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Radio Resource Sharing Among Users in Hybrid Access Femtocells

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Abstract

A problem related to deployment of femtocells is how to manage access of users to radio resources. On one hand, all resources of the femtocell can be reserved for users belonging to a closed subscriber group (CSG), which is a set of users defined by a femtocell subscriber. This approach, known as closed access, however, increases interference to users not included in the CSG as those users do not have a permission to access this femtocell. Contrary, resources can be shared by all users with no priority in an open access mode. In this case, the femtocell subscriber shares radio as well as backhaul resources with all other users. Thus, throughput and quality of service of the subscriber and the CSG users can be deteriorated. To satisfy both the CSG as well as non-CSG users, a hybrid access is seen as a compromise. In this paper, we propose a new approach for sharing radio resources among all users. As in common cases, the CSG users have a priority for usage of a part of resources while rest of the resources is shared by all users proportionally to their requirements. As the simulation results show, the proposed resource sharing scheme significantly improves throughput of the CSG users and their satisfaction with granted bitrates. At the same time, throughput and satisfaction of the non-CSG users is still guaranteed roughly at the same level as if conventional sharing schemes are applied.

Keywords: Femtocells, hybrid access, radio resource sharing, admission, closed subscriber group

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1. Introduction

One of suitable approaches how to fulfil user's requirements on throughput in future mobile networks is to deploy large amount of small cells. As the ratio of data traffic generated from indoor continuously rises, small cells should be deployed especially inside buildings to provide adequate signal quality. For this purpose, conventional base stations can be replaced by low cost alternative, known as femtocells. The femtocells, in 3GPP denoted as Home eNode B (HeNBs), are deployed to improve signal quality in buildings or to offload a macrocell Base Station (eNB) [1]. The HeNBs are located mostly in user's premises or in offices to overcome limited signal quality from the eNB due to attenuation by walls. The HeNBs are characterized by low transmitting power and low cost. Furthermore, the HeNBs are typicaly connected to the operator's core network through a user's internet connection represented by a wired link (e.g., xDSL, cable, optical fibre, etc.).

The HeNBs can provide three different types of accesses: open, closed, and hybrid [1] . In case of the open access, the HeNB gives no preferences to any user equipment (UE) and all UEs under its coverage are threat equally. Thus, this type of access enables to offload the eNB [2]. This access is assumed to be used especially in public areas such as malls, stadiums, etc. Contrary, the closed access is designed for home UEs who want to increase coverage and throughput inside their houses but who do not want to share their network connection with other UEs. The closed access HeNB admits only UEs included in so-called Closed Subscriber Group (CSG) list [3]. The CSG list, introduced in LTE release 8 [4], is defined by owner/subscriber of the HeNB. The number of UEs registered in the CSG list is limited to a low number of UEs, typically, the HeNB intended for home usage can support 3–5 UEs and enterprise HeNB is designed for 8–16 UEs [5]). In LTE release 9 [6], information whether the HeNB is in closed access mode is provided by means of broadcasted CSG Indicator (CSG ID). It is a single-bit flag indicating if the cell is admitting also the UEs not belonging to the CSG [7]. Usage of the CSG list as a way to allow UEs to exploit resources of the HeNB is specified in [8]. As presented in [4], the open access HeNB provides a higher mean throughput experienced by the UEs when compared to the closed one for low densities of the UEs. However, the closed access is preferred for high density of the UEs attached to eNB [9]. In case of the closed access, the HeNB can introduce interference to the UEs) served by the eNB and not registered in the CSG (non-CSG users [10]. At the same time, the non-CSG UEs can take advantage of the open access HeNB since it can increase their throughput, especially at cell edges. On the other hand, the CSG UEs located indoor prefer to maximize their own throughput by restricting access for the non-CSG UEs to the radio and backhaul resources. Therefore, a compromise between both access modes, denoted as the hybrid access, is seen as a promising way how to ensure satisfaction of all UEs by offloading the eNB and providing high quality connection for the non-CSG UEs [11].

An important challenge consists in sharing of radio resources among the CSG and non-CSG UEs. Currently, 3GPP does not define how to divide resources between both types of UEs. In general, two types of sharing can be distinguished: static [12][13][14] and dynamic [15][16][17]. The static sharing can be seen as less efficient but it is easy to implement and less demanding in terms of management. Contrary, the dynamic approach requires more complex algorithm to allocate radio resources and it also implies additional overhead to exchange required information among involved networks entities.

The simplest option of the static sharing is to assign a fix amount of resource blocks (RBs) to the CSG UEs and leave the rest of RBs available to all UEs [12] . However, in this case, a part of radio resources can stay unused if the CSG UEs require only low bit rates. Analogically, the permanent amount of radio resources can be allocated for the non-CSG UEs and available resources, not used by the non-CSG UEs, can be shared by the CSG UEs. A drawback of this appraoch consits in reduced satisfaction of the CSG UEs.

The contribution of this paper consists in design of a new algorithm for radio resource sharing in hybrid access HeNBs. The algorithm is based on prioritization of the access to individual fragments of the radio resources. A part of resources is dedicated to the CSG UEs. However, all unused blocks reserved for the CSG users can be reused by the non-CSG users originally prohibited from exploitation of these resources. The resources not reserved for the CSG users are then shared by both groups, i.e., CSG and non-CSG UEs, in a proportionally fair manner.

The rest of this paper is organized as follows. The next section gives an overview on related work in the area of resource sharing in hybrid access HeNBs. Then, Section 3 describes common appraoches for the radio resource allocation and the proposed algorithm. Section 4 defines simulation models and scenarios. The results of performance evaluation are presented in Section 5. The last section summarizes major conclusions and outlines future research directions.

