Fuzzy Logic Controllers for Traffic Sharing in Enterprise LTE Femtocells

J. M. Ruiz-Avilés, S. Luna-Ramírez, M. Toril, F. Ruiz
University of Málaga, Communications Engineering Dept., Málaga, Spain
Email: {jmruiz,sluna,mtoril,ferv}@ic.uma.es

***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 Long-Term Evolution (LTE) femtocells in an enterprise scenario. Several traffic sharing algorithms based on automatic tuning of femtocell parameters are considered. The proposed algorithms are implemented by fuzzy logic controllers. Performance assessment is carried out in a dynamic system-level simulator. Results show that tuning handover margins and transmit power can be an effective means to solve localized congestion problems in these scenarios.**

***Index Terms*—Femtocell, traffic sharing, optimization, handover margin, transmit power.**

I. Introduction

In the last years, femtocells have become 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 cell load balancing [2][3][4]. For this purpose, the service area of cells can be modified so that 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 transmit power or antenna radiation pattern. As these actions might affect coverage, they must be handled with care. Alternatively, a second group changes parameters in Radio Resource Management (RRM) processes, such as Cell Reselection (CR) and HandOver (HO) [5]. 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][5].

Although international projects such as BeFemto have developed advanced RRM algorithms for femtocells, which will be extremely valuable for manufacturers, few studies have investigated traffic sharing in enterprise femtocells with legacy equipment, which is of interest to network operators. Such scenarios have several important differences with residential scenarios often covered in the literature, namely that: a) enterprise scenarios have usually a three-dimensional 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 concentration both in space (e.g., canteen) and time (e.g., coffee break, meeting end); and d) open access instead of closed (i.e., limited) access. All these properties suggest that traffic management problems in these scenarios could arise and traffic sharing is a means to make the most of existing femtocell resources.

This paper evaluates the impact of different traffic sharing strategies on the performance of enterprise Long-Term Evolution (LTE) femtocells. The proposed algorithms change femtocell service areas by modifying their transmit power or handover margins by fuzzy logic controllers. Assessment is based on a dynamic system-level LTE simulator. This work is the sequel of [6]. While [6] was focused on the design of the simulation tool, this work is focused on the analysis of traffic sharing techniques. The main contribution of this work is a thorough analysis of classical traffic sharing techniques in an extreme, albeit realistic, enterprise femtocell scenario. The rest of the paper is organized as follows. Section II formulates the traffic sharing problem in enterprise femtocells. Section III outlines several traffic sharing algorithms based on automatic femtocell parameter tuning. Section IV presents simulation results and Section V summarizes the main conclusions.

II. Problem Formulation

In enterprise scenarios, localized traffic demand causes severe congestion problems. Traffic sharing aims to balance the traffic among femtocells in the hope that this will decrease the overall blocking ratio, thus increasing the total carried traffic in the network. For this purpose, cell service areas are modified to reduce or increase traffic served by a cell. Narrowing a cell service area decreases carried traffic in that cell at the expense of enlarging the service area (and, hence, increasing the traffic) of surrounding cells. Such changes can be achieved by tuning HO margins and/or cell transmit power.

The HO margin parameter from cell i to cell j, $Margin_{PBGT}(i,j)$, defines by how much the signal level received from a neighbor cell j must exceed that of the serving cell i to trigger a HO from i to j. In the case of Power Budget (PBGT) HO, a HO is triggered when

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

This work has been funded by the Spanish Ministry of Science and Innovation (grant TEC2009-13413) and Junta de Andalucía (grant TIC-4052).

978-1-4673-0990-5/12/$31.00 ©2012 IEEE

where $RxLEV(i)$ and $RxLEV(j)$ are the pilot received signal level from the serving cell i and neighbor cell j in dBm, respectively, and $Margin_{PBGT}(i,j)$ is the margin in dBs. As observed in (1), margins are defined on an adjacency basis. Therefore, adjusting this parameter in a single adjacency only has an influence on that particular adjacency. To avoid instabilities, a hysteresis region is maintained by synchronizing changes in both directions of the adjacency (i.e., if the HO margin from cell i to j is increased by +X dB, the margin from j to i is reduced by -X dB).

