Self-Organization for LTE Enterprise Femtocells

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***Abstract*—Femtocells are envisioned to be deployed in indoor environments in order to improve both radio coverage and system capacity. This paper focuses on the self-organization of enterprise femtocells, which is certainly more challenging than that of home femtocells. In the context of 3GPP LTE, we propose solutions to automatically tune parameters such as radio spectrum, pilot power, resource blocks, and access control mechanisms for optimal performance via self-organization network (SON). Furthermore, on-site radio measurements and system-level simulations are used to benchmark their performance.**

***Index Terms*—Femtocells, HeNB, LTE, Self-Organization Network, Indoor network planning.**

I. Introduction

Recently, the optimization of the indoor coverage and capacity using specific solutions such as relays, picocells or femtocells has gained much of attention. Therefore, it is expected that future indoor networks will be heterogeneous as illustrated in Fig. 1. Among these technologies, special attention must be given to the development of femtocells due to the many benefits they can offer. [1].

Originally, femtocells were designed mainly for the home environment, but they could also be a cost effective solution for enterprises because of their self-organizing networks (SON) characteristics. Femtocells, on the contrary to relays and picocells, will be deployed by the end-customers without any human supervision, i.e., they do not require to be planned or maintained by cellular operators. As a result, from the operator point of view, it will be of lower cost sending femtocells to enterprises, in which they can self-deploy, as compared to performing sophisticated planing and optimization tasks.

Nevertheless, installing femtocells inside enterprise environments, where more than one femtocell may be necessary, and where many guest users may enter the femtocell coverage, leads to major technical challenges as summarized in Table I. Due to these challenges, the self-organization of enterprise femtocells is more challenging than the one of home femtocells, and hence more efficient interference mitigation schemes are required [2]. In particular, open space offices (in which only cubicles separate the enterprise users) are very challenging because there may be no major obstacle between neighboring cells. In this way, the overlap and interference between cells increases.

Many studies in the literature deal with the topic of self-organization of home femtocells [3], [4], [5] where femtocells are in the presence of neighboring macrocells and femtocells.

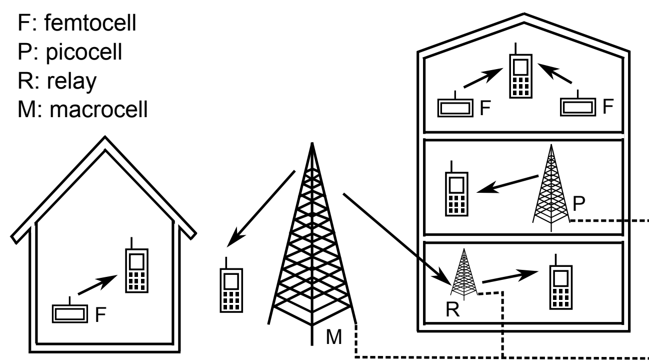

Fig. 1. Heterogeneous networks with a home (left) and an enterprise (right)

TABLE I
Comparison between home and enterprise scenarios

	Home	Enterprise
Number of femtocells	one	multiple
Main interference	cross-tier	co- and cross-tier
Guest users	few	many

To the best of authors knowledge, the self-organization of enterprise femtocells has not been well investigated.

Furthermore, the access control modes to femtocells can be [6]:

- *Open access* where everybody is allowed to make use of the femtocell.
- *Closed access*[1] where only a list of predefined users can connect to the femtocell.
- *Hybrid access* where part of the resources are open and others closed.

In enterprise scenarios, open access femtocells will lead to a decreased performance of the enterprise users when the number of guest users is too high, due to the sharing of resources and the heavy interference conditions. Furthermore, in CSG mode, it may be that the macrocell coverage will not be sufficient to satisfy the quality of service (QoS) requirements of the guest users. Hence, it is important that femtocells can optimally balance their access control mechanisms.

This research paper will focus on the self-organization of Long Term Evolution (LTE) enterprise femtocell networks.

[1] also referred to as CSG for Closed Subscriber Group

It presents a new framework for the analysis of novel self-organizing solutions involving: access control mechanisms and spectrum as well as power allocations. A SON approach is also proposed and experimentally evaluated using simulation.

This paper will be organized as follows: In Section II, the proposed approaches for self-organizing different parameters of enterprise femtocells are presented. In Section III, an experimental evaluation based on on-site measurements and system-level simulations is described. In Section IV, the obtained results are discussed and finally Section V concludes the work and gives future work/research guidelines related to enterprise femtocells.