2. Related Work

In this chapter, we provide overview of the available research papers focusing on the problem of sharing radio resources among the CSG and non-CSG UEs in the hybrid access HeNBs.

The simplest way of the hybrid access management is to classify resources to those available only to the CSG users (reserved resources, n_{res}) and the rest of resources is then available for the non-CSG users (non-reserved resources). Ratio of the reserved resources to all available resources is flexible and can be set depending on the operator's and user's preferences. If n_{res} resources are restricted for usage by the CSG-users only, then amount of resources available for the non-CSG users is equal to $(1-n_{res})$. This basic approach is described in [12]. In our paper, this approach is later denoted as Restricted Allocation for CSG users (RAC). In this algorithm, $(1-n_{res})$ resources are reserved for the non-CSG UEs while n_{res} resources are uniformly divided between the CSG UEs. This approach guarantees that the CSG-users do not perceive variation of their Quality of Service (QoS) due to incoming connections of the non-CSG users. However, the spectral efficiency is impaired as the reserved resources might remain unused most of the time if either CSG or non-CSG UEs are not served by the HeNB.

The spectral efficiency problem can be relaxed by an enhancement of the basic approach by partial sharing of unused resources as presented in [12] and in [13]. Like in case of the RAC, fixed ratio of radio resources is always available for the CSG UEs. The non-CSG UEs cannot access these resources even if those are not utilized by the CSG UEs. The number of available resources for the non-CSG UEs has to be selected and balanced by the operator depending on the offered type of service. Contrary to the RAC, the resources not occupied by the non-CSG users can be consumed by the CSG UEs. In our paper, this algorithm is labelled as Permanent Allocation for Non-CSG users (PAN).

Open, closed and hybrid (shared) accesses in the downlink are compared in [14]. In this paper, the hybrid access with sharing resources between the CSG and non-CSG UEs is proposed. The authors target satisfaction of the UEs with offered QoS and maximization of the network throughput. As the results show, total throughput of the network increases due to the fact that the CSG UEs experience higher SINR than the non-CSG UEs. On the other hand, QoS of the non-CSG UEs is lowered.

Apart from the static methods for the resource sharing, also several dynamic methods are described in literature. In [15] and [16], the authors consider QoS of UEs for decision on handover to the hybrid access HeNBs if it implies higher capacity for the UE. A part of resources is reserved for the CSG UEs, while another part of resources is kept for the incoming non-CSG UEs. The non-CSG UEs can utilize the HeNB's resources if SINR from the HeNB is higher than SINR received from the eNB and if there are enough resources available for the incoming non-CSG. Resources for the CSG and non-CSG UEs are divided equally between UEs in each group. The results show that the use of hybrid access lowers the number of failed handovers and alleviate the interference problems. Nevertheless, the authors do not investigate an impact of the resource reservation on the CSG and non-CGS UEs.

In [16], the authors propose to use a principle of refunding between the eNB and the HeNBs to offload traffic from the eNB to the HeNBs. In this algorithm, the throughput of the non-CSG UEs increases as the HeNB accepts the non-CSG UEs because the HeNB is being refunded for this by the eNB. The refunding is done by releasing RBs of the eNB and leaving them for usage by the HeNB to satisfy non-CSG UEs. Similar principle is used in [17], where contract theory is used to optimize spectrum allocation between the eNB and the HeNBs. Decision on how much spectrum the HeNB receives depends on the number of resources available for the non-CSG UEs. The algorithm for sharing resources of the HeNBs is not related to resource allocation but it rather targets interference mitigation.

3. Proposed sharing of resources in hybrid access femtocells

In this section, we describe fundamentals of a common division of the HeNB's resources among the CSG and non-CSG UEs. Furthermore, the proposed scheme for radio resource sharing is described as well.

In general, a part of capacity of the HeNB is reserved for the CSG UEs while rest of the resources is divided among the non-CSG UEs. As shown in **Fig. 1,** the ratio of radio resources assigned to the CSG users (n_{res}) can vary from $n_{res} = 0$ (open access) to $n_{res} = 1$ (closed access). Everything in between those to extreme cases (i.e., $n_{res} \in (0,1)$) corresponds to the hybrid access.

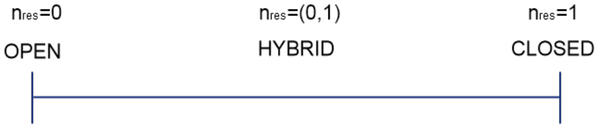


Fig. 1. Amount of reserved radio resources for CSG users in different types of access.

Contrary to the existing schemes, the proposed algorithm enables to share all available resources by all UEs with different priorities. Thus, this approach is denoted as Sharing Available Resources (SAR). In the proposed scheme (depicted in **Fig. 2**), non-reserved resources are available to the non-CSG UEs up to the amount of resources not currently used by the CSG UEs. Consequently, if the CSG UEs require less resources than n_{res}, the rest can be shared by the non-CSG users. For example, if no CSG UE is connected to the HeNB (and thus no resources are required by the CSG UEs), all resources of the HeNB are accessible by the non-CSG UEs. In the same way, if only the CSG UEs are attached to the HeNB, those UEs can share all resources including resources dedicated to the non-CSG UEs. If both CSG as well as non-CSG UEs are served by the HeNB, the reserved resources (n_{res}) are allocated exclusively to the CSG UEs in the first step. If the amount of reserved resources is sufficient for the CSG UEs, all unused resources (including reserved resources not occupied by the CSG UEs) are then proportionally allocated to the non-CSG UEs. If sum of the required resources of all UEs exceeds capacity of the HeNB (n_{HeNB}), the n_{res} resources are allocated to the CSG UEs. Then, rest of the resources (i.e., $1-n_{res}$) is shared by all UEs (i.e., both CSG and non-CSG) with equal priority related to the requirements of individual users.

