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A femtocell location strategy for improving adaptive traffic sharing in heterogeneous LTE networks

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Abstract

Femtocells have been suggested as a promising solution for the provision of indoor coverage and capacity. In this paper, a new planning strategy for placing femtocell access points so as to make the most of automatic traffic sharing algorithms is proposed for a long-term evolution (LTE) heterogeneous network. The aim of the proposed method is to increase overlapping between femtocells by increasing the percentage of area with low dominance of the serving femtocell. Method assessment is carried out by simulating classical traffic sharing algorithms in a three-dimensional office scenario with femtocell location plans designed based on different network performance criteria. Results show that location plans with a larger low dominance ratio achieve better network performance after sharing traffic than plans designed for maximum coverage or connection quality.

Keywords: Femtocell; Antenna; Placement; Overlapping

1 Introduction

Recent advances in radio access technologies have paved the way for mobile broadband services. In parallel, operator revenues keep decreasing as a result of flat rate subscriptions. Thus, the success of future mobile communication systems will largely depend on their ability to provide an adequate quality of service at a lower cost per bit. In this context, a major challenge for cost-effectiveness in mobile networks is the provision of indoor coverage. Recent surveys have shown that more than 80% of mobile traffic is originated at home or work, but nearly half of the houses and premises have poor indoor coverage [1,2]. This problem was solved in the past by increasing the number of base stations, but such an approach is not viable anymore due to lack of scalability.

Alternatively, massive femtocell deployment has been proposed to deal with indoor traffic [2]. Femtocells supply indoor coverage following an easy-to-install paradigm with limited network planning (e.g., no site location or power planning) in contrast to macro/micro cellular network deployments. However, such a limited planning is

also a potential source of problems, namely, poor coverage, poor signal quality, or traffic congestion [3,4]. In such a complex heterogeneous structure, self-organizing network (SON) [5] techniques must be used to solve these problems without human intervention.

Mobility (or handover-based) load balancing has been identified as a relevant SON use case by the industry [6,7] and standardization bodies [8]. Load balancing capability is included to deal with uneven and/or changing traffic distribution, which might cause network congestion problems. These congestion problems are commonplace in femtocell networks due to a high user concentration and the lack of a careful analysis of user trends. Therefore, improving load sharing capabilities is key to ensuring adequate performance in these heterogeneous scenarios.

In the literature, many advanced radio resource management (RRM) algorithms can be found for redistributing traffic between neighbor cells to solve localized congestion problems. Some of them reallocate users by changing antenna settings (e.g., remote electrical tilt [9]), while others adjust RRM parameters in traffic management schemes (e.g., cell re-selection offsets and/or handover (HO) margins [10]). Initial studies on load sharing are focused on macrocellular scenarios in different radio access technologies (e.g., time division

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multiple access/frequency division multiple access - TDMA/FDMA [10], wideband code division multiple access - WCDMA [11], and orthogonal frequency division multiple access - OFDMA [12,13]). Recently, the analysis has been extended to heterogeneous office scenarios with open-access femtocells [14]. Results presented there showed that traffic sharing in OFDMA femtocell networks is a challenging task due to the full frequency reuse currently used by operators.

Any traffic sharing algorithm relies on the existence of some overlapping between adjacent cells. The degree of cell overlapping depends on propagation conditions and site locations. Thus, a good load sharing capability in a heterogeneous network can be reached by a careful design of femtocell locations that ensures an appropriate overlapping between cells. However, femtocell locations are usually designed for purposes other than maximizing load sharing capabilities. Several works have studied the impact of site locations on cellular network performance in terms of coverage and/or signal-to-interference plus noise ratio (SINR). Thus, many different methods have been proposed to find the best location for macrocellular sites to improve network coverage, user connection quality, and/or network capacity [15-21]. Similar methods have been used for optimal location of wireless access points (APs) in indoor environments [22-30]. All these approaches construct a system model, over which a classical optimization algorithm is applied to find the position of base stations that maximize some overall network performance indicator. However, to the authors' knowledge, no study has evaluated the influence of positions of base stations on the effectiveness of traffic sharing schemes. In this paper, the problem of locating femtocell access points to aid automatic traffic sharing algorithms in long-term evolution (LTE) is studied. A preliminary analysis, based on static system-level simulations, aims to find some basic rules to locate femtocells in an office building in terms of different network performance criteria. Unlike previous studies, cell overlapping is also considered as a design criterion. Then, a comprehensive performance analysis of classical traffic sharing algorithms with different femtocell locations is carried out in a dynamic system-level simulator. Such an analysis shows the positive impact of increasing cell overlapping in traffic sharing in LTE.

1.1 Previous work

The antenna placement problem (APP) can be formulated as a discrete optimization problem, where the design variables are the (discrete) base station coordinates and the objective function may be any combination of different overall network performance indicators. For computational reasons, this combinatorial optimization problem is often solved by heuristic approaches. Previous contributions can be classified by the scenario under analysis, the

design criteria for the site location, and the algorithm used to solve the optimization problem.

A first group of references try to find the best site locations in outdoor scenarios. Anderson et al. [15] use simulated annealing to solve the base station location problem in a TDMA/FDMA microcell environment, based on SINR and pathloss indicators. In [16], WCDMA site selection is formulated as an integer linear programming problem, which is solved by tabu search. In [17], the APP is formulated so as to find the minimum number of antennas for a desired coverage level. In [18], several genetic algorithms are proposed for the APP to maximize coverage in Global System for Mobile communication (GSM) while still satisfying a minimum SINR requirement. In [20] and [21], a performance sensitivity analysis is carried out to investigate the impact of site location and antenna tilt angles on the pole capacity in a WCDMA network with uneven traffic distribution. In [19], two randomized greedy procedures and a tabu search algorithm are proposed to solve the APP in order to jointly optimize installation costs, signal quality, and traffic coverage in WCDMA.

A second group of references apply the previous methods to indoor scenarios. In some of them, the APP is formulated to minimize pathloss (or maximize coverage) and later solved by a general-purpose optimization algorithm (e.g., genetic algorithm [22], direct search method [23], simulated annealing [31], or heuristic algorithm [32]). Similarly to [17], [24] proposes a binary integer programming approach to find the minimum number of APs guaranteeing a minimum SINR in the scenario. In [25], a heuristic method is proposed to place APs in a WCDMA indoor scenario with constraints on uplink (UL) and downlink (DL) SINR performance. All recent studies focus on SINR optimization by different methods (e.g., brute force enumeration in WCDMA [33] and LTE [34], particle swarm in WCDMA [28], and reduction approximation in WCDMA [29]).

In [35], a method for femtocell base station placement is proposed to minimize transmit power of mobile users. Alternatively, [36,37] propose methods to find the best Wi-Fi AP placement for optimal localization of mobile users in indoor environments.