The service area of a cell can also be modified by adjusting its cell transmission power, $P_{tx}(i)$. A higher/lower transmit power in a base station is directly linked to higher/lower received signal levels from that cell, which has an influence on cell dominance areas. Unlike margins, transmit power is defined on a cell basis, so that all neighbors are equally affected by changes in the transmit power of a cell. For simplicity, it is assumed here that both data and pilot power are jointly tuned.

The modification of cell service areas not only has an impact on traffic distribution, but also on network connection quality. As a result of traffic re-distribution, a user might not be served by the cell providing the minimum path loss, which might impair user connection quality. Although adaptive modulation and coding in LTE partly alleviates this, the link adaptation capability is limited. Therefore, traffic sharing must be performed with care to keep Quality-of-Service in a satisfactory level. This is important in indoor scenarios where large fading can occur due to shadowing and multi-path reflections.

III. Algorithm Outline

In this section, three traffic sharing algorithms are described. All are based on tuning femtocell parameters, differing in the specific parameter modified and the aim of the tuning process. The underlying techniques were already conceived for 2G macrocellular scenarios, although they have been adapted here to an office LTE scenario. In all methods, parameter tuning is carried out periodically by controllers, whose inputs are network measurements and outputs are femtocell parameters. For stability, parameter tuning is performed slowly based on performance statistics. Thus, the algorithms aim to solve persistent congestion problems due to uneven spatial traffic distribution (and not to temporary traffic fluctuations).

A. Logic behind the controllers

The considered strategies are:

1) *Margin Traffic Sharing* (MTS). In this method, PBGT HO margins are tuned on a per-adjacency basis to balance the call blocking ratio in the source and target cell of the adjacency. To maintain cell overlapping, changes of the same amplitude and opposite sign are performed in the margins of both directions of the adjacency.
2) *MTS constrained* (MTS+C). Similar to MTS, but margin changes are restricted to a limited interval so as to avoid connection quality problems.
3) *Power Traffic Sharing* (PTS). Cell transmit power is tuned on a per-cell basis to balance the call blocking ratio of a source cell against the average call blocking ratio of its adjacencies. Cells start at their maximum transmit power and decrease (increase) their power if their call blocking ratio is larger (smaller) than that of their neighbors. Transmit power is limited to the maximum default value. No synchronization between neighbors is considered and, consequently, cell overlapping can be affected.

B. Implementation of controllers

Tuning methods have been implemented by Fuzzy Logic Controllers (FLCs) to simplify the design of the controllers. FLCs [7] are expert systems described by means of ”IF-THEN” rules. Due to the fact that FLCs are described in linguistic terms, it is easier to integrate previous knowledge into the controller. Thus, FLCs are especially suited when the experience of an operator is already available (as it is the case for telecommunication networks). The main difference of FLCs with conventional rule-based controllers is their capability to trigger several rules simultaneously, which achieves smoother control actions.

For instance, Fig. 1 shows the FLC of the MTS strategy. In this work, an incremental FLC structure is adopted, where the output of the controller is the suggested parameter change to be added to the previous parameter value (and not the final value itself). As observed in the figure, FLC inputs are key performance indicators (e.g., cell call blocking ratios) and current parameter values (e.g., HO margins), while FLC outputs are changes in femtocell parameters (e.g., HO margin step). Specifically, $BR_{diff}(i,j)$ is the call blocking rate difference between cells i and j, $Margin_{PBGT}(i,j)$ is the current margin value, and $\Delta Margin_{PBGT}(i,j)$ is the margin step (in dB) for such an adjacency (i,j). Not shown in the figure is the fact that the output of the controller is rounded to the nearest integer.