II. Self-organization for enterprise femtocells

Enterprise femtocells must be self-organizing units that integrate the procedures of configuration and optimization in a set of built-in automatic and autonomous functionalities. In this way, femtocells are able to collect on-site accurate measurements and statistics, and optimize their performance without supervision from an operator.

Enterprise femtocells will withstand a variety of issues: they must mitigate cross- and co-tier inter-cell interference from/to the neighboring macrocells and femtocells, respectively; they must ensure a minimum QoS to the enterprise users, i.e., the rightful users of these femtocells; they must provide access to guest users until some extent. Hence, in order to solve these technical challenges without any external human control, we propose the concept of self-organization as described below.

A. Self-configuration

We assume that a self-configuration system will be deployed in the core network, similar to the one in [7], and it will be responsible for the initial configuration of a newly connected femtocell (IP address, gateway association, software update, parameter set up, etc.).

B. Spectrum selection

Let us assume that these enterprise femtocells will be deployed on top of a classic orthogonal frequency-division multiple access (OFDMA) macrocell network using three sectors per site and a frequency reuse factor of three.

Under these circumstances, we propose that after a new femtocell is powered on, it starts up in user equipment (UE) mode. Thereafter, the new femtocell scans the neighboring macrocells and accesses the one providing the best pilot strength through a standard random access procedure. Afterward, the new femtocell gets connected to this macrocell and derives which spectrum fragment it uses. This can be done through exchanging data with the macrocell. Finally, the new femtocell terminates the UE mode and switches to the femto mode.

After learning which spectrum fragment the closest macrocell is using to transmit, the new femtocell will only operate in the remaining free bandwidth, i.e., two fragments. In this way, cross-tier interference is significantly reduced, but not completely avoided since other neighboring macrocells might also interfere with this enterprise femtocell.

C. Power tuning

In order to further mitigate cross-tier interference and to reduce the interference from/to neighboring femtocells, we propose to tune the transmitted power by the femtocell in such a way that its coverage is adjusted to a given area, i.e., the rooms or offices that the femtocell has to serve.

This approach consists of a power control technique that is targeted at providing a tailored coverage. Each femtocell sets its power to a value that guarantees a given received signal strength to its farthest attached user. This scheme is assisted by standard measurement reports, which are performed by the users and fed back to the cells for cell selection and handover purposes [8].

In more detail, user U_u^f sends a measurement report to its serving femtocell F_f regularly, i.e., T_{mr} time units. This report indicates the received signal strength $w_{u,f}^{pilot}$ measured by this user U_u^f in the pilot of femtocell F_f.

After receiving reports from all its connected terminals, the femtocell then identifies which is the farthest one. It should be noted that since femtocells are likely to uniformly distribute their power among all subcarriers in order to avoid large average to peak power ratios (this is a common approach widely used in literature [9]), the farthest user is the one having the smallest average[2] received pilot strength $\hat{w_{u,f}^{pilot}}$.

Thereafter, the femtocell adjusts its transmitted power P'_f in every subcarrier according to the following equation:

$$P'_f = min \begin{cases} P_f + \underbrace{w_f^{aim} - \hat{w_{u,f}^{pilot}}}_{\text{power increment to meet the target}} \\ P_f^{max} = \frac{P_f^{tot}}{R} \end{cases} \quad (1)$$

where P_f^{tot} is the maximum power of the femtocell F_f; P_f denotes the current power radiated in each subcarrier; P'_f denotes the power to be transmitted in each subcarrier; R represents the total number of existing subcarriers; $\hat{w_{u,f}^{pilot}}$ is the average received signal strength estimated for the farthest user (derived using measurement reports); w_f^{aim} is the targeted received signal strength by the cell for the farthest user.

This power control runs on regular basis (at a frequency f_{pc}) in order to adapt the femtocell coverage to any kind of environment and to cope with the mobility of users within the offices.

D. Resource block assignment

In order to further reduce cross- and co-tier interference, the following channel dependent assisted scheduling is implemented in the femtocells.

This approach consists of a resource block (RB) assignment technique that operates independently in each enterprise femtocell. The target of the optimization procedure is to minimize the sum of the interference suffered by the connected users, while ensuring a minimum service to the enterprise users. Let

[2] Let us note that average values over several measurement reports are used to overcome the effects of fast fading.

us note that a femtocell that is targeted at minimizing its own interference tends to allocate those RBs that are not being assigned by its neighboring cells [10].