1.2 Contribution of this work

In most of the abovementioned references, the focus has been on the computational efficiency of the method used to find the optimal locations of base stations. However, the properties of the site location plan resulting from the optimization process have not been analyzed in detail. Thus, no basic rules have been proposed to build near-optimal solutions without the need for the optimization process in real scenarios. Moreover, to the authors' knowledge, no study has evaluated the impact of femtocell positions on

the performance of automatic traffic sharing algorithms in a heterogeneous LTE network.

The main contributions of this work are a) the definition of a network performance indicator to quantify cell overlapping, easy to measure and interpret, from which to estimate *a priori* the effectiveness of traffic sharing in LTE femtocell scenarios, b) the identification of some basic rules for placing femtocells in a building to maximize cell overlapping, or some other network performance indicator (e.g., coverage or connection quality), and c) a performance comparison of different femtocell placement strategies with classical traffic sharing schemes in a heterogeneous LTE office scenario with congestion problems due to uneven traffic distribution. Results prove the value of the proposed overlapping indicator and femtocell location technique, since the femtocell layout designed for maximizing that indicator boosts femtocell traffic sharing capability and, as a consequence, network performance, even for slightly uneven spatial traffic distributions. Also importantly, the analysis presented here explains why traffic sharing schemes modifying both transmit power and HO margins outperform those that only change HO margins.

The rest of the paper is organized as follows. Section 2 formulates the different design criteria that can be used for placing femtocells. Section 3 presents a preliminary analysis showing the properties of femtocell location plans constructed by solving the APP with different design criteria in an office building. Section 4 outlines several classical traffic sharing schemes proposed in the literature. Section 5 presents a comprehensive performance analysis of the traffic sharing schemes introduced in Section 4 with the femtocell locations plans designed in Section 3. Finally, conclusions are presented in Section 6.

2 Formulation of design criteria for placing femtocells

In this work, four design criteria are used to select femtocells positions in the network planning stage. A first criterion is based on pathloss, as proposed in [22,23,31,32]. Two other criteria are based on SINR statistics, taken from [24,25,28,29,33,34]. A fourth new criterion based on cell overlapping is proposed in this paper.

2.1 Minimum average pathloss

The average pathloss, \overline{PL} , is used as a measure of network coverage obtained by a femtocell location plan. Such an indicator is calculated by averaging the minimum pathloss provided by the serving femtocell in each point of the scenario, as

$$\overline{PL} = \text{Avg}_j \left(\min_i (PL(i,j)) \right), \quad (1)$$

where $PL(i,j)$ is the pathloss (in dB) from femtocell i to point j in the scenario, which depends on femtocell positions and propagation environment.

2.2 Maximum worst connection quality

The tenth percentile of the overall DL SINR distribution is used as a measure of network connection quality problems with a femtocell location plan. Assuming that all cells have the same transmit power and system bandwidth, and noise floor is negligible, the DL SINR for each point j in the scenario (in dB) can be approximated as:

$$\text{SINR}_{DL}(j) \simeq -PL(s(j),j) + 10 \cdot \log \sum_{\forall i \neq s(j)} P_{\text{col}}(s(j),i) \cdot 10^{-\frac{PL(i,j)}{10}}, \quad (2)$$

where $s(j)$ is the serving cell in point j (i.e., that providing minimum pathloss) and $P_{\text{col}}(s(j),i)$ is the probability that cell $s(j)$ collides in the air interface with cell i . In most network planning tools, $P_{\text{col}}(s(j),i)$ is approximated by the estimated physical resource block (PRB) utilization ratio. Once the overall SINR distribution is constructed by aggregating all points in the scenario, the tenth percentile of DL SINR, $L_{10\%,\text{DLSINR}}$, is the SINR value exceeded by 90% of points in the scenario. Such a value depends on femtocell positions, propagation environment, and PRB utilization ratios.

2.3 Maximum average connection quality

The average DL SINR in the scenario, SINR_{DL} , is used as a measure of average network connection quality obtained by a femtocell location plan. Such an indicator is calculated by averaging the DL SINR value in all points in the scenario provided by (2), which is also given by femtocell positions, propagation environment and PRB utilization ratios.

2.4 Maximum cell overlapping

The size of low dominance areas is used to quantify the degree of cell overlapping with a femtocell location plan. A point j is in a low dominance area when:

$$\min_k (PL(k,j) - PL(s(j),j)) \leq \Delta PL \quad \forall k \neq s(j), \quad (3)$$

where $s(j)$ is the serving cell in point j and ΔPL is the low dominance threshold. Thus, cell overlapping is quantified by the low dominance ratio, LDR, defined as the share of points in low dominance areas. In this work, $\Delta PL = 3$ dB. Maximum cell overlapping is obtained by maximizing low dominance ratios, which is only influenced by femtocell positions and propagation conditions.

3 Preliminary analysis of femtocell location strategies

The aim of this section is to build several femtocell location plans in a three-dimensional office scenario with the design criteria described in the previous section. These location plans are used later in Section 5 to check the impact of femtocell locations on traffic sharing algorithms. This preliminary analysis is carried out in a static system-level simulator that computes pathloss, DL SINR, and low dominance ratios in a grid of points. For clarity, the analysis setup is described first, and the results are presented later.

3.1 Analysis setup

Figure 1 shows the layout of the considered heterogeneous scenario, which is the one presented in [14]. The simulation scenario covers an area of 3×2.6 km served by three co-sited trisectorized macrocells (black hexagons). An office building (blue square) is included in one of the macrocells, 500 m away from the macrocellular site. To avoid border effects, a wrap-around technique is used to create multiple replicas of the main scenario (blue hexagons). The building consists of five floors of 50×50 m, each with four symmetrical offices. As a constraint of the femtocell location plan, 1 femtocell is included per office (i.e., 4 femtocells per floor, for a total of 20 femtocells in the building). Figure 2 shows the floor layout. Lines in the figure represent walls. Blue circles reflect femtocell positions for a specific layout used as benchmark (hereafter referred to as original layout, OrL). Other layouts may have different femtocell locations.

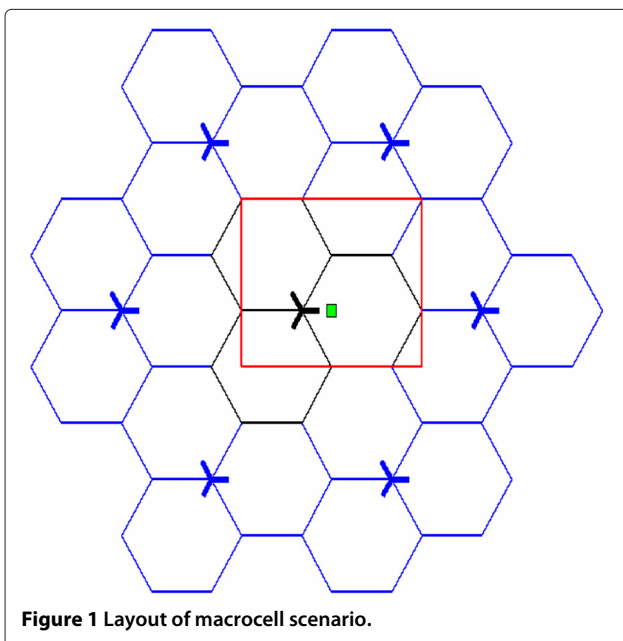


Figure 1 Layout of macrocell scenario.

