease through the distribution of reduced resources due to hybrid access; it offers non-subscribers adequate service levels when significant interference ensues from nearby femtocells while maintaining network capacity in similar levels with compared schemes.

The rest of this manuscript is structured as follows: Section 2 presents the related work on the field. Section 3 describes the system model analysis. Section 4 presents the proposed mechanisms regarding femtocells' transmission, and in Section 5, we evaluate these mechanisms through simulations and comparisons. Finally, in Section 6, our conclusions are drawn up, and steps for future work are suggested.

2. RELATED WORK

The decision over the allocation of resources in hybrid access is a complex task, and many methods have been proposed. The authors in [7] propose a mechanism in resource partitioning, which 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 bounds of the spectrum regions that may be allocated to these users. In [8], the authors 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 [9]. 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 traffic-aware orthogonal frequency-division multiple access hybrid small-cell deployment for quality of service (QoS) provisioning and an optimal admission control strategy are proposed in [10]. A novel traffic-aware utility function differentiates the user QoS levels with the user's prior-

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ity indexes, channel conditions and traffic characteristics, and based on this function, an admission control algorithm is developed to improve QoS performance. In [11], a dynamic algorithm for spectrum shared hybrid access femtocells is proposed, which determines resource allocation based on femtocell users' satisfaction and depending on the level of congestion in the network.

The authors in [12] propose a pricing mechanism that decides for the hybrid access of femtocell 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 femtocell owners motivation to share their resources, [13] is based on profit sharing among the macrocell and femtocell owners, trying to optimize macrocell's benefit by deciding the ratio of revenue distribution to femtocell owners.

Power control has also been an important and efficient way to address cross-tier interference. In [14], a power control algorithm is proposed, which can provide QoS support in minimum SINRs for all users while exploiting differentiated channel conditions. The algorithm uses noncooperative 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.

In [15], femtocells perform subchannel and power allocation based on partially overheard channel state information from the macrocell users to the macrocell. That way, the control overhead is also decreased relative to conventional methods of acquiring interference information. On the other hand, [16] utilizes 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.

Power control based on pricing mechanism is adapted in [17] and [18]. The former uses a pricing mechanism to price the transmit power of femtocells and construct the utility function and proposes a power self-optimization algorithm with guaranteed convergence for the established noncooperative game framework. As a result, increase in network throughput and reduction in average transmit power are achieved. The latter, on the other hand, establishes a radio resource management mechanism where the macrocell tries to maximize its revenue by adjusting spectrum utilization price, while the femtocells try to maximize their revenues by dynamically adjusting the transmit power.

Finally, because we also address transmit coordination of femtocell clusters, [19] tackles the accumulative interference when femtocell clusters exist, by centrally determining which members of the cluster will operate and which will not, in favour of the overall network performance. Femtocells are considered to work in closed access, and the decision is based on which femtocell inflicts more interference to their surroundings.

While each of the aforementioned papers tackles femtocell performance, none determine the allocation of resources based on the drawbacks inflicted by hybrid access. In addition, none utilize power control that is based on the collaboration of the femtocells towards the less harmful incorporation of non-CSG users to the femto-tier, through a fair distribution of its consequences.

3. SYSTEM MODEL ANALYSIS

In this work, we focus on frequency division duplex systems, and the allocation of the resources is based on orthogonal frequency-division multiple access, which means it is performed in terms of resource blocks of 12 subcarriers, the minimum unit that can be allocated to a user.

In order to estimate the SINR that a user receives at one point of the network, we use the following model. Because SINR depends heavily on the interference added by the rest of the cells that have the user within their range, for the case of a macro user m on subcarrier k, the impact of both the adjacent macrocells and overlayed femtocells must be considered. As mentioned in [20], the SINR is provided by the following equation:

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$$SINR_{m,k} = \frac{P_{M,k}G_{m,M,k}}{N_0\Delta f + \sum_{M'} P_{M',k}G_{m,M',k} + \sum_{F} P_{F,k}G_{m,F,k}} \quad (1)$$

where $P_{M,k}$ is the transmit power of serving macrocell BS M on subcarrier k, M' represents the neighbouring macrocells, and F are the nearby femtocells. $G_{m,X,k}$ is the channel gain between user m and cell X on subcarrier k, where X can be a macrocell or a femtocell. N_0 is the white noise power spectral density and Δf the subcarrier spacing. The expression of a femtocell user is similarly derived by taking into account the interference caused by the macrocells and adjacent femtocells of the topology. Specifically, for a user f on subcarrier k interfered by all macrocells and adjacent femtocells, the received SINR is given by

$$SINR_{f,k} = \frac{P_{F,k}G_{f,F,k}}{N_0\Delta f + \sum_{M} P_{M,k}G_{f,M,k} + \sum_{F'} P_{F',k}G_{f,F',k}} \quad (2)$$

In order to determine the channel gain G, the calculation of path loss is required according to the following expression:

$$G = 10^{-PL/10} \quad (3)$$

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 [21]

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

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 [21] for the case of an indoor femtocell user is estimated, taking into account the penetration loss due to exterior walls:

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

The practical capacity of macro user m on subcarrier k is given by [20]

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

where α is defined by $\alpha = -1.5/\ln(5BER)$. The overall throughput of serving macrocell M can then be expressed as [22]

$$T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \quad (7)$$

where $\beta_{m,k}$ notifies the subcarrier 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 [22].