This scheduling is assisted by channel quality indicators, which are fed back from the terminals to the femtocells and that indicate the level of interference in every RB[3]. The level of interference in each RB can be indicated by suggesting the modulation and coding scheme to be used or measuring the strength of the interference in such RB. The optimization problem can be described as follows:

$$min \sum_{u=1}^{U} \sum_{k=1}^{K} w_{u,k} \cdot \gamma_{u,k}, \tag{2a}$$

subject to:

$$\sum_{u=1}^{U} \gamma_{u,k} \leq 1 \qquad \forall k, \tag{2b}$$

$$\sum_{k=1}^{K} \gamma_{u,k} = D_u \qquad \forall u, \tag{2c}$$

$$\gamma_{u,k} \in \{0, 1\} \qquad \forall z, k, \tag{2d}$$

where

- $w_{u,k}$ indicates the level of interference suffered by user U_u^f in RB k.
- constraint (2b) ensures that a given RB is assigned to at most one user.
- constraint (2c) ensures that all connected users have D_u RBs assigned.
- $\gamma_{u,k}$ is a binary variable (2d) that is equal to 1 if user U_u is using RB k, and 0 otherwise.

Let us note that the number D_u of RBs allocated to each user has to be previously set by the access control policy (enterprise vs. guest users) as well as by the scheduler. However, $\sum_{u=1}^{U} D_u \leq K$, where K is the number of RBs.

This RB allocation event takes place in each femtocell after a random time interval between 1 and T_f^{up} time units (uniformly distributed) after its previous self-organization. In this way, the probability that several femtocells change their RB allocation at the same time is reduced, hence enhancing the coordination between all femtocells.

E. Access control policy

Since CSG access is not suitable for enterprise femtocells (it would lead to huge interference, see Section I), two access control policies are used in our work: *open access* and *hybrid access*. These policies affect the guest users resource usage allowance, while the enterprise users are not being affected. In case of open access, guest users are able to connect to the enterprise femtocells without limitation i.e., there is no differentiation between enterprise and guest users at the level of the resource allocation. In case of hybrid access, the guest users are still able to connect to the enterprise femtocells, but there is a limit set for their resource usage. The number of RBs that can be allocated in each subframe is limited to a given number. The number of these open RBs is a parameter that needs to be set according to the expected number of guests at the site.

[3]Let us note that a perfect channel knowledge is assumed in this work.

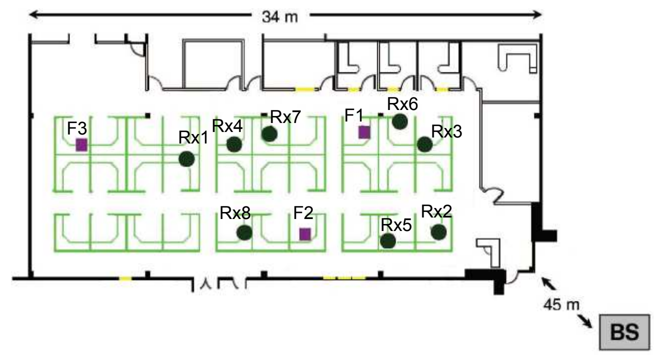

Fig. 2. Map of the office environment, with position of base station (BS), three femtocells (purple squares) and eight measurement locations (black circles).

III. Measurement-based experimental evaluation

The measurements we used in this section were performed at Stanford by Dr. Nicolai Czink. More details can be found in [11].

A. Scenario

Fig. 2 illustrates the scenario utilized in the experiments. This is a typical office environment comprised of 30 cubicles and seven private rooms.

In this scenario, users are assumed to be distributed as follows:

- Enterprise users (i.e., CSG users). 30 users representing staff of the office are located at random locations within their cubicle.
- Guest users. Non CSG users - their number changes - are located at random locations within the office hall.

It is assumed that both enterprise users and guest users are performing voice over IP (VoIP), web-browsing or email services, and therefore, only one RB is required per terminal. In order to provide service to both enterprise and guest users, three femtocells are installed within the office hall (purple squares in Fig. 2). These enterprise femtocells self-organize their parameters as detailed in the previous section. The macrocell is located at the bottom-right corner of the scenario whereby, one of its three sectors points in the direction of the enterprise building (see Fig. 2). This macrocell is assumed to use a frequency reuse factor of three. Therefore, femtocells will use the remaining $2/3$ of the spectrum, since it is assumed that they can identify the location of the closest macrocell sector and the spectrum fragment that it uses.

