Inter-system Cell Reselection Parameter Auto-Tuning in a Joint-RRM Scenario

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***Abstract*—This paper presents an auto-tuning scheme, based on a fuzzy logic controller (FLC), for a standardized inter-system cell reselection (IS-CR) algorithm in a multi-radio access technology network. FLC modifies IS-CR parameters to reduce the number of call redirections between technologies during the admission control stage based on network performance indicators. Experience shows that call establishment delay is thus greatly reduced. To validate the proposed scheme, a dynamic system-level simulator comprising GSM and UMTS radio access technologies has been developed. This simulator includes a joint radio resource management (JRRM) entity, whose parameters are tuned by the FLC. FLC tuning capabilities are checked out in an extreme, albeit realistic, scenario, where most traffic is unevenly distributed in space and technologies. Results show that call redirections in the admission control stage can be significantly reduced, while keeping connection quality almost unaltered at the expense of increasing changes between technologies during the cell reselection process.**

I. INTRODUCTION

In recent years, mobile communications networks have experienced an important development due to the growing number of users demanding mobile services. In parallel, the launch of new services demands more radio resources, requiring new and more complex radio access technologies. Such a large number of users and services can only be handled by deploying several Radio Access Technologies (RATs) in the same geographical area.

In such a heterogeneous scenario, it is important to manage radio resources from different RATs as a whole, offering to the user the best performance. For this purpose, a Joint Radio Resource Management (JRRM) entity is needed. As shown in Fig. 1, JRRM algorithms aim to manage radio resources in each individual technology to offer the best service, [1]. Despite its complexity, the advantages of a successful JRRM are very attractive: (a) trunking gain by sharing resources from different RATs, (b) extended coverage by joining different RAT service areas, and (c) service-user adequacy by choosing the best available radio technology to suit Quality-Of-Service (QoS) needs.

The main JRRM algorithms are: a) Inter-System Cell Reselection (IS-CR) for terminals (User Equipment, UE) in idle mode [2]; b) Joint Admission Control (J-AC) for UEs initiating a connection, and c) Inter-System HandOver (IS-HO) for moving UEs in connected mode [3]. IS-CR takes charge of the initial RAT selection reallocating the user to other cell or RAT if necessary, when UE is in idle mode. J-AC takes

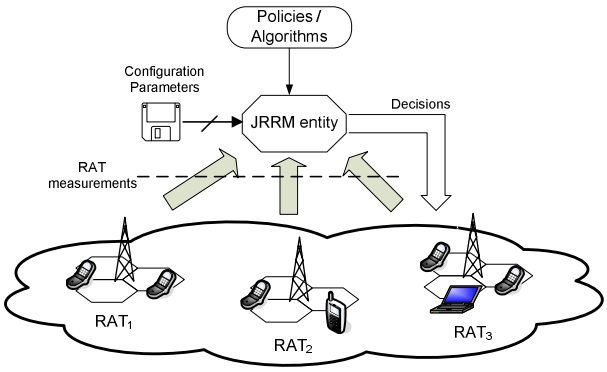

Fig. 1. JRRM decision process

charge of the admission of new calls checking the availability of resouces in the cell an RAT selected during IS-CR process and redirecting the call to other cell or RAT if necessary. The latter is in charge of the assignment of the user to the RAT that, at every moment, can give the best QoS. These mechanisms provide a global coverage and a more efficient use of radio resources.

The optimization of JRRM algorithms has received considerable attention in the literature. Studies deal with IS-HO [4] [5], J-AC [6] and IS-CR [7]. Fuzzy logic (FL) algorithms have been proposed to tune internal parameters in JRRM algorithms as the main tool for optimization improving network performance. The main advantages of FL are: a) the possibility of comparing information with very dissimilar nature, b) an easy integration of the operator know-how into the tuning process, and c) an increased robustness of decisions under imprecise or unreliable input data [8] [9]. Unfortunately, such advanced algorithms are not available in current vendor equipment, and hence no practical results have been presented so far. Moreover, for computational efficiency reasons, performance assessment of self-tuning JRRM algorithms in the literature has traditionally been based on simplistic network models, whose assumptions might not valid in a live environment. To the authors' knowledge, no study has evaluated the capabilities of tuning IS-CR to reduce the call establishment delay based on simulations.