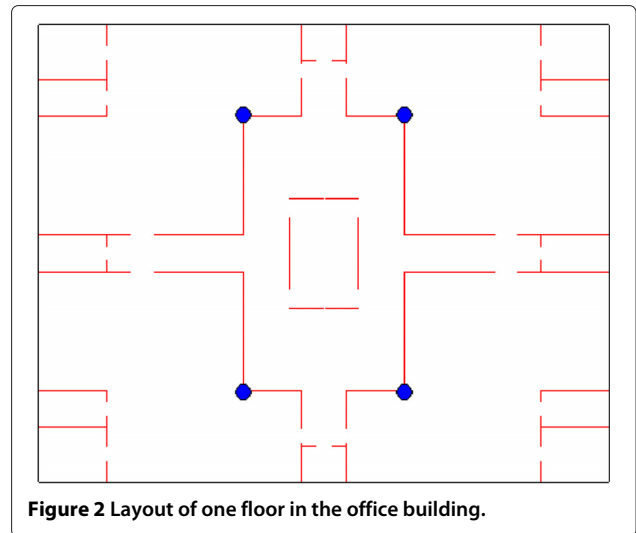


Figure 2 Layout of one floor in the office building.

Propagation models in the scenario are those proposed in the WINNER II project [38]. Different models are used depending on the transmitter and receiver environments, including indoor-indoor, indoor-outdoor, outdoor-indoor, and outdoor-outdoor cases and also depending on their line-of-sight (LOS) or non-LOS conditions. In all cases, PL is calculated as:

$$PL \text{ [dB]} = A \cdot \log(d \text{ [m]}) + B + C \cdot \log(f \text{ [GHz]}/5) + X, \tag{4}$$

where A , B , and C values depend on the propagation environment and X includes the attenuation effect of walls and diffraction. Table 1 details the WINNER II propagation models [38], where h_{BS} and h_{MS} are macrocell and mobile station heights, respectively, FL is the attenuation due to propagation across different floors, n_f is the number of floors between transmitter and receiver, Θ is the angle between the outdoor path and the normal of the external wall, and σ_{SF} is the standard deviation of the log-normal slow-fading attenuation component. For illustrating purposes, Figure 3 (not to scale) shows a colormap with PL values from one of the macrocells to all outdoor points and from one of the femtocells in the first floor to all indoor points in the five floors of the building.

Since the aim is to derive some basic rules to locate femtocells, slow fading is disabled in this preliminary analysis to ensure that optimal femtocell layouts only depend on the scenario geometry and not on the specific realization of slow fading.

A uniform spatial user distribution is considered. To compute SINR values, it is assumed that all cells are fully loaded, so that the PRB utilization factor is 100% (i.e., $P_{col}(i, j) = 1 \forall i, j$).

In the above-described scenario, five femtocell location plans are evaluated. Four of them are obtained by solving

Table 1 Propagation model parameters [38]

Scenario		Path loss		σ_{SF}
Ind2ind	A1	LOS	$A = 18.7, B = 46.8, C = 20$	6
		NLOS	$A = 20, B = 46.4, C = 20$ $X = 5n_w$ (wall att.) $FL = 17 + 4(n_f - 1)$ (floor att.)	
Ind2out	A2		$PL = PL_b(d_{in} + d_{out}) + PL_{tw} + PL_{in}(d_{in})$ $PL_b \rightarrow A = 22.7, B = 41, C = 20$ $PL_{tw} = 14 + 15(1 - \cos(\theta))$ $PL_{in} = PL_{A1}$	6
Out2out	C2	LOS	$d < d_{BP} \rightarrow A = 26, B = 39, C = 20$ $d > d_{BP} \rightarrow PL = 40 \log(d) + 13.47 + 14 \log(h_{BS} - 1) - 14 \log(h_{MS} - 1) + 6 \log(f_c/5)$	4
		NLOS	$PL = (44 - 6.55 \log(h_{BS})) \log(d) + 34.46 + 5.83 \log(h_{BS}) + 23 \log(f_c/5)$	8
Out2ind	C4		$PL = PL_{C2}(d_{in} + d_{out}) + 17.4 + 0.5d_{in} - 0.8h_{MS}$	8

the APP with the design criteria in Section 2. These are referred to as coverage layout (CL), worst-case SINR layout (WSL), average SINR layout (ASL), and overlapping layout (OvL). A fifth location plan with femtocells located in the inside corner of each office, as shown in Figure 2, is used as a benchmark and hence referred to as OrL.

For computational reasons, the search for an optimal femtocell layout with each criterion is divided into three stages. In a first stage, the search problem is limited to one floor. Thus, the positions of the four femtocells in

a floor that maximize the selected criterion is obtained, assuming that no other femtocell exists in other floors. To find the optimal positions, a brute force enumeration approach is used. For computational efficiency, the area of each office is divided into a grid of 13 points, as shown in Figure 4. The finite number of positions might reflect constraints due to wiring, maintenance, and security concerns [39]. This configuration results in 13 candidate positions for each femtocell due to the constraint of one femtocell per office. Exhaustive search requires computing the performance of 28,561 (i.e., $13 \times 13 \times 13 \times 13$) possible femtocell layouts. For each femtocell plan, four overall performance indicators (i.e., \overline{PL} , $L_{10\%,DL}$, \overline{SINR}_{DL} , LDR) are calculated by aggregating all potential user positions, defined by a regular grid of 50×50 points covering the four offices (offices 1 to 4) with 1 m resolution.

In a second stage, the analysis is extended to a second floor. For this purpose, a new floor with four new offices (denoted as offices 5 to 8) is added on top of the original floor. The aims are a) to analyze the impact of femtocells in an upper (lower) floor on femtocells in a lower (upper) floor and, more importantly, b) to check if the addition of femtocells in other floors modifies the optimal location pattern for a single floor. The inclusion of four new femtocells introduces 4 new degrees of freedom, each with 13 new possible positions (i.e., the number of possible combinations is now 13^8). To reduce the computational load, the size of the solution space is reduced by fixing the position of femtocells in one of the floors (offices 1 to 4) to their positions in the optimal solution for one floor, so that only femtocells in offices 5 to 8 can move. Thus, only 13^4 combinations have to be tested in this stage. The price to be paid is the inability to find the optimal solution for two

