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Traffic Sharing Techniques in Enterprise LTE Femtocells*

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Traffic Sharing Techniques in Enterprise LTE Femtocells

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***Abstract*—In cellular networks, traffic demand is unevenly distributed both in time and space. This paper investigates the problem of re-distributing traffic demand between LTE femtocells in an enterprise scenario. A performance comparison of several traffic sharing techniques is carried out based on simulations. For this purpose, an efficient dynamic system-level LTE simulator is built. Results show that the combination of directed retry and load sharing by tuning handover margins and transmit power is an effective means to solve localized congestion problems.**

***Index Terms*—Mobile network, enterprise LTE femtocells, traffic balancing, optimization, handover margins, transmission power.**

I. Introduction

In cellular networks, traffic demand is unevenly distributed both in time and space. Thus, it is common that some cells suffer from severe congestion problems, whereas its adjacent cells are underutilized. Although a proper network dimensioning avoids this problem, changes in user trends might cause that the network design become ineffective. In the long term, this problem can be solved by network re-planning strategies, such as antenna sectorization or the addition of new sites. However, in the short term, advanced Radio Resource Management (RRM) algorithms and network parameter tuning are the only means to solve this problem and make the most of the existing infrastructure.

Femtocells are a promising solution for the provision of high indoor coverage and capacity, which might help to reduce congestion problems in overloaded macrocells [1]. Femtocells are low-power base stations using cellular technology in licensed spectrum providing coverage and capacity indoors over internet-grade backhaul under operator management.

In parallel, the interest in Self-Organizing Networks (SON) has grown in the last years with the advent of the first automatic optimization suites. A key topic in the SON literature is load balancing between cells [2][3][4]. Load balancing aims to relieve traffic congestion in the network by sharing traffic between network elements. Thus, load balancing solves congestion problems caused by localized events (e.g., football matches, shopping centres). For this purpose, the service area of cells can be modified so that the traffic demand is more evenly distributed among cells. Such an effect can be obtained by different techniques. A first group of techniques modifies physical parameters in the base station, such as transmitted power [5] or antenna radiation pattern [6]. As these actions affect coverage, they must be handled with care. Alternatively, a second group changes parameters in RRM processes, such as Cell (Re)Selection (CR) and HandOver (HO) [7]. Since tuning CR parameters is only effective during call set-up, the optimization of HO parameters, such as the HO margins, is the preferred option [2][3][4][7].

In the literature, traffic sharing has been studied in different scenarios (e.g., macrocell, hierarchical macro-micro) and technologies (e.g., GSM, UMTS, LTE). In [8], a load balancing scheme based on transmission power control is proposed for residential femtocells in 3GPP systems. However, to the authors' knowledge, no thorough comparison of the performance of classical traffic sharing techniques in femtocells has been published. Likewise, no previous work has investigated the traffic sharing problem in enterprise femtocells, which are expected to have several important differences with residential scenarios, namely, a) enterprise scenarios have usually a three-dimension structure, where neighbor cells can be located everywhere around the server cell; b) a different, and probably more intense, mobility pattern; c) a higher probability of user concentrations both in space (e.g. cantine) and time (e.g. coffee break, meeting end), and, d) open access instead of closed access (i.e., limited) in residential scenarios. Open access femtocells refer to those cells allowing any, or a very high number, user to transmit. In this scenarios, traffic problems could arise. Enterprise or airport scenarios can be classified into this cathegory. All these characteristics point to traffic sharing as a good strategy to make the most of existing femtocell network resources.

This paper evaluates the impact of different traffic

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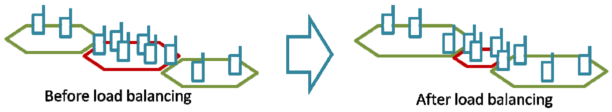

Fig. 1. Cell service area modifications

sharing strategies on the performance of enterprise LTE femtocells. The considered schemes comprise both classical online approaches, based on RRM algorithms (e.g., directed retry, load sharing), and offline approaches, based on the network management system. Those algorithms that change cell service areas modify the transmit power and/or the handover margin of femtocells. The assessment of methods is based on a dynamic system-level LTE simulator. The main contributions of this work are: a) an efficient simulation tool for entreprise LTE femtocell scenarios, and b) a performance comparison of several classical traffic sharing techniques in enterprise femtocell scenarios.