Inside, the FLC consists of three stages: fuzzification, inference and defuzzification. In the *fuzzification* stage, each value of the input variables is mapped into adjectives (e.g., high, low, ...) by a membership function, which defines the degree with which each value of the input can be associated to the adjective. Figure 2 (a) presents the membership functions for MTS. VN, N, Z, P and VP stand for very negative, negative, zero, positive and very positive, respectively. Note that, unlike conventional controllers, in an FLC, a single input value can be associated to different adjectives with different degrees (and, hence, the term fuzzy). In this work, the number of input membership functions has been selected large enough to classify performance indicators precisely, while keeping them small enough to reduce the set of control rules. For simplicity, the selected input membership functions are trapezoidal, triangular or constant. In the *inference* stage, a set of 'IF-THEN' rules defines the mapping of inputs to output. Figure 2 (b) shows the rule database for MTS. For instance, rule 1 reads as ”IF BR_{diff} is very positive THEN $\Delta Margin_{PBGT}(i,j)$ is very negative”. Roughly, the

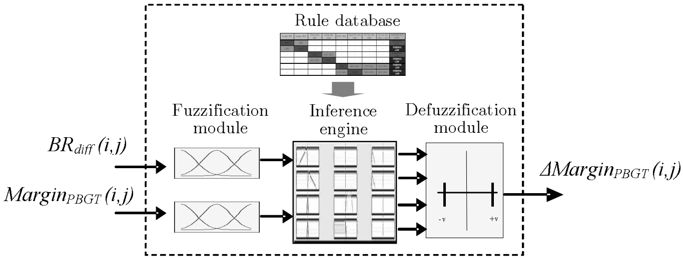
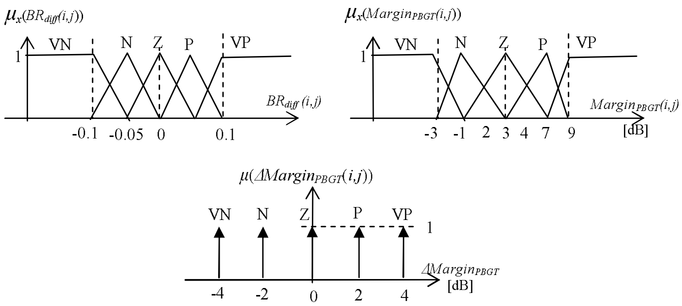


Fig. 1. Structure of fuzzy controller for tuning margins.

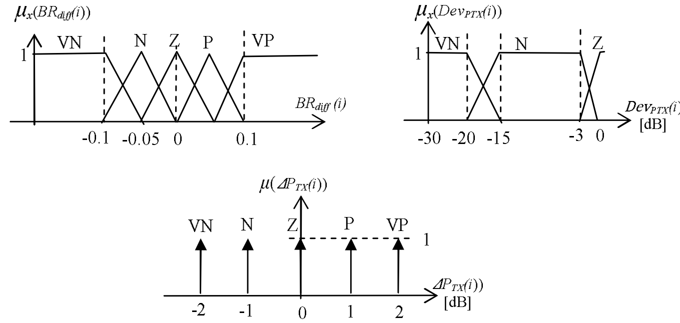


(a) Membership functions

$BR_{diff}(i,j)$	$Margin_{PBGT}(i,j)$	$\Delta Margin_{PBGT}(i,j)$
VP	-	VN
P	-	N
N	-	P
VN	-	VP
Z	VN	P
Z	N	P
Z	P	N
Z	VP	N
Z	Z	Z

(b) Rules

Fig. 2. Details of MTS fuzzy logic controller.



(a) Membership functions

$BR_{diff}(i)$	$Dev_{PTX}(i)$	$\Delta P_{TX}(i)$
VP	-	VN
P	-	N
N	N	P
N	VN	P
Z	VN	P
Z	N	P
VN	N	P
VN	VN	VP
Z	-	Z

(b) Rules

Fig. 3. Details of PTS fuzzy logic controller.

more positive (negative) blocking difference, the more positive (negative) margin step. The last four rules implement are slow-return mechanism to restore the default margin value when no blocking is experienced. In the *defuzzification* stage, the output value is obtained from the aggregation of all rules, for which the center-of-gravity method is adopted. For simplicity, all controllers are designed based on the Takagi-Sugeno approach, where output membership functions are constants, as shown in Figure 2 (a). The number of output membership functions has been selected large enough to allow fine parameter control.