In this paper, an auto-tuning algorithm is proposed to optimize several parameters in a standardised IS-CR algorithm for traffic sharing between GSM and UMTS. This paper follows

a methodology similar to [10], where IS-HO parameters were optimized. In this work, a novel method to reduce the number of call redirections during the admission control algorithm based on the optimization of IS-CR parameters has been developed. The adaptation rules are implemented in a Fuzzy Logic Controller (FLC), which modifies IS-CR parameters on a long-term basis based on network performance statistics in the network management system. Performance assessment is based on a test case in a dynamic system-level simulator including most current network capabilities. The rest of the paper is organized as follows. Section II describes the IS-CR algorithm whose parameters are optimized. Section III proposes the auto-tuning method and Section IV presents the simulation results. Finally, conclusions are presented in Section V.

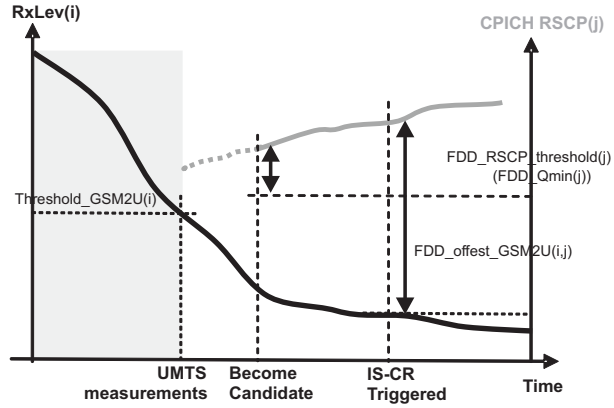

Fig. 2. IS-CR GSM2U algorithm

II. IS-CR ALGORITHM DESCRIPTION

The IS-CR algorithm from GSM to UMTS (GSM2U) and from UMTS to GSM (U2GSM) are detailed in 3GPP standards [11] [12]. A first stage starts when the signal received from the serving cell is below a certain threshold. Thereafter, the UE can initiate measurements of adjacent cells in other RATs. If the signal quality received from any adjacent cell is above a specific threshold, that cell can be considered as a candidate for reselection. Finally, if the candidate cell is better than the serving cell by an offset, the cell reselection process is triggered, and the UE changes the camping cell and RAT. These conditions can be formulated as

$$RxLev(i) < Threshold\_GSM2U(i) \quad (1)$$

$$CPICH\ RSCP(j) \geq FDD\_RSCP\_threshold(j) \quad (2)$$

$$CPICH\ \frac{E_c}{N_0}(j) > FDD\_Qmin(j) \quad (3)$$

$$RxLev(i) < CPICH\ RSCP(j) - FDD\_offset\_GSM2U(i,j), \quad (4)$$

where i indicates the serving cell in the source RAT and j identifies the adjacent cell where the UE may camp on after the IS-CR process. $Threshold\_GSM2U(i)$ is a signal-level threshold for the source RAT, $FDD\_RSCP\_threshold(j)$ and $FDD\_Qmin(j)$ are signal-level and quality thresholds for the target RAT, and $FDD\_offset\_GSM2U(i,j)$ is an offset term defined on a per-adjacency basis to bias CR decisions in favor of any of the RATs.

Fig. 2 summarizes the IS-CR process. When the signal level received from the serving cell is below a specific threshold, as shown in (1), the user can initiate measurements of UMTS cells. Only UMTS adjacent cells satisfying (2) and (3) can be considered as candidate for reselection. Many adjacent cells can fulfill (2)-(3), becoming candidates. All candidate cells are sorted by (4), i.e., the first candidate will have the highest $CPICH\ RSCP(j) - FDD\_offset\_GSM2U(i,j)$. The best cell fulfilling (4) is selected as final cell and IS-CR is triggered. In this procedure, $FDD\_offset\_GSM2U(i,j)$ can be used to redirect calls to the desired target cell, since it is defined in an adjacent basis.