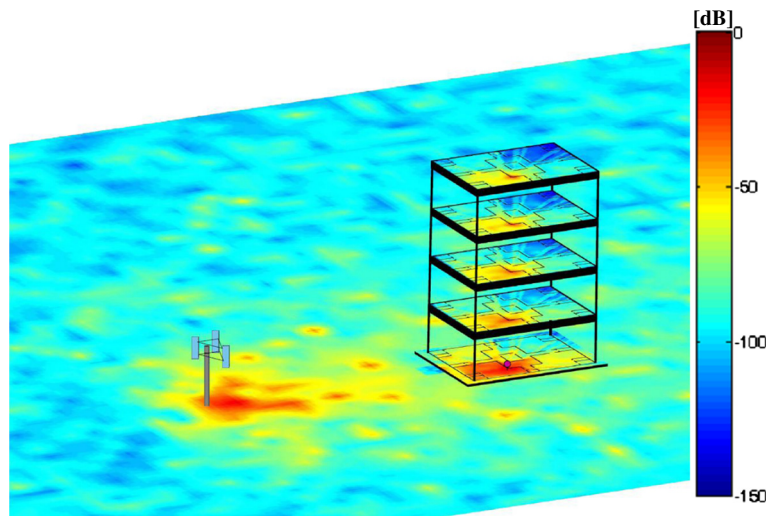
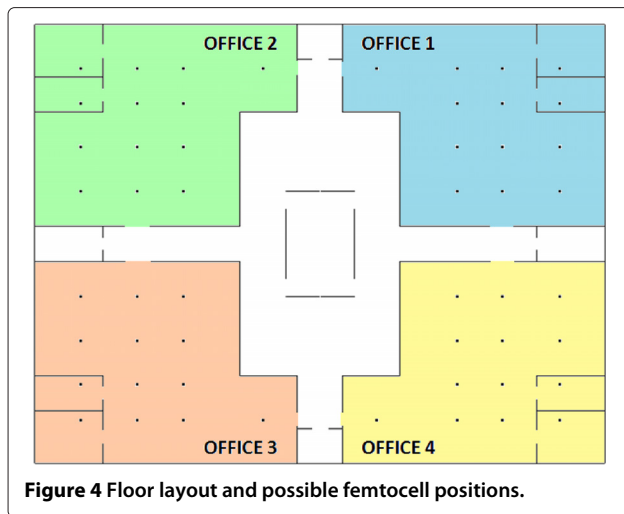


Figure 3 Outdoor-outdoor and indoor-indoor path losses.



floors. Throughout this stage, the area where performance indicators are calculated covers the two floors (offices 1 to 8).

At this stage, some basic rules will have been defined to design femtocell layouts in simplified one-floor or two-floor scenarios. From this knowledge, in a third stage, the complete femtocell layout for the global scenario (i.e., five floors, four femtocells per floor) is constructed for each design criteria. The performance of each femtocell plan is evaluated considering all potential user positions in the building. It should be pointed out that, unlike the solutions obtained in one-floor or two-floor scenarios, the complete layouts are not the result of an optimization process. Thus, there is no guarantee that the complete solutions lead to the optimum of the selected design criteria. Note that finding the best position for $5 \times 4 = 20$ femtocells requires evaluating the performance of 13^{20} location plans by computing the four performance indicators in all user locations in the building. Obviously, this is a very time-consuming task. Moreover, it must also be taken

into account for the design of the complete femtocell layout that the final solution should not favor any particular office at the expense of others, even if this improves the selected overall performance metric. Such a fairness constraint, added to the design criteria, is used to discard unfair solutions. *A posteriori*, it is confirmed that, in spite of these two issues, the proposed solutions ensure a very good value of the selected design criteria, which is enough for the assessment of traffic sharing strategies.

3.2 Analysis results

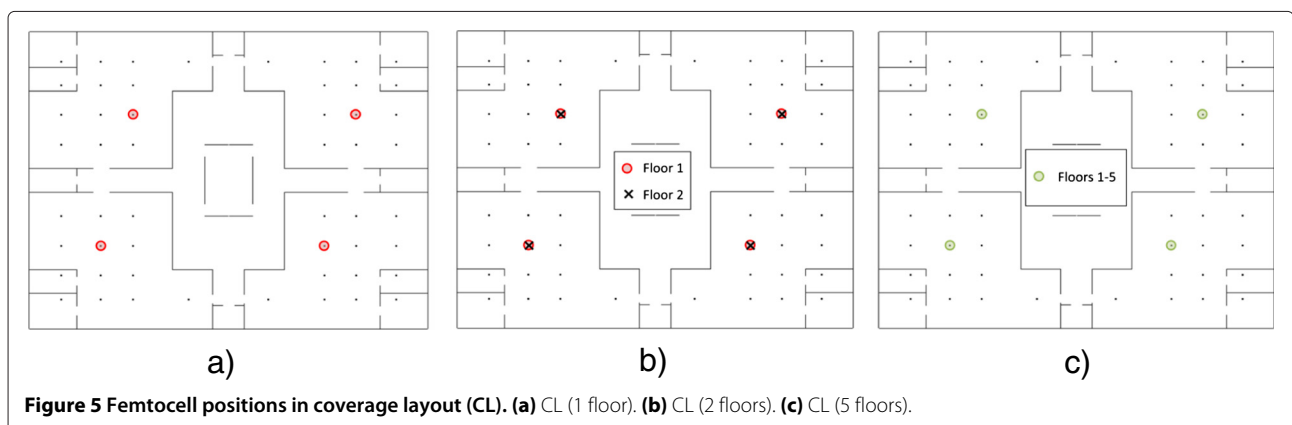
Firstly, the structure of femtocell location plans obtained with different design criteria is analyzed qualitatively. Then, the performance of the different plans is compared quantitatively.

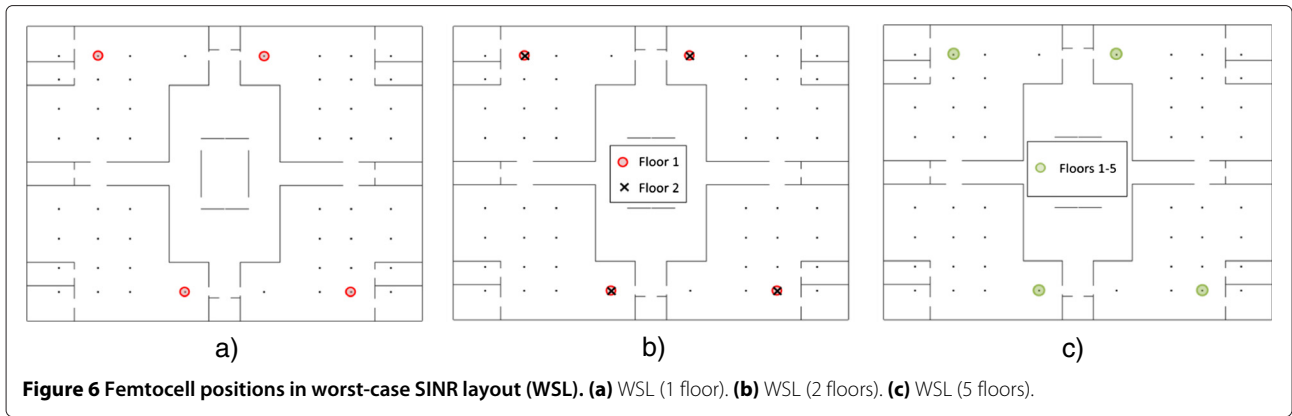
3.2.1 Coverage layout (CL)