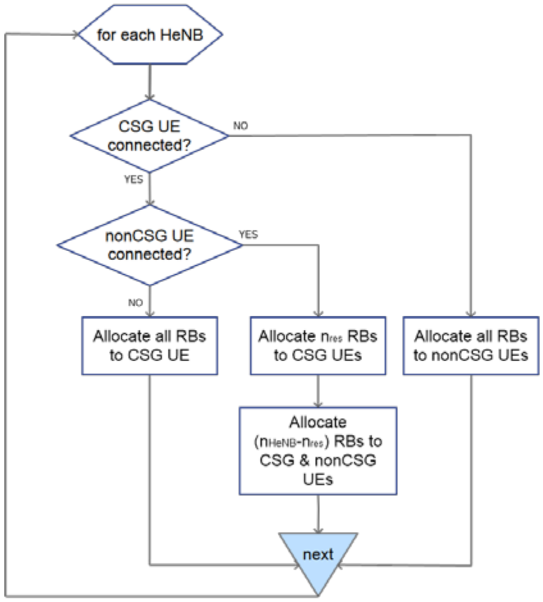


Fig. 2. Principle of resource sharing by the proposed SAR algorithm.

Let's assume the system contains *k* CSG UEs and *l* non-CSG UEs. Then, the amount of resources allocated to the *i*-th UE (n^i_{alloc}) is defined as follows:

$$n^i_{alloc} = n^i_{alloc,res} + n^i_{alloc,share} \tag{1}$$

where $n^i_{alloc,res}$ represents the resources reserved for the CSG UEs and $n^i_{alloc,share}$ is the amount of resources shared by both CSG and non-CSG UEs.

For the CSG users, $n^i_{alloc,res}$ is defined as the $min(n^i_{req,CSG}, n^i_{\max,CSG})$, where $n^i_{req,CSG}$ is the amount of resources required by the UE for data transmission, and $n^i_{\max,CSG}$ corresponds to the highest possible amount of resources that can be assigned in the reserved part. The number of required resources corresponds to the throughput required by the UE and the channel quality. The channel quality, represented by Signal to Interference plus Noise Ratio (SINR), can be mapped to the Modulation and Coding Scheme (MCS), which is directly proportional to the amount of bits per RB [20][21].

The maximum amount of resources that can be allocated to the CSG UE in the reserved part is proportional to the required amount of resources by the i-th UE with respect to the requirements of all k CSG UEs:

$$n^{i}_{\max,CSG} = n^{i}_{req,CSG} \times \frac{n_{res}}{\sum_{j=1}^{k} n^{j}_{req,CSG}} \tag{2}$$

The second part of resources is assigned to the CSG UEs from the non-reserved part. This part is distributed over all $k+l$ UEs proportionally to their requirements respecting the fact that the CSG UEs are already partly or fully served in frame of the reserved resources n_{res}. Therefore, the CSG UEs already satisfied with the grant given in reserved resources are not competing for the shared resources. Consequently, the resources are assigned proportionally to the requirements of all l non-CSG UEs and rest of the requirements of k CSG UEs after allocation of resources in reserved part:

$$n^{i}_{alloc,share,CSG} = \left(n^{i}_{req,CSG} - n^{i}_{alloc,res,CSG}\right) \times \frac{n_{HeNB} - n_{res}}{\sum_{j=1}^{k}\left(n^{j}_{req,CSG} - n^{j}_{alloc,res,CSG}\right) + \sum_{j=1}^{l} n^{j}_{req,nonCSG}} \tag{3}$$

For the non-CSG UEs, no resources are allocated in the reserved part n_{res}. Therefore, the overall amount of resources assigned to the *i-th* non-CSG UE is given by lower value out of requirements of the *i-th* non-CSG UE ($n^{i}_{req,nonCSG}$) and the highest possible amount of resources assigned to the non-CSG UE in the shared part $n^{i}_{\max,nonCSG}$:

$$n^{i}_{alloc,nonCSG} = \min\left(n^{i}_{req,nonCSG}, n^{i}_{\max,nonCSG}\right) \tag{4}$$

Analogically to the distribution of shared resources for the CSG UEs, resources for the non-CSG UEs are proportional to the requirements of all l non-CSG UEs and to the rest of the requirements of k CSG UEs after allocation of the reserved resources:

$$n^{i}_{\max,nonCSG} = n^{i}_{req,nonCSG} \times \frac{n_{HeNB} - n_{res}}{\sum_{j=1}^{k}\left(n^{j}_{req,CSG} - n^{j}_{alloc,res}\right) + \sum_{j=1}^{l} n^{j}_{req,nonCSG}} \tag{5}$$

4. Simulation models and scenario

In this section, models and scenarios for performance evaluation are defined. The evaluation is carried out by means of simulations in MATLAB. Major parameters of the simulation (see **Table 1**) are in line with recommendations for networks with small cells as defined by Small Cell Forum [18]. Parameters of the physical layer and frame structure are based on LTE-A mobile networks according to release 11 [21].

For the simulation purposes we define two scenarios with different numbers of indoor and outdoor users. In the *Scenario 1*, the number of both indoor and outdoor users is set to 64. In the *Scenario 2*, the number of indoor users is 192 while only 50 outdoor users are connected to the HeNBs.

Table 1. Simulation parameters.