An analog process occurs for the IS-CR algorithm from UMTS to GSM (U2GSM), not shown here for brevity. U2GSM IS-CR algorithm also establishes an offset term, $RxLev\_offset\_U2GSM(i,j)$, defined on a per-adjacency basis to select the target cell.

With this procedure, offset parameters control the call flow management. If the selection of a cell and RAT in the cell reselection process is optimized by tuning offset parameters, it is possible to reduce the call redirections between RATs during admission control needed in the network to accept a new call. Note that call redirections during admission control cause a significant delay in call establishment. Hence, it is important to reduce the number of redirections in this process. Such offsets, $FDD\_offset\_GSM2U(i,j)$ and $RxLev\_offset\_U2GSM(i,j)$, will be the main focus of the auto-tuning process described in the next section.

III. AUTO-TUNING SCHEME

The proposed algorithm is implemented by a Fuzzy Logic Controller (FLC). Fuzzy logic is especially suitable to take decisions from imprecise information as it is the case when optimizing JRRM parameters from real network indicators.

In this work, two FLCs are defined, one for each direction in IS-CR (U2GSM and GSM2U). GSM2U FLC generates the increments in $FDD\_offset\_GSM2U(i,j)$ parameters for each i cell and j adjacent, based on Call Rejection Rate statistics ($CRR_r(i)$). $CRR_r(i)$ measures the number of *rejected* calls in i cell and r radio access technology divided by the total number of UEs camped on that cell and technology. The rejected calls are the calls that cannot be carried through the cell and RAT where UE camped on, wherever the UE camped on after the initial attempt. U2GSM FLC computes $RxLev\_offset\_U2GSM(i,j)$ changes in a similar way. For simplicity, all FLCs are implemented based on the Takagi-Sugeno approach [13]. For brevity, only one direction in IS-CR (i.e., from GSM to UMTS) is detailed here.

FLC consists of three main blocks: *fuzzifier*, *inference engine* and *defuzzifier*, [13], as shown in Fig. 3. FLC in-

puts provide information about network state. In this work, $CRR_{GSM}(i)$ and $CRR_{UMTS}(j)$ are supplied as inputs.

The *fuzzifier* translates input values into linguistic values based on several input membership functions, μ_x. This functions reflect the degree of membership to a linguistic term with values in the range [0,1]. For instance, $\mu_{low}(CRR_{GSM}(i))$ function indicates how low is Call Rejection Rate for the serving cell of GSM. With the '0' value the function represents that $CRR_{GSM}(i)$ is not low at all while the '1' value indicates that $CRR_{GSM}(i)$ is definitely low. For simplicity, the selected input membership functions are trapezoidal, as shown in Fig. 4, and are similar for both inputs. This can be expressed as

$$\mu_x(CRR_y(i)) = \mu_x(CRR_y(j)) \quad , \tag{5}$$

where $x \in$ {L(low), M(medium), H(high)} and $y \in$ {GSM, UMTS}.

The *inference engine* relates input fuzzy sets with output fuzzy sets by a set of IF-THEN rules. Table I defines the set of rules used in the auto-tuning process of IS-CR algorithm from GSM to UMTS. For instance, rule 6 reads as 'if $CRR_{GSM}(i)$ is High and $CRR_{UMTS}(j)$ is Low then the $FDD\_offset\_GSM2U(i,j)$ value is reduced' to favor the change between the i cell and the j adjacent. Briefly, the offset increment is positive when the $CRR_{GSM}(i)$ is lower than the $CRR_{UMTS}(j)$ to avoid call reallocations between the i and j cells. Conversely, the offset increment is negative when the $CRR_{GSM}(i)$ is higher than the $CRR_{UMTS}(j)$ to favor call reallocations between the i and j cells. U2GSM FLC rules are similarly defined.