For the needs of our simulations, we consider the following configuration to determine the pilot power transmission of femtocells, that is, when they are first deployed and no hybrid access or coordination has taken place. The method is introduced in [23] and ensures a constant coverage femtocell radius. 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 $P_{\max}$. The FBS transmit power can be calculated in decibels as

$$P_f = \min(P_m + G - PL_m(d) + PL_f(r), P\max) \quad (8)$$

where $PL_f(r)$ is the line of sight path loss at the target cell radius r, 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).

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4. PROPOSED SCHEME

In this section, we propose the mechanism that dictates femtocell transmission parameters. First, the mechanism coordinates femtocells and macrocells, to determine the allocation of spectrum resources of femtocells when hybrid access is employed. Next, we describe how it determines the power levels in femtocell clusters, that is, multiple femto-BS deployments in a small area, and how they coordinate their power transmission, in order to balance the performance reduction of the femtocells that operate in hybrid access.

4.1. Threshold region determination

In hybrid access, when a non-subscribed user is connected to a femtocell, a portion of its resources will be allocated to this user. The spectrum allocated to the external user should be dependent on various parameters. The main concept of our proposal is that deploying a femtocell must have a minimum impact on the rest of the network. Therefore, the femtocell will allocate resources to the non-subscribed user in order to compensate for its impact on the latter's performance. The mechanism takes into account the throughput achieved by the user before the deployment of 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. Although this would may require a major part of femtocells' spectrum, we study indoors scenarios with a significant distance from the macrocell BS. The attenuation for the macro user is therefore significant, and the prior user's performance would be easy to reach. This scenario is highly likely because it represents exactly the conditions that would make a femtocell deployment necessary.

So, if CAP_{bef} denotes the throughput of the non-subscriber before the deployment of femtocell and CAP_{aft} is the target throughput of the user under the service of the femtocell, then we want $CAP_{bef} = CAP_{aft}$ which, based on the model described in Section 2, yields to

$$\frac{REQ_{subc}}{TOT_{subc}} = \frac{(\log(1 + SINR_{u,m}))}{(\log(1 + SINR_{u,f}))} \tag{9}$$

REQ_{subc} represents the number of subcarriers that must be allocated by the femto-BS to the user, in order to reach earlier level of performance, and TOT_{subc} is the number of subcarriers the user used to utilize when he or she was connected to the macrocell. $SINR_{u,m}$ and $SINR_{u,f}$ are the SINR experienced by the user, when he or she is connected to the macrocell and the femtocell, respectively. We stress again the fact that $SINR_{u,m}$ is calculated disregarding the interference of the femtocell that the user will eventually connect to (because 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.

4.2. Proposed power control

In hybrid access mode discussed earlier, the femtocell would allow access to its resources to the non-subscribed user. This, however, will reduce the capacity of its subscribed users. In the preceding texts, we propose a power control scheme to compensate for that, based on the case that other femtocells are in the vicinity of this femtocell. Inadequate services in an area will probably lead many different individuals to the femtocell solution, and that means that multiple femtocells within a small area is a highly possible future scenario. In this case, the non-subscribed user located near such a cluster of femtocells will experience high interference caused by all nearby femtocells. However, when connected through hybrid access, it will cause reduction solely to the hybrid femtocell' users. The power control, instead, will try to make all femtocells in the cluster share the burden of providing services to the non-CSG users.