The rest of the paper is organized as follows. Section II formulates the traffic sharing problem in enterprise femtocells. Section III outlines several solution techniques based on automatic network parameter tuning. Section IV presents first the simulation tool used in the experiments and the initial setup, and, then, the results of the performance comparison. Finally, Section V summarizes the main conclusions of the study.

II. Problem Formulation

In enterprise scenarios, localized traffic demand cause severe congestion problems. Even if femtocells in this scenario have similar resources, the uneven user distribution will lead to different blocking figures. Traffic sharing techniques aim to balance the traffic among different femtocells in the hope that this will decrease the overall blocking ratio, thus increasing the total carried traffic in the network.

The modification of cell service areas might reduce or increase the traffic carried by a cell. The cell service (or dominance) area is the area where any user is served by that cell. The narrowing of a cell service area decreases carried traffic, but it necessary implies the widening of neighbor cells, figure 1. Changes of service area are often implemented through RRM parameter modifications. In this work, two such parameters are adjusted: handover margins and cell transmission power.

Handover margins, $Margin_{PBGT}$, define by how much the signal level received from a neighbor cell must exceed that of the serving cell to trigger a handover. In the case of Power Budget (PBGT) HO, a handover is triggered when

$$RxLEV(j) - RxLEV(i) \geq Margin_{PBGT}(i,j) \ , \quad (1)$$

where $RxLEV(i)$ and $RxLEV(j)$ are the received signal level from the serving cell i and neighbor cell j, respectively. As observed in (1), $Margin_{PBGT}$ is defined on an adjacency basis. Therefore, adjusting this parameter in a single adjacency only has an influence on that particular adjacency.

Cell service areas can also be modified by adjusting transmission power. A higher/lower transmission power in a base station is directly linked to higher/lower received levels in that cell. Unlike $Margin_{PBGT}$, transmission power is defined on a cell basis, so all neighbors are equally affected by changes in i-cell power.

In addition to the HO procedure, traffic sharing can also be performed by Admission Control (AC). One such schemes is Directed Retry (DR), where a blocked call in the cell where the call was initiated can be re-directed to a neighbor cell with free resources. A minimum signal level threshold, $DR_{threshold}$, must be exceeded to be able to retry in a neighbor cell, as

$$RxLEV(j) \geq DR_{threshold}(j) \ . \quad (2)$$

By re-allocating users in surrounding cells, DR shares the traffic during the admission stage. Note that DR is not considered here a handover, since it occurs during the AC stage.

Regardless of the tuned parameter, an important consideration is the frequency of parameter changes. A high frequency (i.e., in the order of seconds) is desired when RRM must react to sudden changes in traffic demand, due to, e.g., start/end of a meeting in a room. In contrast, low frequencies (i.e., in the order of hours or even days) are oriented to the network re-configuration due to some persistent unbalance between cells in the scenario (e.g., working point or new premises). Present contribution studies network optimization in persistent traffic unbalanced scenarios, so slow strategies will be tested in this paper.

III. Algorithm Outline

In this section, different traffic strategies are outlined. The main differences between them are: a) the RRM parameter to modify, and d) which input network indicators are used for output parameter modifications. Seven strategies are defined:

1) Benchmark. The initial scenario situation. Neither parameter modifications nor DR are allowed.
2) DR. In order to see DR influence over the network performance, $DR_{threshold}$ parameter is swept. A suitable $DR_{threshold}$ value is finally selected and applied over the subsequent techniques.
3) MLB (Margin Load Balance). $Margin_{PBGT}$ parameter is modified through a Fuzzy Logic Controller (FLC) structure with cell load indicators.

4) MTS (Margin Traffic Sharing). $Margin_{PBGT}$ parameter is modified through a FLC with network cell blocking indicators.
5) MTS&C (MTS Constrained). Similar to MTS technique but parameter modifications are constrained to a limited interval.
6) PIC&MTS (Power Interference Control & MTS). Additionally to the MTS scheme, a PIC machine modifies cell power transmission when ping-pong effect is appreciated through the parameter

$$PP(i) = \frac{\sum_j N_{QualHO}(j,i) \cdot (Margin_{PBGT}(i,j) < 0)}{\sum_j N_{PBGT\_HO}(i,j)}, \quad (3)$$

where $N_{QualHO}(j,i)$ is the number of handovers from j to i for quality reasons, and $N_{PBGT\_HO}(i,j)$ is the number of handovers from i to j through the PBGT handover algorithm, (1). The condition of a negative value for $Margin_{PBGT}$ parameter forces to count only those handovers going to a destination cell with a poorer level than in the origin cell.
7) PTS&MTS (Power Traffic Sharing & MTS). MTS modification structure plus a power transmission modification structure with network blocking and ping-pong, (3), input indicators.