The *defuzzifier* obtains a crisp output value from the output fuzzy set. The output membership functions for $\Delta FDD\_offset\_GSM2U(i,j)$ are constants with 'negative', 'null' and 'positive' values (i.e., -5, 0 and 5, respectively) as shown in Fig. 5. The defuzzifier uses the centre-of-gravity method to compute the output value, [13].

Finally, $FDD\_offset\_GSM2U(i,j)$ values are restricted to a limited variation interval [-50,50]dB. This is in line with operator policies, trying to avoid excessive changes or possible instabilities in mobile networks.

TABLE I
GSM2U FUZZY LOGIC CONTROLLER RULES

No	$CRR_{GSM}(i)$	$CRR_{UMTS}(j)$	$\Delta FDD\_offset\_GSM2U(i,j)$
1	L	L	Null
2	M	M	Null
3	L	M	Positive
4	L	H	Positive
5	M	L	Negative
6	H	L	Negative
7	H	M	Negative
8	M	H	Positive
9	H	H	Null

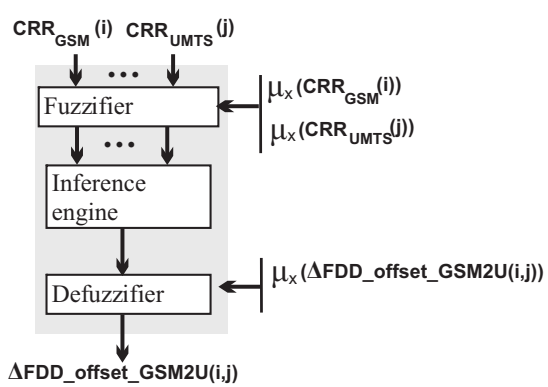

Fig. 3. Fuzzy controller diagram

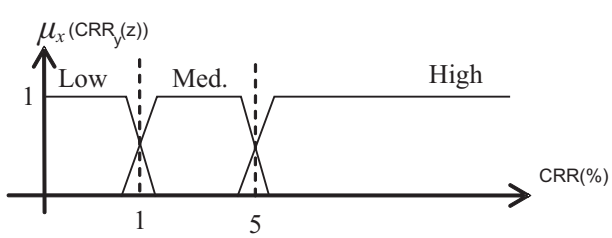

Fig. 4. Example of input membership functions

IV. PERFORMANCE ANALYSIS

A. Simulation Set-up

A dynamic system-level simulator has been developed in MATLAB©. The simulator includes GSM and UMTS technologies and JRRM algorithms. Note that intra-system RRM have also been implemented (i.e., admission control, intra-system cell reselection and intra-system handover as the most significant ones). An IS-CR algorithm from and towards both RATs have also been developed.

The simulation scenario models a macro-cellular environment where full overlapping between GSM and UMTS coverage areas exists. The layout, shown in Fig. 6, consists of 19 tri-sectorised sites evenly distributed in the scenario. Thus, every site has 3 GSM cells and 3 UMTS cells (i.e., GSM and UMTS cells are co-sited). To reproduce a realistic case, traffic demand is unevenly distributed in the scenario following a log-normal distribution, implemented as in [14]. Fig. 7 shows the probability of starting a call in a location. It is observed that the spatial traffic distribution has a central peak. Moreover, traffic distribution results in an unbalanced scenario where most of the users are camped on GSM cells. This can be considered as a worst-case scenario, since most of the traffic is generated in