B. Radio coverage evaluation

In order to perform accurate system-level simulations (SLSs), realistic radio coverage maps of the cells have been computed, based on the Stanford measurement campaign described in [11].

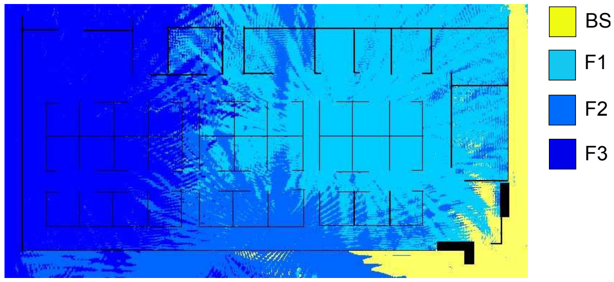

Fig. 3. Best serving areas of the calibrated simulations for base station

TABLE II
SYSTEM-LEVEL SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Scenario size $[m]$	19×34	Femto. ant. gain	$0\,dBi$
#Femtos. (F)	3	Femto. ant. pattern	Omni
Carrier frequency	$2.4\,GHz$	UE ant. gain	$0\,dB$
Channel bandwidth	$10\,MHz$	UE body loss	$0\,dB$
Duplexing	FDD	UE ant. pattern	Omni
$T_{subframe}$	$1\,ms$	UE noise figure	$9\,dB$
total RBs	50	Traffic model	full buffer
RBs for femto.	33	#Enterp. users	30
Data symbols/subf.	11	#Guest users	$0 - 30$
Femto. TX power	$10\,dBm$	#Snapshots	2000

In this experiment, the path losses of the three indoor femtocells (with omnidirectionl antennas) and outdoor macrocell sector (with a $120°$ sectorial antenna) have been measured at eight different locations (represented by black circles asshown in Fig. 2). These measurements were performed using a channel sounder and signal generator at the frequency of $2.4\,GHz$. These measurements were utilized to calibrate the propagation tool presented in [12] based on the model proposed in [13]. It is out of scope of this paper to give more details about this propagation tool, but it should be noted that it is based on finite difference time domain (FDTD), which takes into account many existing obstacles and materials. Thus, it takes into account attenuation and shadowing effects. It was found out that it can provide accuracy of up to $4\,dB$ between measurements and simulation.

Fig. 3 illustrates the best serving areas according to our prediction tool without taking power control into consideration.

C. System-level simulation

An event-driven dynamic SLS was utilized in order to model the operation of this two-tier macrocell-femtocell network. Samples of user performance in terms of signal-to-interference-plus-noise ratio (SINR), throughput and other indicators were collected at regular intervals. The presented results reflect the average of 2000 of such samples. The enterprise users were uniformly distributed within their cubicle boundaries, whereas the guest users were uniformly distributed within the office boundaries. A full buffer model is used to simulate the user traffic, i.e., there is always available data to be transmitted for each user. Moreover, as mentioned before, all users are allocated to one RB. This SLS also supports adaptive modulation and coding. Furthermore, subframe errors were modeled based on block error rate (BLER) look-up-table imported from [14]. The parameters of this SLS are summarized in Table II. More details about this simulation tool can be found in [10].

IV. RESULTS

Fig. 4 shows the CDF of the user SINR (in dB) as a function of the number of guest users. As expected, the guest users have a strong impact on the performance of the global network. In Fig. 5, the average throughput per user depending on the number of guest users is plotted for two configurations:

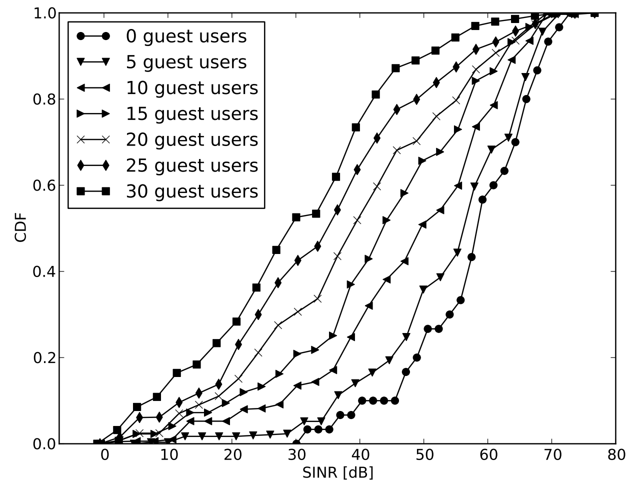

Fig. 4. Performance in open access: CDF of the user SINR in dBs depending on the number of guest users

- Open access without SON, i.e., the sub-channels are randomly allocated and their power is fixed.
- Open access with SON based on the approach (spectrum selection/power tuning/RB assignment) proposed in Section II.