When a femtocell serves a non-subscriber, its capacity decreases depending on the level of access it provided to the user. In a cluster, its capacity suffers because of the neighbouring femtocells,

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too. Instead of allowing this hurtful combination to occur, when a femtocell serves a non-user, it will notify its neighbours of the event, in order for them to reduce their power transmission. Thus, instead of a single femtocell to suffer a large decrease in its performance, all femtocell members of the cluster will exhibit a small decrease. First, we consider the case where only one member of the cluster changes its access policy to hybrid and the rest remain in CSG mode. So, the relative decrease in the performance of the hybrid femtocell's subscribers due to spectrum' partition will be

$$DEC_{cap} = 1 - CAP_{aft}/CAP_{bef} \tag{10}$$

To distribute the decrease, we set the target performance to represent half the actual reduction. We partially relax neighbours' burden requirement by half, because the aforementioned approach is exposed to a possible extreme power transmission degradation by the neighbours trying to compensate for the hybrid access femtocell. This approach also reflects the greater responsibility of the hybrid access femtocell, because a nearby user implies increased chance of affiliation with its owner. Thus,

$$CAP_{tar} = 0.5 * DEC_{cap} + CAP_{aft}/CAP_{bef} \tag{11}$$

and we pass the reduction to the entity representing the interference in the model of Section 2, through which we find the required SINR to be

$$SINR_{tar} = (2 * CAP_{tar} * \log 2(1 + a * SINR_m) - 1)/a \tag{12}$$

Because in this case, we investigate indoors scenarios and especially clusters where multiple femtocells are located near to each other, it is safe to assume that the major part of interference comes from these neighbouring femtocells and the interference induced by the macrocell can be ignored. This means that we merely adjust those femtocells' power levels by the required factor, that is,

$$Pnew = (SINR_{tar}/SINR_{curr}) * P_{curr} \tag{13}$$

Because, as a result, multiple femtocells will adjust their transmission downwards, the interference on neighbouring femtocells will decrease, too. Thus, the aforementioned reduction in the power transmission, and therefore in SINR, represents the maximum probable reduction in their performance.

4.3. *Refined power control for multiple hybrid access femtocells*

There are two concerns regarding the approach mentioned previously. First, it is limited by the fact that only one femto-BS may operate in hybrid access. So, we enhance the mechanism to allow any number of femtocell members to admit non-subscribed users. The choice of which femtocell will subject to the reduction and to what degree is based on their own hybrid access parameters, and these are dictated by the spectrum allocation algorithm, described earlier. Then, the principle of the generalized mechanism is to distribute the burden of the femtocells operating in hybrid access to the entire cluster, in a fair way. This means that femtocells with no or small spectrum allocation to non-subcarriers will experience greater reduction in their power transmission if this is found to be beneficial to the ones who exhibit more reduction due to hybrid access.

The second problem is that it may cause significant reduction to the overall capacity. This is because the decrease in neighbouring femtocells' power transmission may be disproportionate to the improvement of the hybrid femtocell's performance. This may be attributed to large distance, interference from multiple sources or significant noise. Thus, adjusting downwards its power levels would have a negative effect on its performance, without any satisfying benefit for the neighbouring femtocell, causing a great decrease in the overall capacity. In order to protect femtocells from reducing their power transmission without a similar gain, the reduction depends on the effect this change would have. Thus, the reduction is subject to its impact by the following equation for each neighbouring femtocell:

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$$IMPj,i = \frac{P_{j,k} G_{x,j,k}}{N_0 \Delta f + \sum_M P_{M,k} G_{x,M,k} + \sum_F P_{f,k} G_{x,f,k}}, f \neq i \tag{14}$$

which represents the fraction of the SINR reduction on a user connected to femtocell i caused by femtocell j, to the reduction caused by the total interference the user experiences.

So, the adjustment in power transmission is relative to the difference of the performance reduction between femtocells due to hybrid access and the effect this power transmission change has on every neighbour:

$$PC(i) = \sum \left(SINR_{d,i} - SINR_{d,j}\right) * a * IMPj,i \tag{15}$$

where a ensures that any power reduction will take place only in respect to the femtocells that have suffered greater reduction in their SINR due to hybrid access.

$$a = \begin{cases} 1, & \text{if } SINR_{d,j} - SINR_{d,i} > 0 \\ 0, & \text{otherwise} \end{cases} \tag{16}$$

Assuming that most of the interference originates from nearby femtocells, we can easily extract the required decrease in power transmission of the neighbours through

$$P_{new(i)} = (1 + PC(i)) * P_{curr}(i) \tag{17}$$

where $P_{new(i)}$ and P_{curr} are the new and current power level transmission of the femto-BS, respectively. The assumption is based on the fact that femtocells are indoors and, in a significant distance from the macrocell antenna, a scenario that would lead to multiple femtocell utilization.

When the power control concludes, the mechanism starts again when any change is detected, such as the arrival of additional users. Next, we summarize the mechanism.