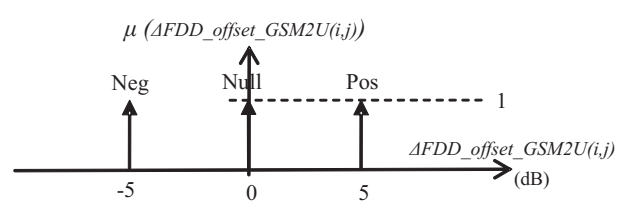

Fig. 5. Example of output membership functions

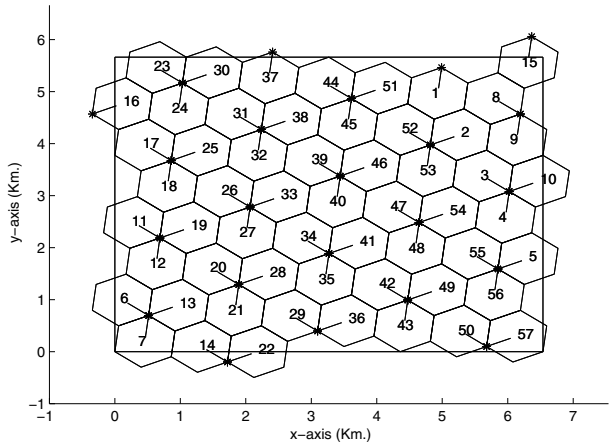

Fig. 6. Simulation scenario

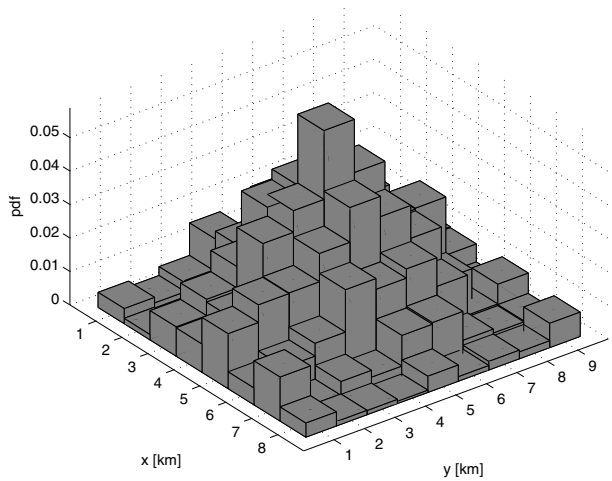

Fig. 7. Spatial traffic distribution

a few cells of a specific RAT, which are adjacent to each other. As a result, limited trunking gain is achieved by traffic sharing. The average system traffic load is set to 15%, which results in a low global blocking probability. Table II summarises the main characteristics and default parameters in the simulator. The reader is referred to [15] [16] for a detailed description of the parameters.

$Threshold\_GSM2U(i)$ is configured in such a way that UEs always measure in UMTS technology, as suggested in [11]. The default values selected for $FDD\_offset\_GSM2U(i,j)$ and $RxLev\_offset\_U2GSM(i,j)$, shown in Table II, prevent RAT changes during IS-CR process in the scenario. During the tuning process, $FDD\_offset\_GSM2U(i,j)$ and $RxLev\_offset\_U2GSM(i,j)$ are progressively modified by FLCs with the aim of allowing changes between RATs. The FLCs have been developed using the MATLAB Fuzzy Logic Toolbox [17].

During the analysis, 15 iterations of the control algorithm have been simulated under conditions described in Table II. Such a number of iterations is enough to ensure that the system

TABLE II
SIMULATION PARAMETERS

Scenario	TU3, MACRO, cell radius 0.5km 57 UMTS cells + 57 GSM cells
Propagation model	Okumura-Hata with wrap-around Correlated log-normal slow fading, SF=8dB
Mobility model	Random direction, constant speed 3km/h
Service model	Speech, mean call duration 210s, activity factor 0.5
BS model	Tri-sectorised antenna, EIRPmax=43dBm 1 TRX (GSM), 1 channel code tree (UMTS)
Frequency plan	TCH 1/3 RH3
Adjacency plan	Symmetrical adjacencies, 32 per cell
User Distribution	Nonuniform
Average traffic load	15%
Initial JRRM parameters	FDD_offset_GSM2U 5 dB RxLev_offset_U2GSM 30 dB Inter-system Handover disabled
Time resolution	480ms (GSM), 100ms (UMTS)
Simulation time	1h (per optimisation iteration)

comprising the network and the controller reaches the steady state. As a result, the total network simulated time is 15 hours.