Results show that SON improves the user throughput by more than 15%. This is mainly because in the overlap between the cells has been reduced and co- and cross-tier interference is mitigated.

However, since the SON technique proposed here improves the performance of all the users, this may not be acceptable for enterprises who do not want to reduce too much of the performance of their employees when the number of guests is high. Thus, in Fig. 6 the performance of users based on the hybrid access proposed in Section II is studied for the worst case scenario (i.e., the same number of enterprise and guest users).

Results show that the hybrid access scheme is an efficient solution to limit the negative effect of guest users on the performance of enterprise users. For example, in this scenario, if up to 10 RBs are left open, there is no impact on the performance of the guest users, whereas guest users still have a 400 kbits/s data rate which is reasonable. The choice of

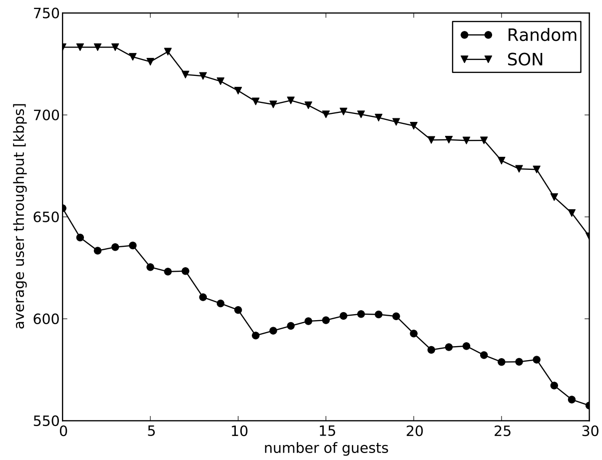

Fig. 5. Performance in open access: Average throughput per user depending on the number of guest users

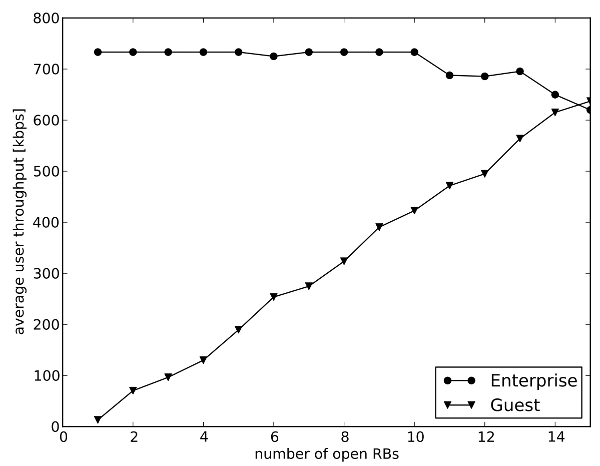

Fig. 6. Performance with hybrid access: Average throughput per user depending on the number of open RBs. 30 enterprise and 30 guest users are considered.

the optimal number open resources to leave open depends of course on the requirement of the enterprise (i.e., which priory they should give to guest users).

V. Conclusion

In this paper, performance of LTE femtocells in an office environment were presented. This investigation was based on on-site radio measurements in a scenario covered by one outdoor macrocell and three femtocells. The measurements were used as an input for our system-level simulation and the impact of accepting guest users on enterprise users was studied. A procedure for the self-organization of femtocells was also proposed and evaluated. In particular, it was shown that when enterprise femtocells are deployed in an open access mode accepting guests have an impact on the performance of the staffs of the enterprise. Therefore, in order to reduce the negative impact of guest users, an hybrid solution where femtocells keep part of their resources in CSG mode can be employed. Moreover, the proposed self-organization outperforms random allocation based approaches. However, the impact of guest users on enterprise users must be analyzed taking into account more realistic traffic models. These traffic models will impose new outage conditions, e.g., minimum throughput and delay. In addition, fast fading effects must be included to investigated the effects of signal variations in the utilized self-organization.

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