To sum up, the aim of Mxx techniques is to adjust HO margins so that cell service areas are changed to equalize load (MLB) or traffic (MTS). Pxx techniques modify cell transmit power (jointly for data and pilot carriers) with the aim of decreasing interference (PIC) or sharing traffic (PTS).

Controller for parameter tuning

Techniques 3)-8) have been implemented by an FLC. As shown in Figure 2, FLC inputs are key performance indicators (e.g., cell blocking ratios) and FLC outputs are adjusted parameters (e.g., steps in HO margins). Specifically, $LR_{diff}(i,j)$ defines the difference of load ratio between i and j cells and $\Delta Margin_{PBGT}(i,j)$ (dB) is the margin modification for such adjacency (i,j). An FLC consists of fuzzyfication, inference engine and defuzzyfication modules. Briefly, input indicators are labeled with some qualitative terms (e.g., 'low', 'high', 'medium') according to their numerical value and some membership functions defining the strength with which those values can be linked to the qualifier. Figure 3 presents the membership function for MLB strategy. VN, N, Z, P and VP stand for Very Negative, Negative, Zero, Positive and Very Positive. The inference engine applies common-sense rules in the form of IF-THEN statements (e.g., IF load in cell 1 is 'high' AND load in cell 2 is 'low', THEN 'highly' decrease $Margin_{PBGT}(1,2)$). Finally, the defuzzyfication module translates back the

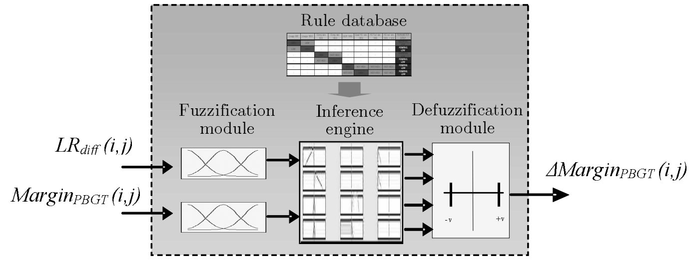

Fig. 2. Structure of fuzzy controller for tuning margins

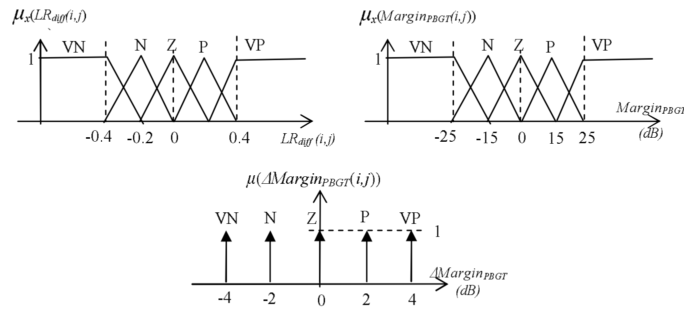

Fig. 3. Membership functions in MLB FLC

resulting qualitative action to a numerical value showing the increment or decrement of current parameter value.

MTS FLC has a similar configuration to MLB, but blocking ratio difference between cells, BR_{diff} (instead of LR_{diff}) is used as an input. Thus, MTS FLC tries to balance average traffic instead of load (note that two cells with a load close to 100% can experience completely different blocking ratios). As a result of the tuning process, a very negative value of $Margin_{PBGT}(i,j)$ could be reached. Such a negative value might hand over terminals to neighbor cells j where $RxLev(j) \ll RxLev(i)$, as shown in (1). This might cause that the SINR ratio could become significantly worse for that terminal (note that the margin is a rough approximation of the minimum SIR obtained by the terminal in the new cell). MTS&C limits margin values, forcing that $Margin_{PBGT}(i,j) \in [-6.9 \quad 9.9]$ dB, trying to avoid severe connection quality problems after a HO. A HO margin modification in adjacency (i,j) (e.g., +2 dB) automatically modifies the (j,i) value in the way round (i.e., -2 dB), keeping a 3 dB hysteresis (i.e.,$Margin_{PBGT}(i,j)$+$Margin_{PBGT}(j,i) = 3dB$) to avoid ping-pong effect.

PIC uses a similar FLC structure, with the ping-pong indicator, $PP(i)$, as input parameters, and $\Delta P_{TX}(i)$ as output parameter. The controller only performs changes when $PP(i)$ has a non-negligible value and margins are negative. Figure 4 depicts membership functions in the PIC FLC, which are different from those in MLB.