Performance assessment is based on two network indicators: (a) number of call reallocations between RATs during the cell reselection process and (b) number of redirected calls during the admission control process. The baseline situation used for benchmarking purposes is the initial situation, where IS-CR parameters are set to default values, (i.e. before optimization). Such a parameter setting causes that the number of call reallocations between RATs during the cell reselection process is restricted. The changes between RATs needed to support new calls are made during the admission control process. The low number of inter-system UE reallocations in the CR process causes that most of calls try to be carried through the cell where the UE camped on, resulting in a large value of CRR in GSM.

B. Simulation Results

It is important to understand the modifications produced by the FLC to IS-CR offsets during the auto-tuning process. As already explained in section II, the auto-tuning process modifies $FDD\_offset\_GSM2U(i,j)$ and $RxLev\_offset\_U2GSM(i,j)$. These offsets are defined on a per-adjacency basis so offset evolution must be checked for each i and j cell in the original and destination RAT, respectively.

Fig. 8 and Fig. 9 aim to show how the controller works. Fig. 8 represents the input of the controller: the Call Rejection Rate (CRR) evolution for GSM cell number 40 (i.e. $CRR_{GSM}(40)$), and three UMTS adjacent cells (i.e. $CRR_{UMTS}(40)$, $CRR_{UMTS}(33)$ and $CRR_{UMTS}(47)$), Fig. 6. Fig. 9 shows the output of the controller: the

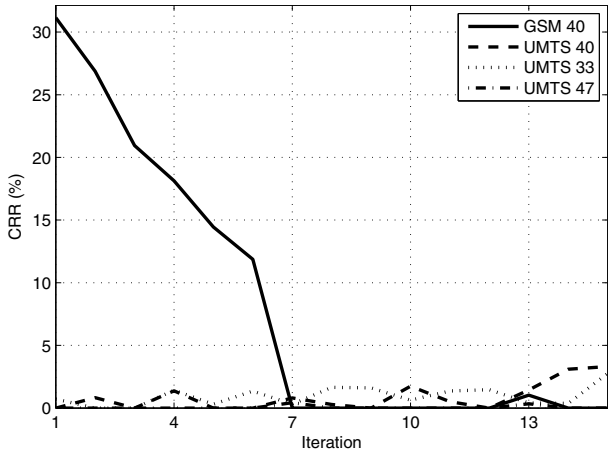

Fig. 8. Call Rejection Rate for a cell of GSM and three adjacent cells of UMTS

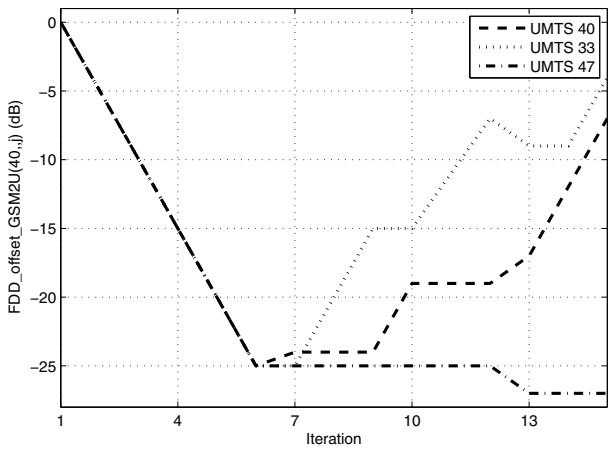

Fig. 9. Cell reselection offsets for the three adjacent cells of UMTS

$FDD\_offset\_GSM2U(40, j)$ evolution for the three first (i.e. best candidates) j adjacent cells.