Figure 5a,b,c shows the femtocell layout that minimizes \overline{PL} (i.e., CL) for one, two, and five floors, respectively. Figure 5a illustrates CL for one floor. It is shown that, to minimize average pathloss in a single floor, femtocell APs (red circles) have to be placed in a centered position in each office. Figure 5b shows CL when two floors are analyzed. It is observed that the solution that minimizes pathloss for two floors is exactly the same as that for one floor. This result is logical, since pathloss only depends on the serving cell, which hardly ever changes with new floors due to the large attenuation between floors (i.e., $FL = 17$ dB in Table 1 [38]). Figure 5c presents CL for five floors, designed for minimizing \overline{PL} in the whole scenario, where femtocells are placed at the center of every office in all floors of the building.

3.2.2 Worst-case SINR layout (WSL)

Figure 6a,b,c show the femtocell layout that maximizes $L_{10\%,DL} \text{ SINR}$ (i.e., WSL) for one, two, and five floors. Figure 6a illustrates WSL for one floor. It is observed that an asymmetrical layout must be selected to increase the tenth percentile of SINR in one floor. A deeper analysis



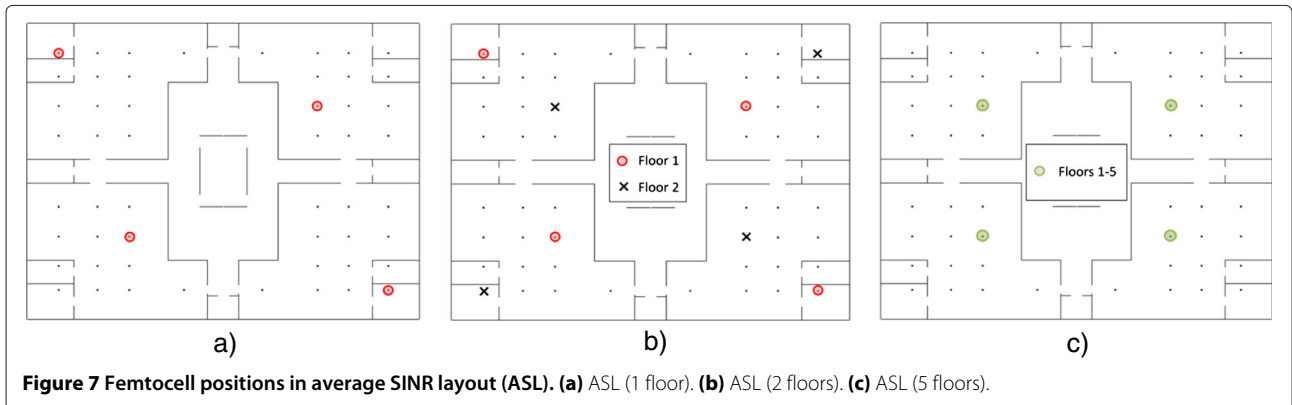


shows that this asymmetry ensures that, in areas where signal level from the serving femtocells is low (i.e., common areas and corridors), one femtocell is clearly dominant against the others. This is achieved by enforcing that at these critical points, pathloss from any cell other than the serving cell includes attenuation of, at least, two walls, so that interference is significantly attenuated. Both conditions ensure that cell-edge SINR improves. Figure 6b presents WSL for two floors. It is observed that the solution that maximizes $L_{10\%,DL} \text{ SINR}$ for two floors is exactly the same as that for one floor. It is concluded that femtocells in different floors must be aligned vertically to maximize $L_{10\%,DL} \text{ SINR}$. Aligned positions ensure a constant (very large) difference between signal levels received from cells in different floors, equal to the attenuation between floors (i.e., $FL = 17 \text{ dB}$ in Table 1). Figure 6c presents WSL for five floors, designed for maximizing $L_{10\%,DL} \text{ SINR}$ in the whole building, where femtocells are located asymmetrically so that corridors and common areas are covered by a single femtocell and aligned vertically along the five floors.

3.2.3 Average SINR layout (ASL)

Figure 7a,b,c shows the femtocell layout maximizing $\overline{\text{SINR}}_{DL}$ (i.e., ASL) for one, two, and five floors. A quick

inspection of Figure 7a reveals that, when one floor is analyzed, ASL follows the same principles as those for WSL. By hiding two femtocells in small rooms in opposite corners of the building, it is enforced that for a large share of points in the scenario, the path to any cell other than the serving cell crosses, at least, two walls. Thus, average SINR is improved. Figure 7b illustrates ASL when two floors are analyzed. It is observed that, when a new floor is added, femtocells must be staggered vertically to maximize $\overline{\text{SINR}}_{DL}$. Not shown is the fact that both ASL solutions (one and two floors) improve the overall average SINR by deteriorating the average SINR in some offices (i.e., those where femtocells are hidden in small rooms). As this is not acceptable, a new ASL solution is constructed for the whole building. Figure 7c shows the ASL plan for five floors, which has been designed with the following heuristic criteria: 1) femtocells cannot be located inside small rooms in the office, 2) femtocells are located trying to maximize PL to the serving area of other femtocells (by reducing interference level from other femtocells, it is expected that average SINR increases), and 3) femtocell positions from ASL for one and two floors are reutilized, given that they fulfill criteria 1) and 2). *A posteriori*, it is checked that ASL in Figure 7c presents the largest average



SINR for the whole building when compared to the other four proposed layouts (i.e., OrL, CL, WSL, and OvL).

3.2.4 Overlapping layout (OvL)

Figure 8a,b,c shows the femtocell layout maximizing LDR (i.e., OvL) for one, two, and five floors. From Figure 8a, it is inferred that in OvL for one floor, LDR is increased by locating femtocells together in pairs as far as possible from the central common areas. Thus, it is ensured that both femtocells in each pair provide nearly the same signal level in common areas, resulting in a larger area of low dominance. Figure 8b shows OvL for two floors. It is observed that as in ASL, femtocell positions differ significantly between floors. Femtocells in the second floor end up in the small office in the corner of the building so as to reduce signal levels in its office and thus create regions of low dominance. This solution would increase LDR at the expense of deteriorating connection quality in floors where femtocells are hidden, similarly to what happened in ASL. Thus, the OvL solution for five floors, shown in Figure 8c, does not include femtocells in the corners of the building. On the contrary, femtocells are located symmetrically within a floor with respect to corridors, maximizing overlapping in one floor, and alternated in odd and even floors, maximizing overlapping areas between different floors. Again, it is checked *a posteriori* that the OvL solution for five floors has the largest LDR of all layouts.