Algorithm 1 Power control

for non-subs user u near a femtocell i **do**
  {calculate required spectrum for hybrid access}
  $REQ_{subc} = \frac{TOT_{sub} * (\log(1+SINR_{u,m}))}{(\log(1+SINR_{u,f}))}$
end for
for femtocells i,u ∈ cluster and j u's user **do**
  {calculate effect of FBSs to neighbouring FBSs' users}
  $IMP(i,j) = (\textit{Impact on } j \textit{ by } i)/(\textit{Impact by all})$
  {calculate power adjustment}
  $Padj(j) = \sum IMP(i,j) * a * (SINR_{d,j} - SINR_{d,i})$
  where $a = \begin{cases} 1, & \text{if } SINR_{d,i} - SINR_{d,j} > 0 \\ 0, & \text{otherwise} \end{cases}$
  {calculate power transmission}
  $P_{new(j)} = (1 + PC(j)) * P_{curr}(j)$
end for

5. PERFORMANCE EVALUATION

In this section, we provide information on the simulation framework and the parameters of the used network model. Afterwards, we present several results obtained through simulations in order to evaluate the proposed mechanism.

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Table I. Simulation parameters.

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

BS, base station.

5.1. Simulation parameters

The simulator's network configuration consists of nine macro sites of radius 250 m, wherein 100 femtocells have been deployed. The femtocells are uniformly distributed to the cell area defined by the cell edge and the condition; the distance from the macrocell is greater than 125 m (half the cell radius). This scenario is realistic because places that are further away from the macro-BS are more likely to be chosen, because weak signal will act as a drive for a femtocell purchase. One-hundred subscribed users are deployed in the proximity of the femtocells, considering for simplicity and without affecting the outcomes that each one serves exactly one CSG user. One-hundred non-subscribed users are also deployed in the area. Each femtocell may serve up to one non-subscribed user. The users' position is considered fixed, and a full buffer traffic model is considered. The macrocell BS is located at the centre of each site, transmitting with a predefined power value of 46 dBm, while the maximum allowed power transmission for femtocells is set to 20 dBm. Clusters are considered multiple close by femtocell installations, with at least three femtocell members. In order for a femtocell to be considered a member, it must be deployed in a maximum distance of 15 m from two other femtocell members of the cluster. The environment is considered urban, affecting the calculation of the path loss and justifying the increased probability of high-density femtocell deployment. Table I provides an overview of the simulation parameters. Values' selection is based on the simulator in [23].

5.2. Experimental results

First, we depict the problem by evaluating the effects on non-subscribed users in the area when CSG mode is adapted by the femtocells deployed. Figure 1 displays the CDF of SINR for macrocell users comparing the cases, where there are no femtocells deployed, and when they have been deployed in CSG mode. The figure examines users who are located inside the range of the femtocells; thus, the decline of their SINR is significant. This is also explained by the fact that macrocell users are located indoors along with the femtocells. Thus, the attenuation due to external walls along with the interference has a significant effect on their performance.

In Figure 2, we examine macrocell users' performance when hybrid access mode is allowed by the femtocells, compared with CSG. For hybrid access mode, we evaluate two cases. In the first case, the femtocell sets a default number of subcarriers that users may have access to. This number is predetermined and cannot change. The second case of hybrid access follows the scheme described in the previous section. More subcarriers become available in order for the femtocell to compensate for the impact it caused. Because our spectrum allocation policy is based on the users achieving their prior performance, indeed, the two lines coincide. This means that in this case, it was feasible for the algorithm to completely achieve its goal. An upper limit of available subcarriers has been set, for the macrocell users not to drain all resources from the rightfully femtocell subscribers. In the aforementioned case, where we considered mostly cell edge indoor users, the allocation within the boundaries is usually enough.

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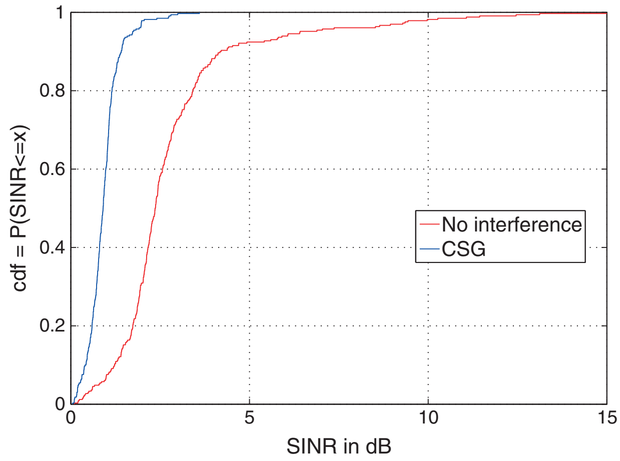

Figure 1. CDF of macrocell users signal to interference plus noise ratio (SINR) before and after the deployment of closed subscriber group (CSG) femtocells.