Parameter	**Value**
Simulation area	450m x 130m
Carrier frequency	2000 MHz
Total eNB Tx power	43 dBm
Total HeNB Tx power	10 dBm
External wall attenuation (L_{ow})	20 dBm
Internal wall attenuation (L_{iw})	5 dBm
HeNB Deployment ratio	0.2
Shadowing factor	8 dB
Bandwidth	20 MHz
Resource Blocks	110
Cyclic prefix	normal
Amount of indoor UEs for Scenario 1/2	64/192
Amount of outdoor users for Scenario 1/2	64/50
Speed of UEs	1 m/s

Path loss models, defined by the Small Cell Forum [18], are used for modelling of the signal propagation. Depending on the UE's location and its serving cell (eNB or HeNB), one of the models presented in **Table 2** is considered. Each path loss model is described by several parameters where R denotes distance between the UE and the cell (eNB or HeNB), q is the number of the walls separating the UE and its serving cell, and $d_{2d,indoor}$ is the distance between the UE and external wall. Two-dimensional correlated shadowing model with temporal time correlation [19] is used as well.

Table 2. Path loss models used for performance evaluation.

UE to eNodeB	UE is outside	$PL_{dB} = 15.3 + 37.6\log_{10}R$
	UE is inside an apt.	$PL_{dB} = 15.3 + 37.6\log_{10}R + L_{ow}$
UE to HeNB	UE is inside the same apt. stripe as HeNB	$PL_{dB} = 38.46 + 20\log_{10}R + 0.7*d_{2d,indoor} + q * L_{iw}$
	UE is outside the apt. stripe	$PL_{dB} = \max(15.3+ 37.6\log_{10}R; 38.46+20\log_{10}R) + 0.7*d_{2d,indoor} + q*L_{iw} + L_{ow}$
	UE is inside a different apt. stripe	$PL_{dB} = \max(15.3+ 37.6\log_{10}R; 38.46+20\log_{10}R) + 0.7*d_{2d,indoor} + q*L_{iw} + 2*L_{ow}$

Based on the path loss, throughput of the UE is derived using a mapping function for SINR and MCS as defined in [21]. Data traffic is modelled as a Constant Bit Rate (CBR) where all UEs request a specific constant throughput.

All UEs are moving within an area composed of two-stripes of buildings defined in [18] (see **Fig. 3**). The outdoor UEs are randomly deployed at the beginning of the simulation and then they move along the streets according to Manhattan Mobility model with speed of 1 m/s.

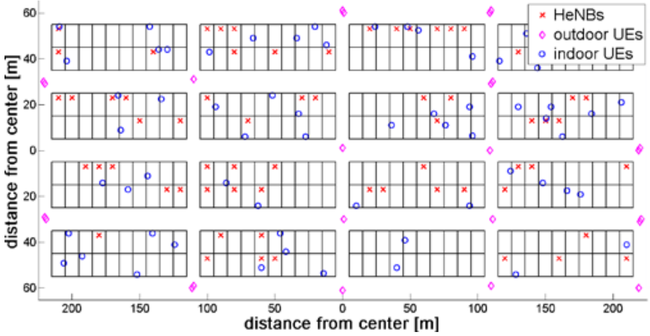


Fig. 3. Simulation scenario with example of deployment of buildings, users, HeNBs and eNB for simulations.

Inside the buildings, the HeNBs are randomly dropped to the apartments with equal distribution in a way that 20% and 60% of apartments are equipped with a HeNB for the *Scenario 1* and the *Scenario 2*, respectively. In every apartment with HeNB, one indoor UE is placed. Therefore, there are 64 and 192 indoor UEs in the area for the *Scenario 1* and *Scenario 2*, respectively**.** Movement of the indoor UEs is modeled according to [22] where the UEs move within an apartment at discrete positions, as is shown in **Fig. 4**.

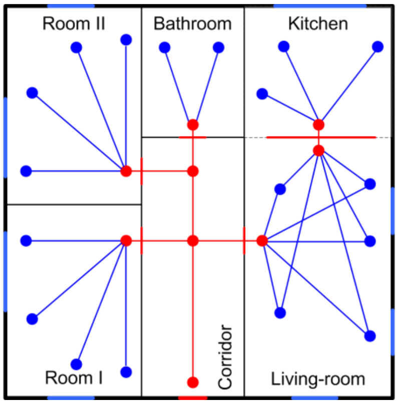


Fig. 4. Model for movement of indoor UEs.

The UEs stays for a given time at the positions of stay marked by blue dots in **Fig. 4**. Time spent by the indoor UE in each spot is given by distributions and their parameters as defined in **Table 3** [23]. Movement among the points of stay is through temporal positions (red dots).

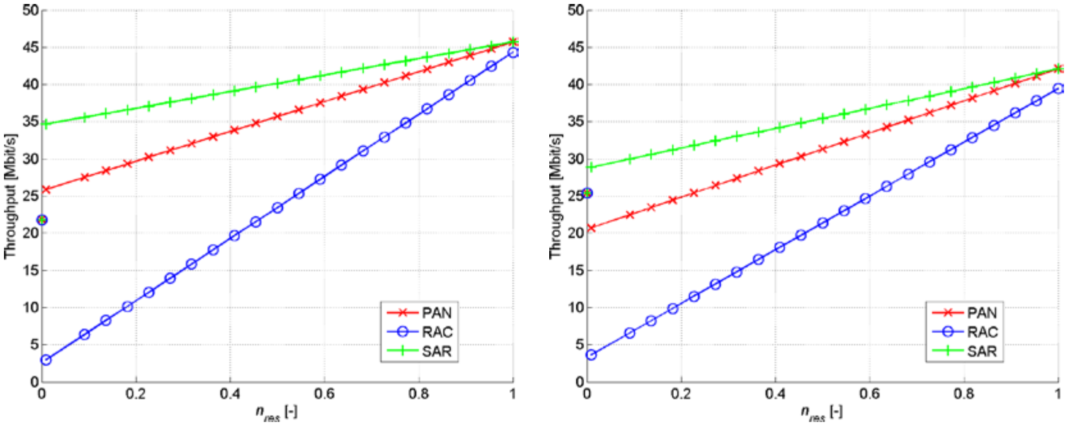
Table 3. Distribution of time of stay in specific rooms for indoor movement [23].