3.2.5 Overall performance comparison

To validate the above-described design rules, Table 2 compares the performance of all solutions built with different criteria for five floors against that of the reference solution (i.e., OrL), shown in Figure 2. For each layout, \overline{PL} , $L_{10\%,DL} SINR$, \overline{SINR}_{DL} , and LDR are presented. As expected, CL, WSL, ASL, and OvL achieve the best value of the indicator they were designed for (highlighted in bold). The OrL shows intermediate values for all indicators and can thus be considered as a compromise solution between coverage and radio link efficiency. Specifically,

Table 2 Propagation performance of OrL, C, WSL, ASL, and CvL solutions

Scenario	\overline{PL} [dB]	$L_{10\%,DL} SINR$ [dB]	\overline{SINR}_{DL} [dB]	LDR [%]
OrL	60.50	0.92	7.98	14.41
CL	59.29	0.83	8.99	11.95
WSL	62.52	2.70	8.99	6.48
ASL	59.39	0.74	9.01	13.03
OvL	60.84	-1.25	7.27	21.23

the tenth percentile and average SINR values in OrL are only 1.7 and 1 dB less than the best values obtained by WSL and ASL, respectively. Furthermore, it is observed that OvL achieves the largest cell overlapping at the expense of deteriorating all other indicators. Specifically, LDR in OvL is 50% higher than that in OrL, which is the second best layout in terms of overlapping. However, \overline{PL} , $L_{10\%,DL} SINR$ and \overline{SINR}_{DL} in OvL are 1.5, 4, and 1.7 dB worse than the best values achieved by CL, WSL, and ASL, respectively.

Once a femtocell layout that maximizes each criterion is available, the aim is to find the one with the largest traffic sharing capability.

4 Traffic sharing techniques

The following paragraphs describe several traffic sharing approaches proposed in the literature for indoor environments [14]. The aim of traffic sharing is to solve localized and persistent congestion problems by equalizing call blocking ratio (CBR) throughout the network. CBR is the ratio of the number of connection attempts blocked due to lack of resources to the total number of connection attempts. Traffic sharing is performed by modifying cell service areas, which can be achieved by tuning two femtocell parameters: HO margin, $Margin_{HO}$, which is defined on per-adjacency basis and femtocell transmit power, P_{TX} , which is defined on a per-cell basis.

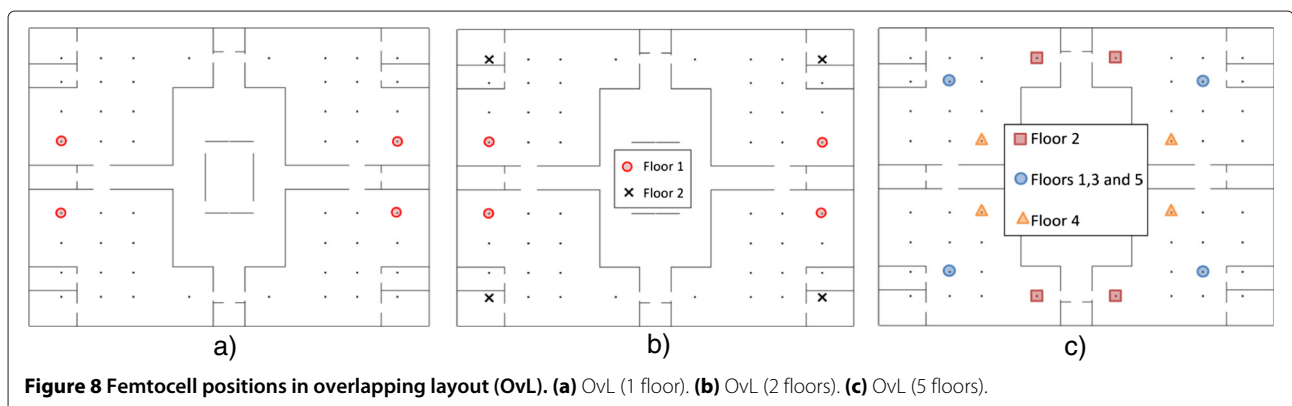


Figure 8 Femtocell positions in overlapping layout (OvL). (a) OvL (1 floor). (b) OvL (2 floors). (c) OvL (5 floors).

Automatic adjustment (or self-tuning) of network parameters is often implemented as an iterative process, where parameters are gradually changed with a certain period (referred to as optimization loop) based on network performance statistics. Parameter changes continue until the difference in CBR between adjacent cells is negligible. Since the goal is to solve persistent congestion problems, and not temporary fluctuations of traffic demand, input statistics are collected for a sufficiently long time period (e.g., 1 h). The traffic sharing approaches considered in this work are as follows [14]:

- *Margin traffic sharing (MTS)*: HO margins are modified on a per-adjacency basis (i.e., $\text{MarginHO}(i, j)$) with the aim of balancing CBR between adjacent cells i and j . Changes of the same amplitude and opposite signs are performed in margins of both directions of the adjacency to maintain cell overlapping, i.e.:

$$\text{MarginHO}(i, j) + \text{MarginHO}(j, i) = \text{Hyst}, \quad (5)$$

where Hyst is a constant defining the hysteresis value. In this work, $\text{Hyst} = 6$ dB and the default value of $\text{MarginHO}(i, j)$ is 3 dB. Margins are restricted to a limited interval between -7 and 13 dB to avoid connection quality problems [14].

- *Power traffic sharing (PTS)*: Femtocell transmit power is modified on a per-cell basis (i.e., $P_{\text{TX}}(i)$) with the aim of balancing CBR of cell i compared to the average CBR of its neighbors. A femtocell decreases (increases) power if its CBR is larger (smaller) than that of its neighbors. It is assumed that both data and pilot power are jointly tuned. Thus, traffic steering is effective not only for connected users but also for idle users, since it has an impact on both cell reselection and HO processes.
- *Combined traffic sharing (CTS)*: CTS modifies both P_{TX} and MarginHO parameters. By alternating both changes, the limits inherent to individual approaches (i.e., MTS and PTS) are overcome. First, MarginHO settings are modified while P_{TX} settings remain unchanged. Only when all $\text{MarginHO}(i, j)$ values in cell i have reached their limits, $P_{\text{TX}}(i)$ is modified. As a result, traffic sharing in cell i is achieved with minimal deviation of transmit power from default values (and, hence, minimal impact on network coverage) [14].

5 Analysis of traffic sharing schemes for different femtocell location plans

In Section 3, multiple femtocell layouts for a building in an LTE heterogeneous network have been presented.

Each layout is designed to maximize some coverage, interference, or overlapping indicator. In this section, those layouts are tested in a dynamic system-level simulator implementing a highly loaded and extremely unbalanced indoor scenario, where traffic sharing must be carried out. The aim of the analysis is to find the layout with the best network performance after traffic sharing. For clarity, simulation setup is first discussed and results are presented later.