As a result of the tuning process, very negative margin values could be reached. Such a negative value might cause that users are handed over to neighbor cells j where $RxLev(j) \ll RxLev(i)$, as deduced from (1). This might cause that the signal-to-noise and interference ratio (SINR) experienced by those users was significantly worse after the HO (note that the margin value is a rough approximation of the minimum SINR obtained by the user in the new cell). To avoid this problem, MTS+C limits margin values by forcing that $Margin_{PBGT}(i,j) > -6.9$ dB. Thus, it is ensured that, after a HO, SINR is never below -6.9 dB (i.e., the threshold below which the scheduler in the base station does not assign radio resources to a connection). Of course, this constraint limits its traffic sharing capability.

As an alternative to modifying HO margins, PTS modifies transmit power to equalize the traffic in a cell with its neighbors. Specifically, the transmit power of cell i, $P_{TX}(i)$, is tuned to reduce the difference in blocking ratio against its neighbors. As an input, PTS FLC has the average blocking ratio difference, $BR_{diff}(i)$, defined as

$$BR_{diff}(i) = BR(i) - \frac{\sum_{j \in N(i)} BR(j)}{|N(i)|} \ , \qquad (2)$$

where $N(i)$ is the set of neighbors of cell i and $|N(i)|$ is the number of neighbors of cell i. The other input is the current deviation from the default (maximum) transmit power value, $Dev_{P_{TX}}^{(l)}(i)$, defined as

$$Dev_{P_{TX}}^{(l)}(i) = P_{TX}^{(l)}(i) - P_{TX}^{(0)}(i) \ , \qquad (3)$$

where superindex denotes time interval, and $P_{TX}^{(l)}(i)$ and $P_{TX}^{(0)}(i)$ are the current and initial (default, maximum) transmit power of cell i, respectively. Figure 3 depicts membership functions and rules for PTS FLC.

It should be pointed out that $P_{TX}(i)$ refers to both data and pilot transmission power. Thus, PTS has an impact not only on HO but also on cell re-selection.

TABLE I
SIMULATION PARAMETERS

Time resolution	100 ms	
Propagation model	indoor-indoor	Winner II A1
	indoor-outdoor	Winner II A2
	outdoor-outdoor	Winner II C2
	outdoor-indoor	Winner II C4
BS model	EIRP	13 (femto) / 43 (macro) dBm
	Directivity	omni (femto) / tri-sector (macro)
	Access	open access (macro/femto)
MS model	Noise figure	9 dB
	Noise density	-174 dBm/Hz
Traffic model	Calls	Poisson (avg. 0.97 calls/s)
	Duration	exponential (avg. 180 sec)
	Spatial distribution	Log-normal
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	C1-C2
	Access control	Directed Retry ($DR_{threshold} = -44$dBm)
	Handover:	PBGT, Qual
	Scheduler: RR-BC	Time: Round-Robin (RR) Freq.: Best Channel (BC)
Simulated network time	1 h (per loop)	

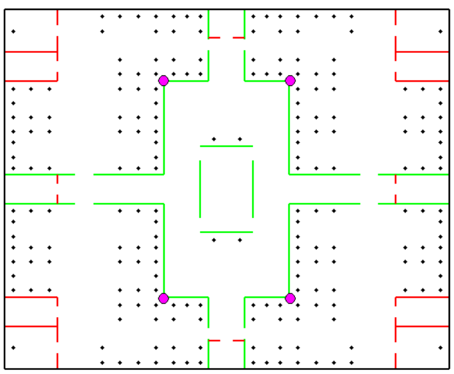


Fig. 4. A floor diagram.

IV. PERFORMANCE ANALYSIS

A. Simulation set-up

A three-dimensional enterprise scenario has been developed in a dynamic LTE system-level simulator [6]. Table I shows the properties of the simulator. The scenario includes an office building with femtocells in a larger scenario of $3 \times 2.6\,\mathrm{km}^2$ comprising a single macrocellular site consisting of 3 tri-sectorized cells. The number of floors inside the building is 3, each comprising 4 femtocells. All adjacencies are considered inside the building. The floor plan and femtocell positions are the same in all floors. Fig. 4 shows the layout of one of the floors. Dark circles represent femtocell positions, lines are walls, and small diamonds are working stations. The considered propagation models are those of the Winner II project. A random waypoint mobility model is implemented for indoor users. Changes of floor are not considered. For more details, the reader is referred to [6].