Room	**Distribution and its parameters**
Room I, room II, and living-room	Normal, μ=1800, σ =150
Kitchen	Normal, μ=1200, σ =150
Bathroom	Normal, μ=300, σ =22
Corridor	Normal, μ=80, σ =22

5. Performance evaluation

This section presents results of the simulations and provides comparison of the proposed algorithm with competitive RAC [12] and PAN [13] algorithms. The number of reserved resources n_{res} is normalised to values between 0 and 1, where 0 and 1 represent 0 and 110 RBs. The value of 110 PBs corresponds to 20 MHz channel bandwidth according to 3GPP.

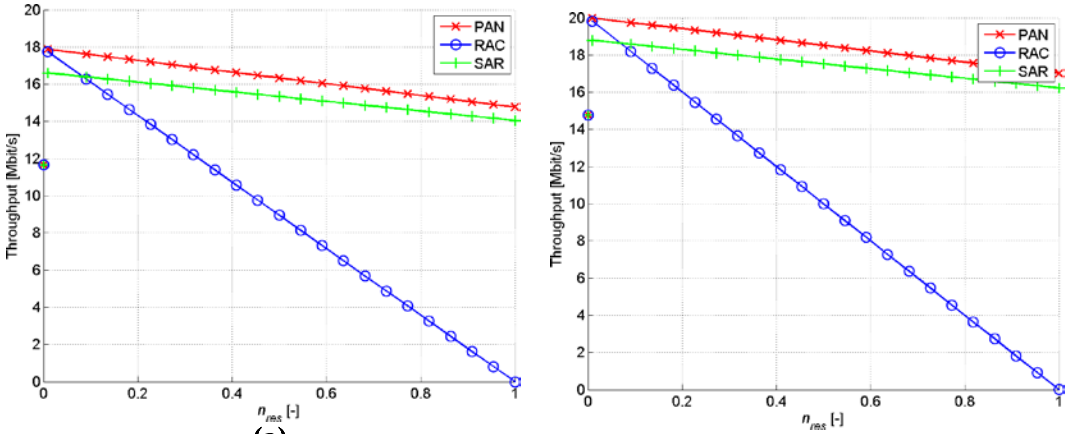
In the first step, we compare mean throughput achieved by the CSG and non-CSG UEs depending on the amount of resource block reserved for CSG UEs (n_{res}). Comparisons are depicted in **Fig. 5a** and **Fig. 5b** for the simulation *Scenario 1* and *Scenario 2*, respectively. More resource blocks reserved for the CSG UEs lead to a higher throughput of those UEs as less resources are available for the non-CSG UEs. Only exception is the situation with $n_{res}=0$. In this case, all algorithms reach the same throughput as the system operates in the open access mode where no non-CSG UEs are present (all UEs are understood as the UEs with access to all HeNBs). Consequently, all algorithms divide RBs in the same way and reach the same performance, which is represented by stand-alone markers on the y-axis (roughly 22 and 25 Mbit/s in **Fig. 5a** and **Fig. 5b**, respectively). Further, we can observe that our proposed algorithm SAR outperforms both competitive algorithms in terms of throughput of the CSG UEs. The gain is up to 10.8 and 33.7 Mbit/s (i.e., 41.8 and 1146%) comparing to the PAN and RAC algorithms, respectively, for the *Scenario 1*. For the *Scenario 2*, the gain is up to 8.2 and 25.3 Mbit/s (i.e., 39.6 and 696%) comparing to the PAN and RAC algorithms, respectively.



(a) **(b)**

Fig. 5. Throughput of CSG UEs over the number of reserved RBs for Scenario 1 (a) and Scenario 2 (b).

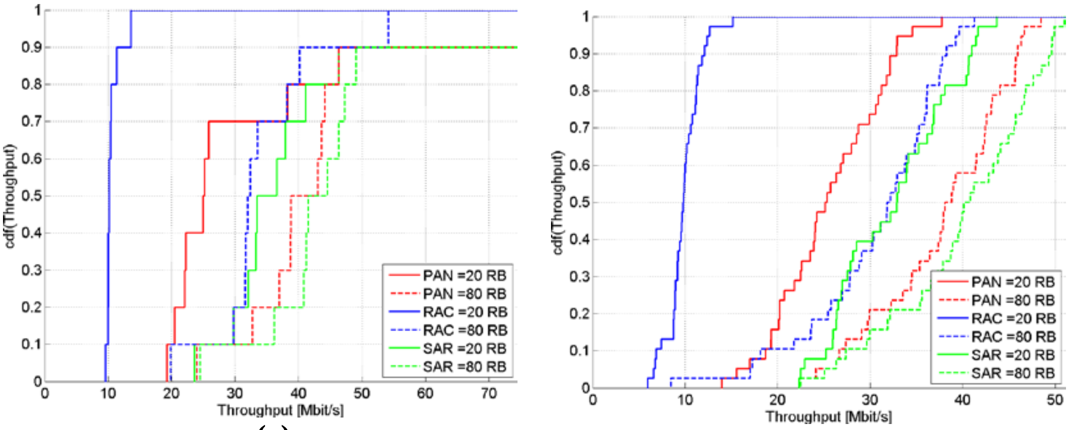
In **Fig. 6**, mean throughput of the non-CSG UEs is depicted. Contrary to the throughput of CSG UEs, the throughput of non-CSG UEs decreases with increase in the number of reserved RBs. The figure shows roughly the same performance of the SAR and PAN algorithms. In the *Scenario 1*, the proposed algorithm shows only minor drop comparing to PAN algorithm (up to 1.2 Mbit/s, i.e., 6%). This decrease in throughput of the non-CSG UEs is negligible with respect to the gain reached by the CSG UEs, which is 40% (as presented in **Fig. 5a**). Analogical results can be observed also for the *Scenario 2*. Note that for the open access ($n_{res}=0$), the CSG UEs experience nearly two times higher throughput than the non-CSG UEs (22 vs. 12 Mbit/s and 26 vs. 14.5 Mbit/s for the *Scenario 1* and the *Scenario 2*, respectively) due to their proximity to the HeNBs.