Finally, PTS modifies the transmit power, $P_{TX}(i)$,

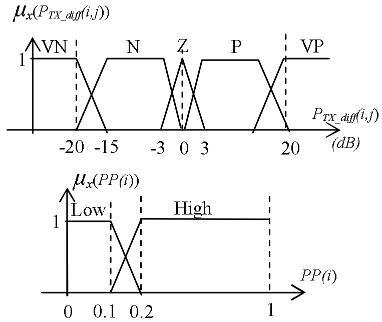

Fig. 4. Membership functions in xPLB FLCs

having $BCR_{diff}(i,j)$ (blocking ratio difference between cells i and j) and $PP(i)$ as FLC inputs. Note that $P_{TX}(i)$ is referred to both data and pilot transmission power.

IV. Results

Simulation tool

In order to perform and assess different traffic sharing techniques, an LTE dynamic system-level simulator has been developed, [9]. The main loop, including the more relevant tasks (i.e., mobility management, propagation/interference calculation, radio resource control), performs N iterations, each representing 100 ms of network time. After N iterations, network performance indicators are analyzed by the controller and a new network parameter setting is configured to improve the network behavior. By implementing an outer loop, it is possible to check changes in the network behavior after each optimization step and thus evaluate the efficacy of each optimization action. Such a tuning process is referred to as 'optimization loop'. Table I shows the most important properties of the simulator.

The propagation models in the simulator are based on those proposed in the WINNER II project, [10]. Such models consider different environments, comprising indoor-indoor, indoor-outdoor, outdoor-indoor and outdoor-outdoor. All models share the same function structure including important characteristics as line of sight/non line of sight, wall attenuation and diffraction. To speed up simulations, propagation losses are computed beforehand. Such a functionality computes a matrix showing the propagation loss from each BS to a certain location. The losses values in the matrix are calculated adding three components: a) path loss, PL, b) antenna directivity, and c) slow fading, SF. For computational and memory efficiency, each model has a different resolution depending on the correlation distance. In this work, the spatial resolution is 50 m for C2 and 1 m for A1, A2 and C4.

Fast-fading is also pre-computed with a similar methodology. In this case, the grid resolution must be higher in order to appreciate the fast fading (15 cm). The large size of the scenario and the higher resolution avoids the need for building a grid covering the whole scenario. Instead, a grid of 48 m x 48 m has been implemented.

TABLE I
Simulator parameters

Time resolution	100 ms	
BS model	PIRE	$BS_{femto} = 13dBm$ $BSmacro = 43dBm$
	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	Calls	Poisson, 0.22 calls/(user*hour)
	Duration	Exponential (Av.=180 sec)
	Spatial distribution	Uniform
Mobility model	Outdoor	3 km/h, random direction & wrap-around
	Indoor	Random waypoint
Service model	VOice over IP	16 kbps
RRM model	6 PRBs (1.4 MHZ)	
	Cell Reselection	
	Access control	
	Handover:	PBGT, Qual, Umbrella
	Scheduler: RRBC	Time: Round-Robin Freq.: Best Channel

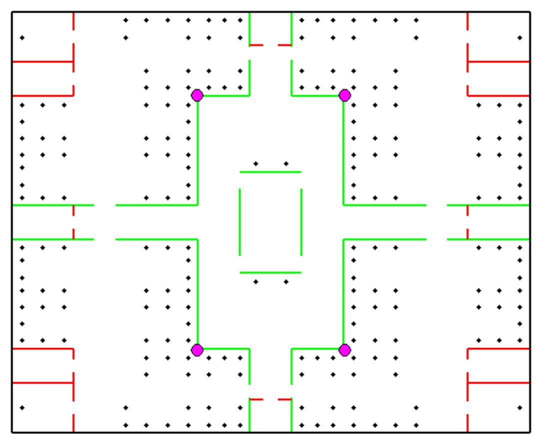

Fig. 5. A floor diagram

The enterprise femtocell network under study is inside a larger environment of 3x2.6 km, comprising a single macrocellular site consisting of three tri-sectorized cells. The wrap-around technique has been implemented to avoid unwanted border. Inside the coverage area of one macrocell, an office building with dimensions 50m x 50m has been placed. The number of floors inside the building is configurable (5 floors in this work). The floor plan is the same for all floors. Figure 5 shows the layout of one of the floors. Magenta circles represent the femtocells position, the lines are the walls (different colors represent their thickness), and black diamonds are possible terminal positions

A random way point mobility model is implemented in the simulator for indoor users. In such a model, users move between certain points of interest (e.g., workstation, doors, restrooms,... figure 5) with a certain probability. When users are moving, their speed is 1 km/h. Changes of floor are not considered. As in the previous sub-sections, a matrix with trajectories is pre-computed and later used during the simulation.