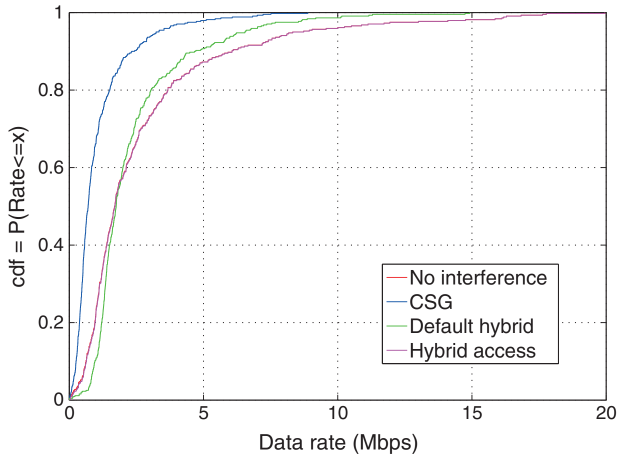

Figure 2. CDF of non-subscribed users' data rates for the different access modes.

Figure 3 shows the percentage of spectrum that was required to be allocated to macrocell users by the femtocells across the network, in order to achieve the prior performance as shown in Equation 9. The number of subcarriers varies, depending on the performance the user exhibited, initially because of its distance from the macrocell and femtocell BS and the penetration loss. More subcarriers become available if necessary in order for the femtocell to compensate for the impact it caused.

Although macrocell users benefit from femtocell resource allocation, CSG users utilize less spectrum. To investigate the impact of hybrid access compared with CSG on femtocell users' performance, Figure 4 depicts the resulting CDF of throughput for these users when resource allocation follows the scenario investigated earlier.

As expected, CSG case provides the best performance for the subscribers because of higher resource utilization. However, both the default setup and the adaptive hybrid setup offer adequate high level of services, probably without the subscribed users acknowledging the decrease in the performance.

The latter illustrates the benefits of hybrid access, because for a small decrease in subscribers' performance, the entire network is benefited. Even subscribed users are benefited in the long term, because with the high level of femtocell penetration that is expected, chances are high the CSG user will become non-CSG interfered by other femtocells when not in his or her premises.

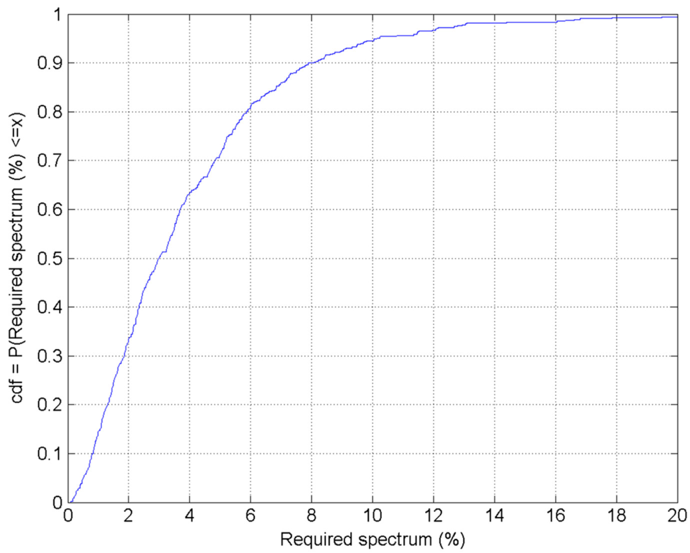

Figure 3. Necessary spectrum allocation to non-closed subscriber group users.

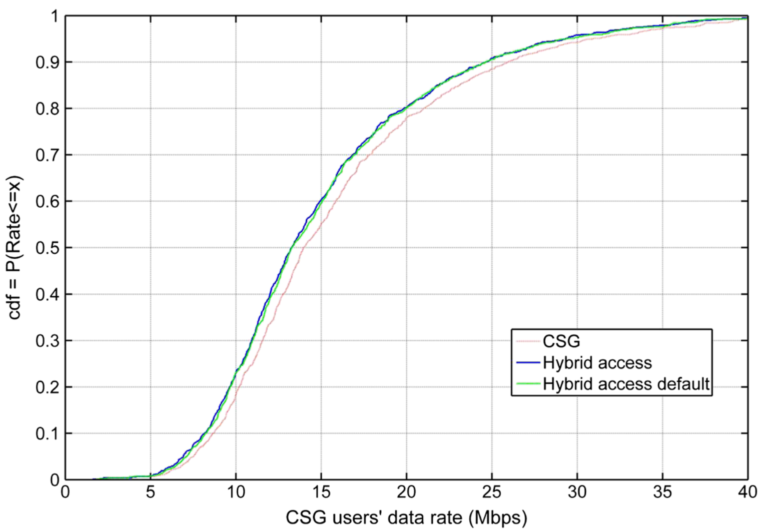

Figure 4. CDF of subscribed users throughput for the different access modes. CSG, closed subscriber group.