(a) **(b)**

Fig. 6. Throughput of non-CSG UEs over the number of reserved RBs for Scenario 1 (a) and Scenario 2 (b).

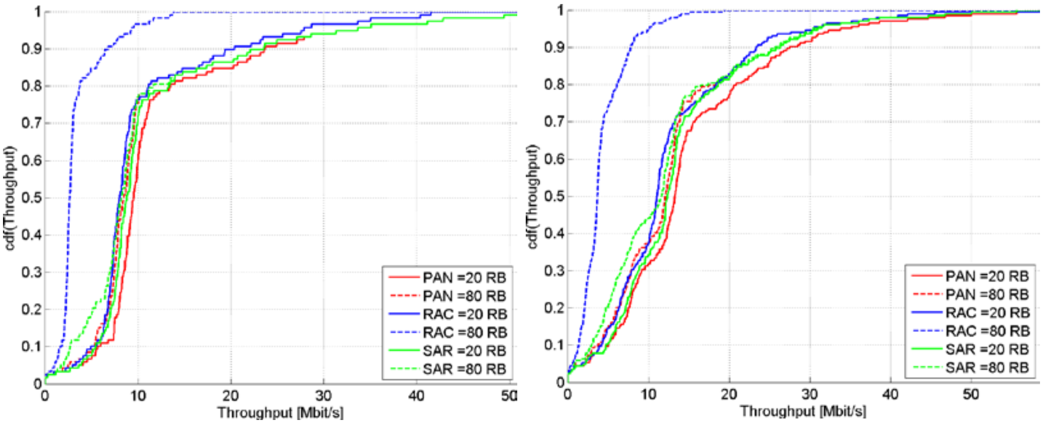
In addition to the mean throughput, also cumulative density functions of the throughput of CSG UEs for both scenarios are presented in **Fig. 7.** Both figures confirm the conclusions derived from the previous figures focusing on mean throughput. Again, the SAR outperforms both competitive algorithms in terms of throughput for the CSG UEs.



(a) **(b)**

Fig. 7. CDF of the throughput reached by CSG UEs by individual reservation algorithms for Scenario 1 (a) and Scenario 2 (b).

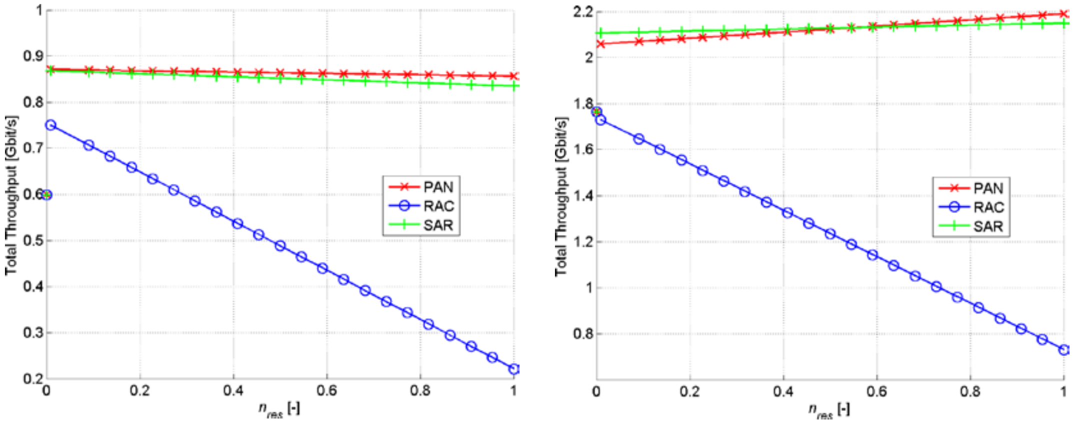
Cumulative density function of the experienced throughput of the non-CSG UEs (**Fig. 8**) shows that the SAR algorithm grant users with similar thoughput as the PANfor both scenarios. The RAC algorithm provides significantly lower throughput than both SAR and PAN algorithms.



(a) **(b)**

Fig. 8. CDF of the throughput reached by non-CSG UEs by individual reservation algorithms for Scenario 1 (a) and Scenario 2 (b).

The overall throughput of all UEs for the *Scenario 1* and the *Scenario 2* is shown in **Fig. 9**. For the RAC algorithm, the more RBs are reserved for the CSG UEs, the lower overall throughput is observed. This is due to the fact that the non-CSG UEs cannot access resources reserved for the CSG UEs. Therefore, resources not consumed by the CSG UEs stay unutilized. Overall throughput reached by both SAR and PAN algorithms is changing only slightly over n_{res}. The PAN is able to negligibly outperform the proposed SAR algorithm for high n_{res}. The gain introduced by the PAN over the SAR is less than 0.04 Gbit/s (i.e., 1.8%) for the *Scenario 1* and 0.02 Gbit/s (2.5%) for the *Scenario 2*. Higher overall throughput for the PAN is due to allocation of majority of resources to the CSG UEs as these UEs usually experience higher channel quality. Nevertheless, this can lead to unbalanced distribution of resources to the user and to the lower satisfaction of users with bitrate as shown later in this paper. Contrary, the SAR allocates non-reserved resources proportionally to both CSG UEs and non-CSG UEs.