Initial simulation set-up

The initial configuration sets a log-normal spatial traffic distribution, where the central floor is highly loaded and has a large Call Blocking Ratio (CBR), while upper and lower flower floors are underutilized. In this scenario, all sharing techniques from section III are tested. Such optimization techniques have been tested along 30 optimization loops, representing 1 hour of network time each. Statistics are collected after each loop, so the evolution of network performance during the optimization process is observed through 30 steps. The benchmark situation is the absence of traffic sharing feature, simulated by one single optimization loop of 1 hour. Technique 2 sweeps $DR_{threshold}$ by 3-dB steps in each loop, ranging from -20 dB to 107 dB. In the other methods, FLC processes network statistics in the loops and configures new values for the parameter to be modified.

Several network performance indicators are collected for comparison purposes: a) CBR, as a measure of blocked traffic, and, thus, carried traffic, b) unscheduled users (i.e., users experiencing an extremely low SINR causing that the scheduler in the RRM module cannot assign them any radio resource) as a measure of connection quality; and c) a handover ratio defined by the average number of HOs and DRs per carried call, as a measure of signaling load. Unsatisfied users indicator is the addition of blocked and unscheduled users. To simplify the analysis, dropped calls have been disabled in the simulations.

Simulation Results

Figure 6 shows the evolution of unsatisfied users for the different traffic sharing techniques. The first value in the DR curve (left upper) is the benchmark situation, showing a very large overall ratio of unsatisfied users (36%) and a very unbalanced network, where cells 13 and 14 (central floor) are 100% loaded, not shown in the picture, and the highest blocking, 61%, is experienced. At the same time, lower and upper floors have free resources (i.e., 2% of cell load and 0% blocking ratio in some cases).

A first experiment aims to find the best value for the DR minimum signal-level threshold, which is later combined with more sophisticated congestion relief algorithms. Figure 6 shows the network evolution. As

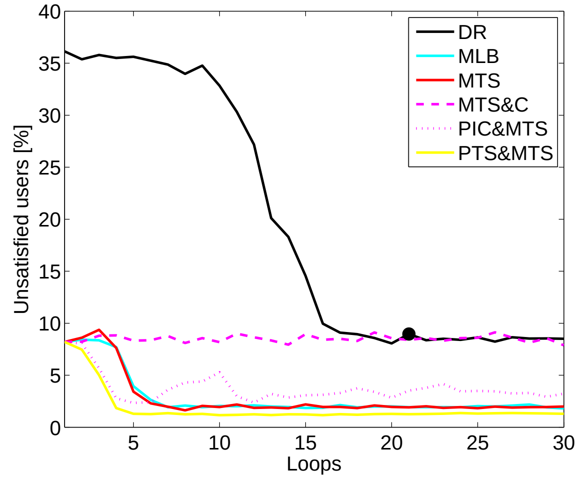

Fig. 6. Evolution of unsatisfied users

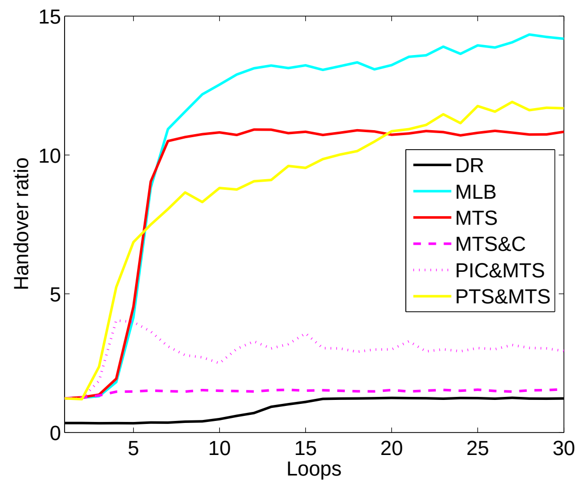

Fig. 7. Handover ratio evolution

$DR_{threshold}$ decreases, redirection of users is favored so that the number of unsatisfied users also decreases roughly by 27%. Around -80 dBm (loop 21), the indicators reach a stable situation and further variations of $DR_{threshold}$ do not have a significant impact on network performance. Hence, $DR_{threshold}$= -80 dBm in further techniques (black point in figure 6), becoming the starting configuration point for later techniques. Such a low $DR_{threshold}$ value increases the number of redirected users and increases network signalling load. Figure 7 depicts the handover ratio for the different techniques. It is observed that DR technique increases network signalling from 0.35% to 1.25%.