5.3. *Power control without IMP factor*

The simple version of power control scheme is first evaluated, applying the power control based on Equation 13 (that is, without taking into account the IMP parameter). The results obtained are shown in Figure 5. The figure displays the three stages of the mechanism for the three femtocell members of the cluster: the first column (blue) represents the throughput of the femtocell subscriber when in CSG mode, the second column (green) is the subscribers' throughput when in hybrid access of Equation 9 and without power control, and finally, the third column of each femtocell presents its subscribers' throughput when the power control of Equation 13 is applied. For simplicity, only one femtocell is operating in hybrid mode, while its two neighbours operate in CSG and are the ones that will require adjusting their transmission, in order to disburden the first femtocell.

As seen by the third column of each femtocell, when power control applies, the hybrid access femtocell has improved partially its performance, at the expense of its neighbours. It is noted that, because the factor that affects the neighbours' transmission was based on the assumption that most of the interference comes from them, the improvement of the hybrid access femtocell might vary.

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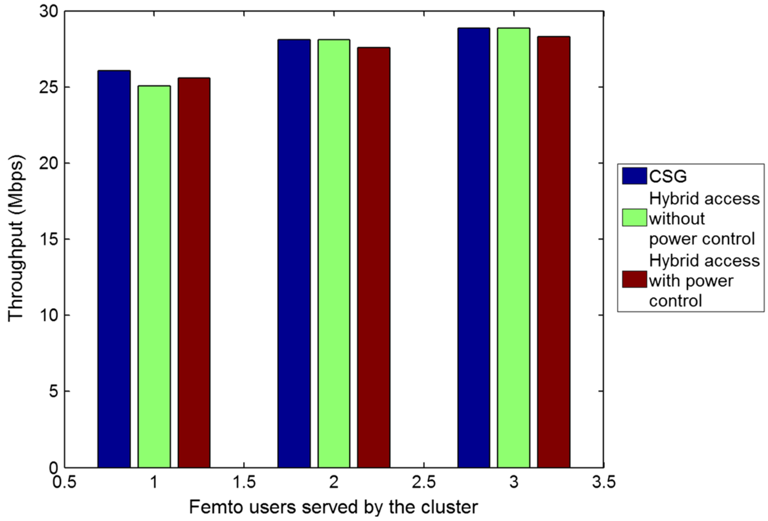

Figure 5. Capacity of closed subscriber group (CSG) users without including IMP parameter.

For a femtocell near the macrocell and the cross-tier interference dominating its performance, the improvement in its throughput will be much less and may not be worth the reduction of neighbouring femtocells. It is worth to note that while many femtocells are affected by the power control mechanism, the entire capacity is not significantly affected.

The figure can also show the disadvantage of the scheme in this form, because although it is fairer, it requires a reduction from all neighbours, which result to a relative small improvement of the first. This can have a significant negative impact on the total capacity. Instead, this is not the case when we evaluate first if a probable reduction will have a corresponding positive impact on its neighbours, thus avoiding such a scenario.

5.4. Complete power control mechanism

To this end, Figure 6(b) provides the evaluation of the complete version of the power control, that is, the one expressed in Equation 16. For comparison reasons, Figure 6(a) represents the evaluation of the simple version of Equation 13 when applied to the same topology and conditions. Similarly with before, the figure shows in columns the data rate initially (first column for each femtocell), the data rate when hybrid access has been deployed with no power control (second column) and finally when hybrid access and power control are applied for every femto-BS (third column).

In the simple case (Figure 6(a)), only the first femtocell in the cluster operates in hybrid mode. In the third column, the adjustments of the neighbours of the femtocell can be seen (femtocells 2, 3 and 4), in order to compensate for the first femtocell's decrease due to less spectrum utilization. The improvement can be seen in femtocell 1 that comes from the reduction of the interference caused by its neighbours.

On the other hand, Figure 6(b) of Equation 16 estimates the performance of the power control scheme including the IMP factor when applied on the same topology. In addition, in this case, all femtocells are allowed to operate in hybrid access, to serve nearby non-subscribed users. Similar to the aforementioned figure, the columns represent the initial state (CSG), the performance when non-subscribers have been admitted and finally the performance when the complete power control has been enforced. This is depicted for all femtocells that participate in the specific cluster.