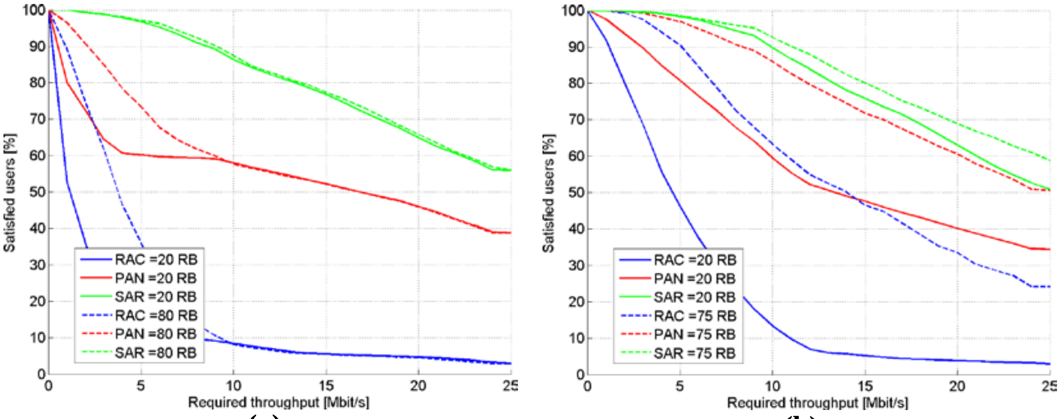


(a) **(b)**

Fig. 9. Overall throughput of all UEs in the network for Scenario 1 (a) and Scenario 2 (b).

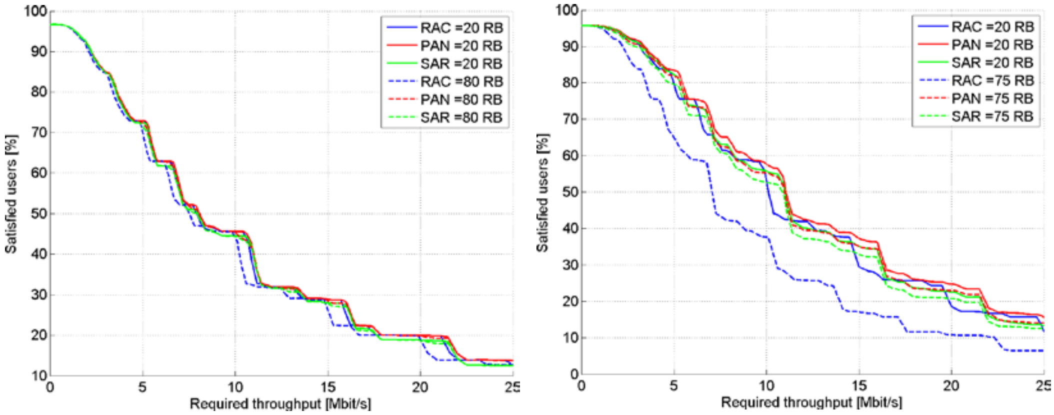
In addition to the throughput, we investigate also satisfaction of the UEs with achieved throughput. For this purpose, we define satisfied UEs as the UEs allocated with amount of resources, which enables to reach required bit rate (i.e., $n^{i}_{alloc} \geq n^{i}_{req}$ for both CSG as well as non-CSG users). In other words, the UE is satisfied if her/his required bit rate is lower or equal to the bit rate offered her/him by the network. The ratio of satisfied CSG and non-CAG UEs is depicted in **Fig. 10** and **Fig. 11**, respectively. As can be seen in **Fig. 10**, the ratio of satisfied CSG UEs decreases with higher requirements of UEs and, at the same time, it increases with amount of reserved blocks. The proposed algorithm is able to significantly improve satisfaction for both scenarios and over whole range of UE's demands on throughput. The gain is higher with lower number of reserved blocks. The gain in satisfaction ratio reached by our proposal with respect to the PAN algorithm is up to 38.2% and 30.6% if 20 and 80 RBs are reserved for the CSG UEs in the *Scenario 1*. For the *Scenario 2*, the proposed SAR improves satisfaction by 34.4% and 10.1% for 20 and 80 reserved RBs, respectively. The RAC is unable to handle higher requirements of UEs and users' satisfaction is decreasing rapidly with increasing requirements.

For the non-CSG UEs (**Fig. 11**), the proposed SAR algorithm reaches roughly the same satisfaction as the PAN and both outperforms the RAC algorithm.



(a) **(b)**

Fig. 10. Satisfaction of CSG UEs over average required bit rate for Scenario 1 (a) and Scenario 2 (b).



(a) **(b)**

Fig. 11. Satisfaction of CSG non-UEs over average required bit rate for Scenario 1 (a) and Scenario 2 (b).

5. Conclusion

This paper introduces a new approach for sharing resources among the CSG and non-CSG UEs in hybrid access femtocells. If only one type of UEs (either CSG or non-CSG) is connected to the HeNB, all resources are shared by the UEs. In case when both CSG as well as non-CSG UEs are attached, the proposed algorithm distributes radio resources among both in the way that a part of resources is shared only by the CSG UEs. Rest of the resources is then assigned proportionally to the non-CSG and CSG UEs depending on their requirements.