5.1 Simulation setup

The heterogeneous network scenario described in Section 3 has been included in a dynamic LTE system-level simulator [40]. Table 3 shows the main simulation features and parameters. A regular spatial user distribution is considered in macrocells, whereas user distribution inside the building may be either regular or irregular. In the latter case, severe congestion problems occur in some femtocells without traffic sharing. A random way point

Table 3 Simulation parameters

Simulation parameters and features		
Time resolution	100 ms	
Propagation models	Indoor-indoor	Winner II A1
	Indoor-outdoor	Winner II A2
	Outdoor-outdoor	Winner II C2
	Outdoor-indoor	Winner II C4
BS model	EIRP	$BS_{\text{femto}} = 13$ dBm $BS_{\text{macro}} = 43$ dBm
	Directivity	femto: omnidirectional macro: tri-sectorial
	Access	macro/femto: open access
MS model	Noise figure	9 dB
	Noise spectral density	-174 dBm/Hz
Traffic model	Arrival process	Poisson (avg. 0.42 calls / (user × hour))
	Call duration	exponential (avg. 180 s)
	Mobility model	Outdoor
Indoor		Random waypoint
Service model	Voice over IP	16 kbps
RRM model	6 PRBs (1.4 MHz)	
	Cell reselection	C1-C2
	Access control	Directed retry
	Handover	Power budget
	Scheduler:	Time: round-robin Frequency: best channel

mobility model is used for indoor users. Changes of floor are not considered. For simplicity, voice-over-IP service is simulated.

Two experiments are carried out. In a first experiment, all femtocell layouts (OrL, CL, WSL, ASL, and OvL) are tested with a uniform user spatial distribution. The aim is to evaluate the performance of femtocell layouts in an interference-limited indoor scenario under uniform traffic distribution. For this purpose, user population is configured so that average PRB utilization ratio is 50% in all cells. Due to the uniform user distribution, there is no point in sharing traffic between femtocells, and only one optimization loop is simulated.

In a second experiment, an extremely uneven user spatial distribution is configured in the scenario. The distribution is designed to model a worst-case scenario, where: a) most users are located in one office, causing severe congestion problems in the corresponding femtocell (and hence the need for sharing traffic with other cells) and b) the remaining users are concentrated on adjacent femtocells, either on the same floor or in the upper/lower floor, which makes traffic sharing more difficult and increases interference levels. Specifically, 87% of users start their connections in one office of the middle floor, 12% in other offices of the middle floor and the other 1% are distributed in other floors. With this uneven user spatial distribution, PRB utilization varies from less than 1% (femtocells of floors 1 and 5) up to 85% (femtocell in office 3, floor 3) with the default network parameter settings. Traffic sharing is therefore needed to reduce congestion in overloaded femtocells. To check the impact of femtocell positions on traffic sharing, 25 optimization loops of MTS are simulated with each femtocell layout.

Having identified in previous experiments that cell overlapping improves traffic sharing, in a third experiment, it is shown that cell overlapping of an existing femtocell layout can be modified in the operational stage by changing network parameters. Note that an already existing layout might have not been designed with the overlapping criterion, and thus, any traffic sharing technique increasing cell overlapping is of interest. MTS does not modify cell overlapping, and it is therefore limited by the quality of the femtocell location plan. In contrast, PTS dynamically changes femtocell transmit power, which has an impact on the overlapping between femtocells and, consequently, on traffic sharing. For this purpose, 50 loops of CTS (i.e., combination of MTS and PTS) are simulated in the reference layout (i.e., OrL, which is not designed for maximum overlapping) with the uneven user distribution.

Two key performance indicators are used to assess femtocell layouts and traffic sharing schemes: a) CBR, as a measure of network capacity and b) outage ratio, OR, defined as the ratio of unserved connection time due to temporary lack of resources or bad SINR of users, as a

measure of network connection quality. For ease of analysis, CBR and OR are aggregated into a single figure of merit, the unsatisfied user ratio, UUR, computed as $UUR = CBR + OR \cdot (1 - CBR)$. All these indicators are collected in each optimization loop, consisting of 1 h of network time. Also for simplicity, dropped calls are disabled in the simulation.

5.2 Simulation results

Table 4 shows the values of CBR, OR, and UUR obtained by different femtocell location plans with uniform traffic distribution. In the last column, it is observed that the lowest values of UUR are obtained for the reference solution (OrL) and the coverage-based solution (CL). As observed in the second column, this is mainly due to their lowest OR. WSL and ASL perform slightly worse in these network conditions. Finally, OvL is the worst layout in terms of CBR, OR, and UUR. This is due to the fact that increasing cell overlapping leads to a higher inter-cell interference level, which degrades connection quality and increases radio resource utilization due to adaptive modulation and coding schemes in LTE. It can thus be concluded that, when user distribution is uniform, a femtocell layout designed for maximizing cell overlapping is worse than layouts designed for better coverage or SINR.

Network performance changes dramatically with uneven traffic distribution. Table 5 presents UUR values obtained by MTS for the different femtocell layouts. Note that all traffic sharing schemes are sequential processes, starting with an initial network configuration, which is later modified until equilibrium is reached. Table 5 details the UUR after the first simulation loop (i.e., before changing HO margins), $UUR^{(1)}$, and UUR at the end of the traffic sharing process (i.e., after 25 optimization loops), $UUR^{(25)}$. For clarity, a third column shows the relative UUR improvement, UUR_{impr} , defined as $UUR_{impr} = \frac{UUR^{(1)} - UUR^{(25)}}{UUR^{(1)}}$.

By comparing the values in the second column, which show UUR with the default HO margin settings, it is observed that, unlike the first experiment, OvL achieves the best network performance even when traffic sharing has not started. Specifically, $UUR^{(1)} = 14\%$ for OvL,

Table 4 Network performance with uniform traffic distribution

Scenario	CBR [%]	OR [%]	UUR [%]
OrL	0.08	0.41	0.49
CL (minimum pathloss)	0.02	0.49	0.51
WSL (maximum 10th percentile of SINR)	0.13	0.67	0.79
ASL (maximum SINR average)	0.04	0.68	0.72
OvL (maximum overlapping)	0.44	2.32	2.74

Table 5 Performance of margin traffic sharing with uneven traffic distribution

Scenario	UUR ⁽¹⁾ [%]	UUR ⁽²⁵⁾ [%]	UUR _{impr} [%]
OrL	17.20	12.30	28.48
CL (minimum pathloss)	15.55	10.55	32.14
WSL (maximum 10th-percentile of SINR)	18.18	12.86	29.27
ASL (maximum SINR average)	17.68	12.45	29.54
OvL (maximum overlapping)	14.00	5.67	59.49