Depending on the level of reduction compared with the average reduction observed in the cluster, the algorithm tries to reach the average as a measure of fairness, as explained in the previous section. The algorithm does not always achieve this goal, because for some cases, it calculates that a probable reduction would not have an equal positive impact to any other femtocell, which would make it justified. This can be seen by observing the fourth femtocell, which does not present any significant change in its performance. For the first femtocell that represents the one experiencing the largest

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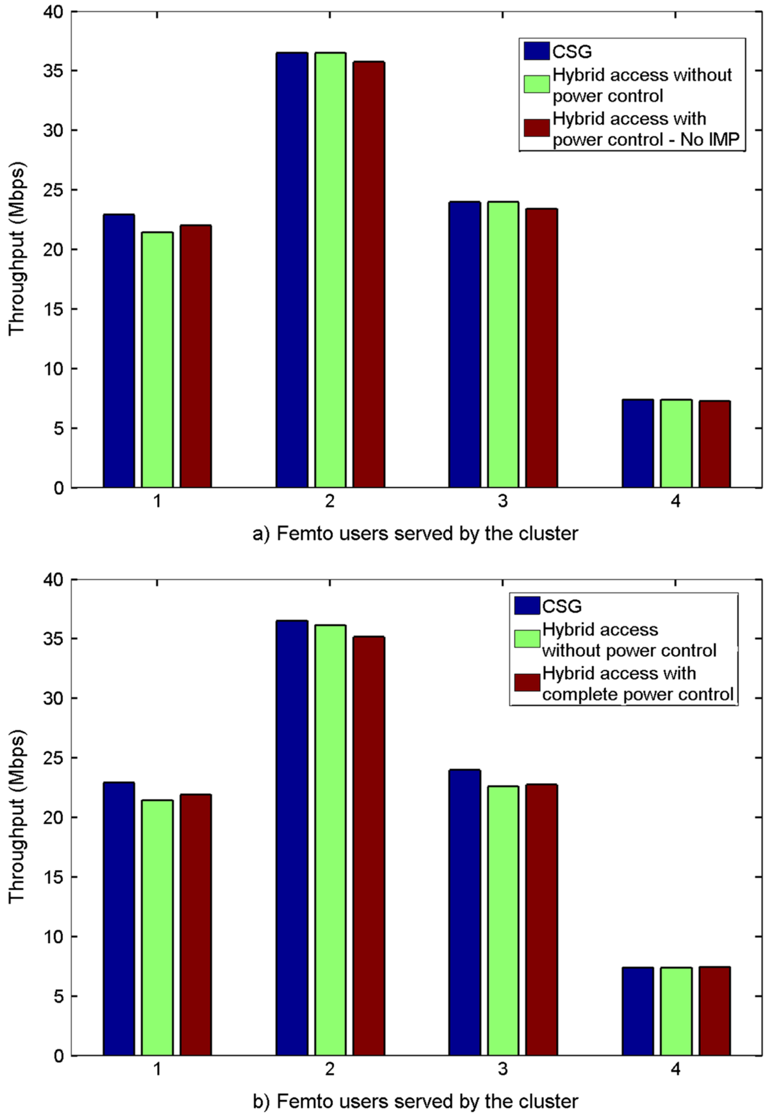

Figure 6. Capacity of closed subscriber group (CSG) users without (a) and including (b) IMP parameter.

percentage decrease due to hybrid access, we can observe a slight increase that comes as a result of the decrease of its neighbours two and three.

More specifically, the user connected at the first femtocell experiences an improvement of 2.4% in its data rate, the user of the second femtocell experiences a decrease of 2.6% and the subscribers of the two last ones experience improvement of 0.7% and 1%, respectively. The last number, representing the last column of the last femtocell, also shows a positive side effect of the power control. Because some femtocells are required to decrease their power levels, some users may experience an increase in their performance, even compared with their initial status, as a result of the reduction of interference.

From the figure, we can see that changes on power transmission are relatively small when all members have suffered a similar reduction, because there is already the balance the mechanism tries to achieve. Instead, when there is a large difference in hybrid access utilization by neighbouring femtocells, adjustments may be severe, both improving the performance of worst-case hybrid FBS and reducing the overall capacity of the cluster as well.

This can be observed better in Figure 7, which presents the impact on subscribed users that each approach results to. It can be seen that as expected, CSG performs best. Hybrid access showcases

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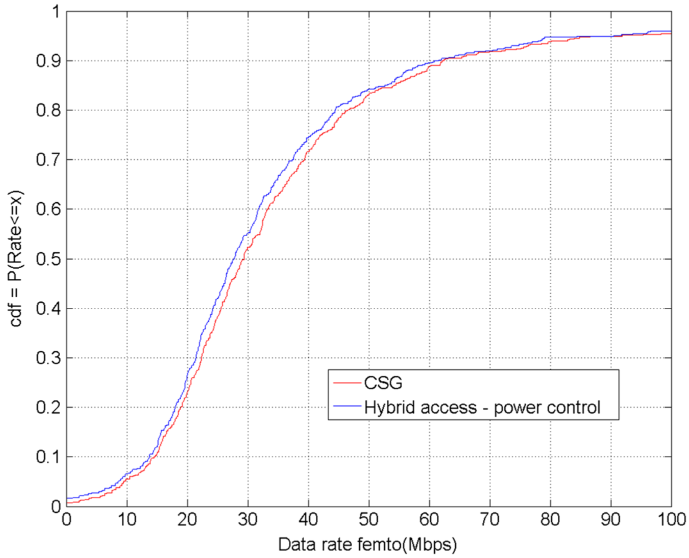

Figure 7. Comparison of overall capacity of the two approaches. CSG, closed subscriber group.