The initial configuration sets a log-normal spatial traffic distribution, where the central floor is highly loaded with one of its cells experiencing large call blocking, while upper and lower floors are underutilized. In this scenario, which can be considered as a worst-case situation, all traffic sharing techniques in section III are tested. Such optimization techniques have been tested along 20 optimization loops, each representing 1 hour of network time. The duration of each loop is enough to ensure robust statistics, while the number of loops ensures that the system reaches the steady state. Nonetheless, to ensure repeatability, the same traffic generation pattern is maintained in all methods and iterations. Thus, the different network parameter settings are compared in exactly the same conditions of traffic intensity and user locations.

Three methods are tested: MTS, MTS+C and PTS. The benchmark is the initial situation (iteration 1), with default parameter settings in all cells. Several network performance indicators are collected for comparison purposes: a) the call blocking ratio (CBR), as a measure of network capacity, b) the 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, and c) the HO ratio, HOR, defined by the average number of HOs per carried call, as a measure of network signaling load. For ease of analysis, CBR and OR are aggregated into the unsatisfied user ratio (UUR), computed as $UUR = CBR + OR(1 - CBR)$. Also for simplicity, dropped calls are disabled in the simulations.

B. Simulation results

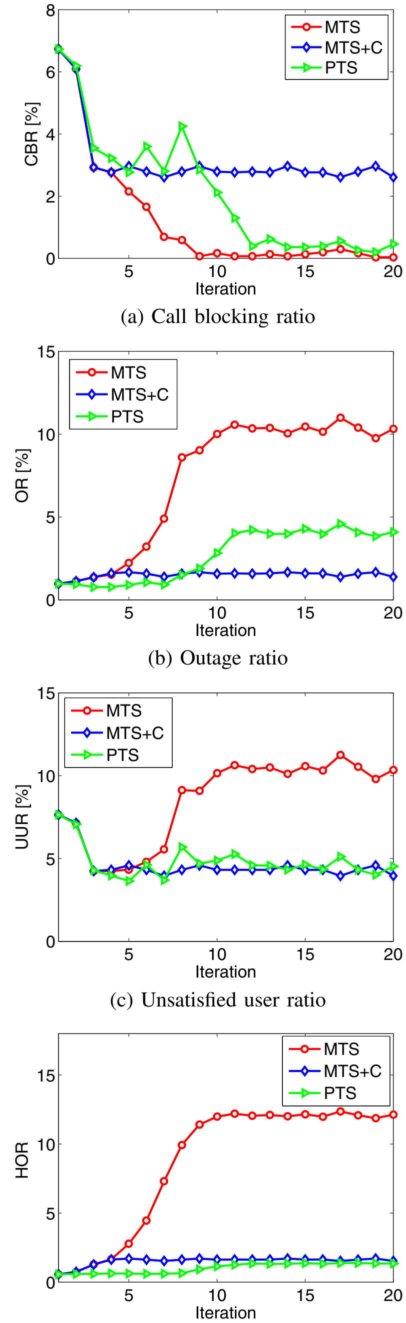
Figure 5 (a)-(d) shows the evolution of CBR, OR, UUR and HOR for the different techniques as iterations progress. The left part of the figures represents the initial situation, with default parameter settings network wide, and the right represents the end of the tuning process. From the figures, it can be deduced that most methods reach equilibrium after a few iterations. Note that fluctuations in the indicators are not due to stochastic noise, since loop duration is large enough to ensure small confidence intervals for the overall ratios (below $\pm$ 1% in absolute terms for 95% confidence level), but to parameter changes in cells and adjacencies of the scenario.

The first value in the curves is the benchmark situation. In Fig. 5 (a) and (c), it is observed that, with this setting, the network shows a large UUR (i.e., 7.6%) due to a large CBR (i.e., 7%). This is a clear evidence of the congestion problem in the scenario. Not shown is the fact that only one cell in the scenario in the central floor is highly loaded, while surrounding cells have free resources.