The proposed scheme is compared with two competitive algorithms to show impact on the mean throughput of the UEs and UE's satisfaction with granted throughput. The results show significant improvement in throughput of the CSG UEs with a gain in throughput up to 41.8 and 1146% comparing to the competitive PAN and RAC algorithms, respectively. At the same time, the negative impact of the SAR algorithm on the throughput of the non-CSG UEs is negligible (less than 6% degradation). In addition, the proposed algorithm allocates resources in the way that ratio of the CSG UEs satisfied with offered bit rate is increased for up to 38.2% comparing to the PAN algorithm. For the non-CSG UEs, the satisfaction ratio stays roughly at the same level as the most efficient competitive algorithm PAN.

In the future, we intend to enhance the proposed scheme by management of the dynamic setting of parameters to change the amount of RBs reserved for the CSG UEs in time according to the estimated amount of required RBs from both CSG and non-CSG UEs.

References

[1] Nortel, Vodafone, “Open and closed access for home NodeBs,” *Contribution to 3GPP RAN WG4 Meeting*, No. R4-071231, Aug. 2007.

[2] Small Cell Forum, “Femtocells – Natural Solution for Offload,” *Small Cell Forum*, June 2010.

[3] 3GPP TS 24.285 V11.0.0**,** “Technical Specification Group Core Network and Terminals; Allowed Closed Subscriber Group (CSG) list; Management Object (MO),” *Release 11*, 2013.

[4] D. Lopez-Perez, A. Valcarce, A. Ladanyi, G. de la Roche and J. Zhang, “Intracell Handover for Interference and Handover Mitigation in OFDMA Two-Tier Macrocell-Femtocell Networks,” *EURASIP Journal on Wireless Communications and Networking*, 2010. Article (CrossRef Link)

[5] J. Zhang, G. de la Roche, *Femtocells: Technologies and deployment*, John Wiley & sons Ltd., 2010. Article (CrossRef Link)

[6] M. Iwamura, A. Umesh, and W. A. Hapsari, “Further enhancements of LTE - LTE release 9," *NTT DoCoMo Technical Journal*, vol. 12, no. 1, pp. 45-53, 2010.

[7] 3GPP TS 23.401 V12.2.0**,** “Technical Specification Group Services and Systems Aspects; General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access,” *Release 12*, 2013.

[8] 3GPP TS 24.008 V12.3.0**,** “Technical Specification Group Core Network and Terminals; Mobile radio interface Layer 3 specification; Core network protocols; Stage 3,” *Release 12*, 2013.

[9] P. Xia, V. Chandrasekhar and J.G. Andrews, “Open vs. Closed Access Femtocells in the Uplink,” *IEEE Transactions on Wireless Communications*, Vol. 9, No. 12, pp. 3798–3809, 2010. Article (CrossRef Link)

[10] H. Jung, J. Lee, “Interference-Aware Downlink Resource Management for OFDMA Femtocell Networks,” *KSII Transactions on Internet and Information Systems*, Vol. 5, No. 3, March 2011. Article (CrossRef Link)

[11] J. G. Andrews, H. Claussen, M. Dohler, S. Rangan and M. C. Reed, "Femtocells: Past, Present, and Future," *IEEE Journal on Selected Areas in Communications*, Vol. 30, No. 3, April 2012. Article (CrossRef Link)

[12] G. de la Roche, A. Valcarce, D. López-Pérez and J. Zhang, "Access Control Mechanisms for Femtocells," *IEEE Communications Magazine*, vol.48, no.1, pp.33- 39, January 2010. Article (CrossRef Link)

[13] L. Yang-Yang, Y. Leon and E. Sousa, "Hybrid user access control in HSDPA femtocells," in *Proc. of IEEE GLOBECOM Workshops*, 2010. Article (CrossRef Link)

[14] H.-S. Jo, P. Xia, and J. G. Andrews, "Open, Closed, and Shared Access Femtocells in the Downlink," *EURASIP Journal on Wireless Communications and Networking 2012*, Dec. 2012. Article (CrossRef Link)

[15] L. Li, W. Zheng, H. Zhang, X. Wen and D. Liu, "Improved performance analysis based on a novel hybrid access algorithm in femtocell networks," in *Proc. of International Conference on Telecommunications (ICT2012)*, April 2012. Article (CrossRef Link)

[16] Y. Chen, J. Zhang and Q. Zhang, "Utility-Aware Refunding Framework for Hybrid Access Femtocell Network," *IEEE Transactions on Wireless Communications*, vol.11, no.5, pp.1688-1697, May 2012. Article (CrossRef Link)

[17] J. Yue, "Contract-based Hybrid Access for Femtocells with Asymmetric Information," in *Proc. of 10th OAPS Working Paper Series*, 2013.

[18] Small Cell Forum, "Interference management in OFDMA femtocells," *Small Cell Forum*, 2010.

[19] I. Forkel, M. Schinnenburg and M. Ang, "Generation of Two-Dimensional Correlated Shadowing for Mobile Radio Network Simulation," in *Proc. of International Symposium on Wireless Personal Multimedia Communications (WPMC2004)*, September 2004.

[20] J. Fan, Q. Yin, G.Y. Li, B. Peng, X. Zhu "MCS Selection for Throughput Improvement in Downlink LTE Systems," in *Proc. of IEEE International Conference on Computer Communications and Networks (ICCCN 2011)*, August 2011. Article (CrossRef Link)

[21] 3GPP TS 36.213 V11.4.0, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures," *Release 11*, 2013.

[22] G. Vivier, et al., "Scenario, requirements and first business model analysis," *Deliverable D21 of ICT-248891 STP FREEDOM project*, 2010.

[23] H. Claussen, L.T. Ho and L.G. Samuel, "Self-optimization of coverage for femtocell deployments," *Wireless Telecommunications Symposium (WTS2008)*, 2008. Article (CrossRef Link)

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