MTS and MTS&C only differ in the constrained or unconstrained characteristic. It is observed in Fig. 6 that, as a result of constraints, MTS&C does not achieve any blocking reduction. This is a clear indication of the limitation on $Margin_{PBGT}$, causing that traffic sharing is not achieved in this scenario, where high attenuation between cells exists due to walls and floors. Unconstrained MTS greatly decreases the number of unsatisfied users, but at the expense of increasing signalling load significantly, as shown in Figures 6 and 7.

Not shown in the figures is the fact that MTS reaches very negative values for $Margin_{PBGT}$. As a result, users are handed over to neighbor cells with very low SINR values due to interference with the original cell. These users are handed over back to the original cell by a QualHO shortly after connecting the neighbor cell. Such an effect will cause lots of ping-pong HOs, generating a very high signalling load, which can be seen in MTS line in figure 7) (11 handovers per call). PIC&MTS techniques try to mitigate such interference problems by reducing transmit power in the original cell. By doing so, PIC&MTS decrease the handover ratio (11 in MTS against 3 in PIC&MTS) at the expense of slightly increasing the number of unsatisfied users compared to MTS (2% and 3.2% ,respectively), as shown in figures 6 and 7.

Finally, PTS&MTS technique performs traffic sharing through the modification of two parameters, $P_{TX}(i)$ and $Margin_{PBGT}(i, j)$. Obviously, this method reaches the best reduction of unsatisfied users, from 8.2% to 1.2%, but with a large increase in network signalling, from 1.2 to 12 HOs/call.

To evaluate the trade-off between unsatisfied users and signaling within the techniques, figure 8 shows the values of the the ratio of unsatisfied users and handover ratio in all the methods along the optimization process. Such a representation aims to identify the Pareto front in the traffic sharing process, which should lie on the lower left part of the figure. Pure traffic sharing techniques (MTS, MTS&C) reduce blocking at the cost of increasing network signaling significantly (which is not an input indicator in their FLCs). In contrast, interference reduction techniques, such as PIC&MTS, obtain limited traffic blocking reduction, but with a lower signaling load. From the figure, it can be concluded that the solution of PIC&MTS is a non-dominated solution (i.e., there is no other configuration of network parameter settings improving both blocking and signaling in the network).

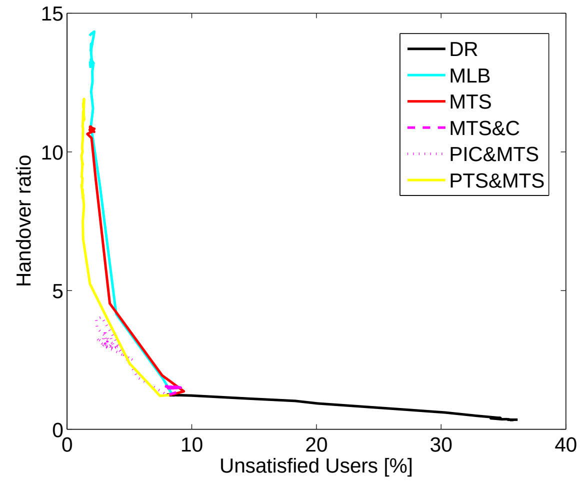

Fig. 8. Evolution of unsatisfied user and mobility ratio

V. Conclusions

In this work, several approaches based on adjusting network parameters have been proposed for traffic sharing in a 3-D enterprise femtocell scenario. Such modifications have been implemented by fuzzy logic controllers modifying transmission power and handover margins. Unbalance in traffic distribution has a persistent nature, so a slow parameter modification strategy for traffic sharing has been tested. The proposed schemes have been tested in an LTE dynamic system-level simulator.

Simulation results have shown that pure traffic sharing strategies reduce call blocking ratios to some extent at the expense of deteriorating connection quality in the network and increasing network signaling due to ping-pong effect. A major source of problems is the interference caused by the congested cell. Having identified interference between femtocells as an important limitation for traffic sharing, slow interference control has been performed by jointly modifying handover margins and transmission power.

Current work aims to find more sophisticated traffic sharing techniques for this challenging scenario, amongst which are inter-cell interference coordination schemes.

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