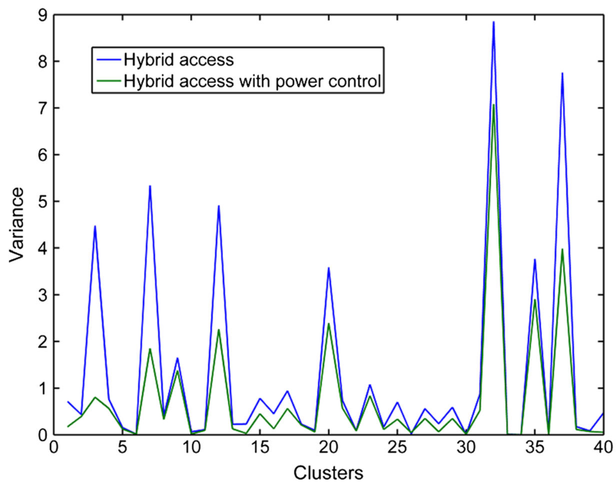

Figure 8. Change in throughput for cluster femtocells.

a reduction attributed to non-subscribed users served. In addition, the proposed power control on hybrid access further decreases the overall capacity because it is based on downward adjustment of power transmission. However, between the two approaches, there is not such a significant difference. Given the served non-subscribers and the overall fairness of the scheme, the trade-off can be conditionally beneficial.

The benefit of fairness between the BSs under the power control can be better seen in Figure 8. The figure depicts the relative change in the throughput for each femtocell within the cluster. Smaller relative change shows that the performance reduction due to spectrum sharing across the members were more homogeneous, suggesting a fairer distribution of the negative effects the hybrid access may have. This also means that users will experience smoother changes when a femtocell admits a non-subscriber and goes from CSG-like utilization of resources to hybrid access mode.

Finally, an extra advantage of the algorithm is the slight improvement of macrocell users in the vicinity of the femtocell cluster, who are not eventually get admitted to any femtocell. Because the algorithm is based solely on the reduction of cluster's power transmission, trying to relief users connected to neighbouring femtocells, non-subscribers will also benefit from the resulting interference reduction in the area.

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6. CONCLUSIONS AND FUTURE WORK

In this manuscript, we introduced a scheme for the femtocells to decide the portion of spectrum that may be allocated to nearby macro users. The mechanism takes into account the user's performance prior to the femtocell's deployment. The simulations showed that the mechanism performs adequately, preserving non-subscribed users' data rate. At the same time, the performance of the subscribed users is not significantly affected.

Next, we introduced a power control mechanism for femtocell clusters, where members of the cluster could operate in hybrid access mode if necessary, estimating as before the necessary spectrum to be given to non-subscribers for the latter to reproduce previous data rate levels. Then it calculates the resulting reduction in subscribers' performance within a femtocell cluster and distributes the reduction burden fairly among the members.

This is achieved by reducing the power levels of the femtocells that suffer the least (or none) reduction from hybrid access, in order to reduce the interference caused on neighbouring femtocells that suffer greater reduction. A check is taking place in order to confirm that such a reduction has a worthy similar positive effect.

The simulation results showed that the mechanism smooths the worst cases for subscribed users, reducing the effect of hybrid access passing a part of the reduction to neighbouring femtocells. Macrocell users connected to a femtocell maintain the performance level achieved prior to the installation of the nearest femtocell, while users who are served by the macrocell are slightly relieved because of interference reduction, as a result of the femtocell's power reduction. The drawback of the mechanism is a reduction of the overall capacity of the cluster regarding the subscribed users. However, the algorithm using the check limits the reduction to acceptable levels. Moreover, it has the beneficial effect to make the decrease of the performance almost unnoticeable to CSG users.

As a next step of this work, dynamic spectrum allocation and the admission of multiple non-subscribed users per femtocell are possible fields that are worth further investigation. Multiple non-CSG users will require greater level of coordination between the cluster in order to define the admission policy of these users, their optimal distribution to the cluster members and the allocation of the available radio resources. The combination of power control with beamforming may also be investigated, in a coordinating manner among the members of the cluster, based on the traffic and the requirements of the users.

Coordination among the members of the cluster will also play a major role, if investigating the case where a user can utilize resources from two BSs 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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