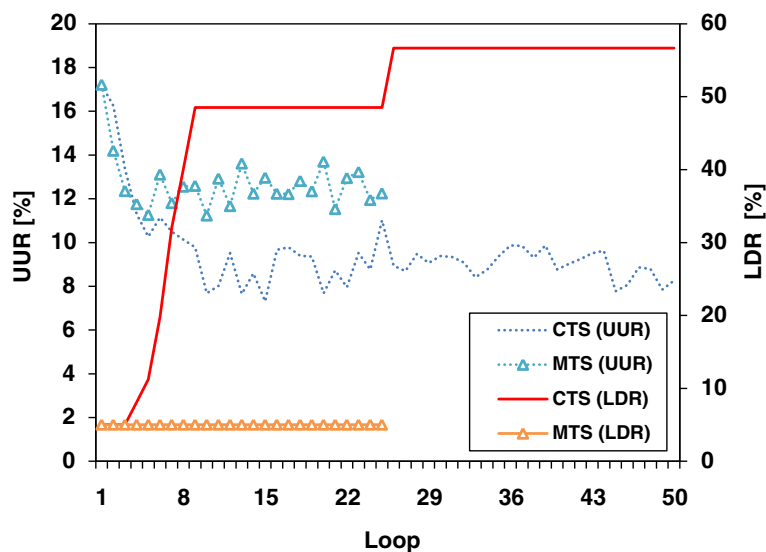
whereas $UUR^{(1)} = 15.55\%$ for the best of the other methods (i.e., OrL). More importantly, MTS provides the best results for OvL at the end of the tuning process. Specifically, $UUR^{(25)} = 5.67\%$ for OvL, which is nearly half that achieved by MTS in the best of other layouts (i.e., 10.55% for CL). From these results, it can be concluded that, even if OvL performs slightly worse than the other layouts for a uniform traffic distribution, OvL performs significantly better than the other layouts with uneven traffic distribution.

Results presented so far are obtained for an extremely uneven spatial user distribution. An important issue is whether OvL also outperforms the other techniques for less uneven distributions. A simulation campaign has been run for the same scenario and different spatial user distributions according to a non-uniformity parameter, x . For $x = 0$, the spatial user distribution is the regular one used in the first experiment. For $x = 1$, the spatial user distribution is the extreme one simulated in the second experiment. For other values of x , the number of users in each office is a weighted average between the values in

the regular and extremely irregular distributions. Results (not shown here for brevity) prove that OvL is the best technique for $x \geq 0.2$. It can thus be concluded that OvL has the best results even for slightly uneven distributions.

Having identified that cell overlapping is a desirable property in indoor scenarios with congestion problems, it makes sense to investigate other traffic sharing strategies that increase cell overlapping in an already existing femtocell layout. Again, recall that MTS does not change cell overlapping. In contrast, PTS (and CTS) modifies coverage areas by changing P_{TX} values, which has an impact on cell overlapping that could overcome the limitations of an existing femtocell layout. At the same time, PTS changes cell service areas, sending users from congested cells (whose power is increased) to empty cells (whose power is decreased).

To check the capability of PTS to improve traffic sharing by increasing cell overlapping, CTS is simulated in the reference layout (OrL, not designed for maximum overlapping) with the same uneven traffic distribution. Figure 9 compares the evolution of UUR and LDR across iterations with MTS and CTS for the most loaded femtocell in the scenario (i.e., office 3 in the third floor). For comparison purposes, the evolution of UUR in 25 loops of MTS is superimposed. It is observed that MTS stagnates after the fifth loop, when $UUR^{(5)} = 12\%$. A closer analysis (not included here) shows that MTS stops after all users in overlapping areas have been sent to neighbor cells. With MTS, overlapping areas are small, which can be inferred from its low value of LDR (i.e., $LDR = 5\%$ for MTS in all iterations). This is the reason why MTS has limited traffic sharing capability with the reference layout. In contrast, CTS (i.e., the combination of MTS and PTS)

**Figure 9** UUR and LDR for MTS and CTS techniques.

decreases UUR from 17.2% up to 8%. In CTS, changes of femtocell transmit power performed by PTS (loops 5, 6, 7, and 27) cause that LDR increases in this scenario. Specifically, LDR increases from 5% up to 57% with CTS. Thus, PTS creates new overlapping areas in the reference layout where traffic can be shared between neighbor cells. Thus, the ability of MTS to steer traffic is enhanced by PTS in CTS. A deeper analysis proves that abrupt changes in LDR coincide with changes in P_{TX} .

6 Conclusions

In this paper, a new strategy for placing femtocell access points based on a cell overlapping indicator has been proposed for LTE heterogeneous scenarios. The aim of the strategy is to make the most of traffic sharing schemes used to deal with irregular user distribution. It has been shown here that this can be achieved by increasing the percentage of areas with low dominance of the serving cell.

A preliminary analysis has been carried out to find some basic rules to locate femtocells in an office building so as to maximize different network performance criteria, amongst which is the proposed novel criterion based on cell overlapping. With these rules, a set of femtocell location plans have been constructed. Then, a comprehensive performance analysis of classical traffic sharing algorithms with the different location plans has been performed in a dynamic system-level simulator.

Results have shown that, with uniform traffic, location plans designed for maximum low dominance ratios have worse call blocking and outage ratios. Specifically, a four-fold increase in both key performance indicators has been observed in the simulated scenario with uniform traffic when compared to the worse values obtained with coverage-based and interference-based femtocell location plans. However, with uneven spatial user distribution, the location plan designed to increase low dominance ratios obtains the best results before and after executing the traffic sharing process. In the simulated extreme scenario, the unsatisfied user ratio obtained by handover-based traffic sharing with the overlapping-based location plan is 40% smaller than that of the best of the other location plans.

Likewise, it has been shown that increasing low dominance ratios in an existing femtocell layout by tuning femtocell power settings helps to improve the performance of handover-based traffic sharing schemes. This has been used to explain the benefit of jointly tuning HO margins and femtocell transmit power for sharing traffic in LTE indoor scenarios.

The proposed femtocell location approach is conceived for office scenarios where traffic is unevenly distributed and femtocells can share traffic, although it is also applicable to more general scenarios. Since the novel design

criterion relies on signal level predictions, it must be used together with propagation prediction models and optimization engines in network planning tools.

Abbreviations

AP: access point; APP: antenna placement problem; ASL: average SINR layout; BS: base station; CBR: call blocking ratio; CL: coverage layout; CTS: combined traffic sharing; DL: downLink; EIRP: effective isotropic radiated power; FDMA: frequency division multiple access; FL: floor losses; GSM: global system for mobile communication; HO: handOver; IP: internet protocol; LDR: low dominance ratio; LOS: line-of-sight; LTE: long-term evolution; MS: mobile station; MTS: margin traffic sharing; NLOS: non line-of-sight; OFDMA: orthogonal frequency division multiple access; OR: outage ratio; OrL: original layout; OvL: overlapping layout; PL: pathloss; PRB: physical resource block; PTS: power traffic sharing; RRM: radio resource management; SINR: signal to interference plus noise ratio; SON: self-organizing network; TDMA: time division multiple access; UL: upLink; UUR: unsatisfied user ratio; WCDMA: wideband code division multiple access; WSL: worst-case SINR layout.

Competing interests

The authors declare that they have no competing interests.

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