The analysis is then focused on the tradeoff between network capacity and quality. In Fig. 5 (a), it is clear that all methods decrease the overall CBR, especially PTS and MTS, reaching values well below 1%. This is achieved at the expense of impairing network connection quality, as deduced from Fig. 5 (b). Specifically, the classical MTS brings OR up to a 10%. The larger increase is experienced from the 4th to the 8th iteration, when HO margins become very negative (i.e., below -6.9 dB) as a result of tuning. In this situation, users close to congested femtocells are sent to neighbor cells, experiencing high interference from the original cell. As a consequence, even if MTS manages to decrease UUR for initial iterations, it ends up with an UUR worse than the initial state. In MTS+C, such an impairment is avoided by restricting HO margins to be above -6.9 dB. This is achieved at the expense of decreasing the traffic sharing capability, as observed in the larger final CBR (i.e., 3%). Nonetheless, the final UUR is 4%, almost half of that in the initial state.

PTS decreases the transmit power of the congested cell so as to equalize received signal levels from other cells (even those in different floors) in the area of the congested cell. Thus, users that were initially in the congested cell now camp (and start calls) in other cells, which is the main reason for the higher CBR reduction (from 7% to 0.5%). At the same time, re-allocated users do not experience such large interference from the original cell. Nonetheless, OR increases compared to the initial situation (e.g. 4% vs 1%).

All methods achieve the traffic sharing effect by re-allocating users in the congested cell to a different cell. When this action is performed by the HO process (as in MTS), the number of HOs is significantly increased, which is observed in Fig. 5 (d). Such an increase is extremely large when ping-pong HOs are generated from users experiencing low SINR in the target cell, returning back to the original (congested) cell and being sent back again to the target cell. This is the case of MTS without constraints, where an 12-fold increase is obtained. In contrast, MTS+C and PTS keep HOR low by constraining HO margins and reducing the transmit power of congested cells, respectively.



(a) Call blocking ratio

(b) Outage ratio

(c) Unsatisfied user ratio

(d) Handover ratio

Fig. 5. Evolution of key performance indicators.

V. Conclusions

In this work, several methods have been proposed for traffic sharing in an enterprise femtocell scenario. The methods are based on tuning handover margins or femtocell transmit power by fuzzy logic controllers. Simulation results in an extreme scenario have shown that the proposed methods can eliminate call blocking completely, but some of them deteriorate network connection quality significantly. Having identified interference between femtocells as an important limitation, the variation of handover margins has been restricted. Thus, most of the congestion relief effect is achieved while connection quality is kept almost unaltered. All the tested methods could be run in a centralized entity or in a distributed manner as long as statistics of neighbors are available in femtocells. Such piece of information can be provided by a central entity since parameters are modified slowly. Likewise, the methods can be applied to other scenarios with open femtocells (e.g., airports). Future work aims to combine the tuning of handover margins and transmit power into a single method.

References

[1] V. Chandrasekhar, J. Andrews, and A. Gatherer, "Femtocell networks: a survey," *IEEE Communications Magazine*, vol. 46, no. 9, pp. 59–67, Sep 2008.

[2] A. Lobinger, S. Stefanski, T. Jansen, and I. Balan, "Load balancing in downlink LTE self-optimizing networks," in *Proc. IEEE 71st Vehicular Technology Conference (VTC)*, May 2010.

[3] R. Kwan, R. Arnott, R. Paterson, R. Trivisonno, and M. Kubota, "On mobility load balancing for LTE systems," in *Proc. IEEE 72nd Vehicular Technology Conference (VTC)*, Sep 2010.

[4] P. Muñoz, R. Barco, I. De la Bandera, M. Toril, and S. Luna-Ramírez, "Optimization of a fuzzy logic controller for handover-based load balancing," in *Proc. IEEE 73rd IEEE Vehicular Technology Conference (VTC)*, May 2011.

[5] M. Toril and V. Wille, "Optimization of handover parameters for traffic sharing in GERAN," *Wireless Personal Communications*, vol. 47, no. 3, pp. 315–336, Nov 2008.

[6] J. Ruiz-Avilés, S. Luna Ramírez, M. Toril, F. Ruiz, I. de la Bandera Cascales, and P. Muñoz Luengo, "Analysis of load sharing techniques in enterprise LTE femtocells," in *Proc. 4th International Workshop on Femtocells, Wireless Advanced 2011*, Jun 2011.

[7] T. Ross, *Fuzzy logic with engineering applications*. McGraw-Hill, 1995.