Fig. 8 shows that, in GSM, the selected cell presents a CRR higher than the three adjacent cells of UMTS. Hence, as observed in Fig. 9, the reduction of $FDD\_offset\_GSM2U(40, j)$ is decreased to these neighbors to favor the reallocation from GSM to UMTS. This changes of technology produce a CRR reduction in the considered cell in GSM. Once the CRR of GSM cell number 40 is similar to the CRR of the adjacent UMTS cells, 40, 33 and 47, the corresponding offsets stops decreasing. Thereafter, $FDD\_offset\_GSM2U(40, j)$ increases for the adjacent cells that have a CRR higher than the cell of GSM.

Fig. 10 aims to show the main benefit on network performance, which is the reduction of the number of call redirections between RATs during AC stage along iterations. The number of inter-system UE reallocations in CR process is very small due at the first iterations due to the default parameter settings in the scenario. Consequently, the required technology changes must be done during the AC process (UE redirections are very high). The traffic load in GSM is higher than UMTS and this is the reason why the number of changes from GSM to UMTS is so high in the AC process.

Along iterations, FLC modifies the IS-CR offsets to favor the changes of technology between cells with low CRR. That produces a significant reduction in the number of call redirections from GSM to UMTS during admission control process, which in turn leads to a reduction of delay in call establishment. After optimization, the required changes to keep the blocked call rate low take place in the cell reselection process.

Changes made by FLC also have an impact on global CRR, $CRR_{global}(r)$ (i.e. the number of calls that cannot be carried through the RAT r where UE camped on). Fig. 11 shows the CRR values across iterations. It is observed that, at the beginning, the CRR produced in GSM is higher than in UMTS due to the fact that traffic is distributed in some cells and most calls are served by GSM. In subsequent iterations, the $CRR_{global}(GSM)$ is reduced to similar values than UMTS.

It should be pointed out that all the results are obtained ensuring connection quality across all iterations and for both radio access technologies. Along the simulation time the probability of experiencing a Bit Error Rate (BER) in GSM

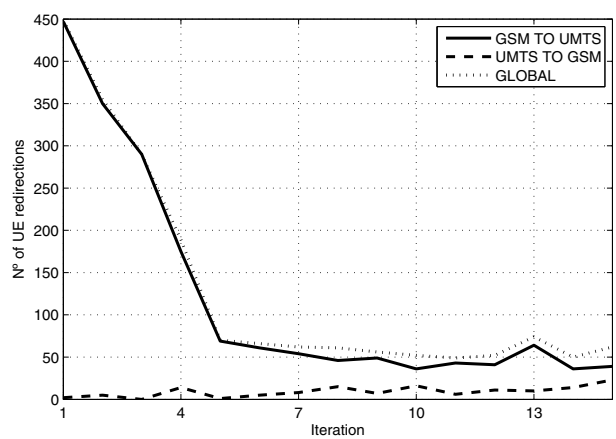

Fig. 10. Number of call redirections during Admission Control

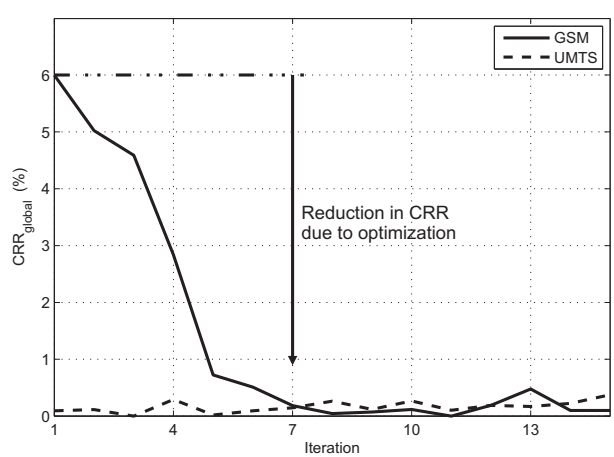

Fig. 11. Global Call Rejection Rate

larger than 5% is less than 1%. Likewise, the probability of experiencing a Blocked Error Rate (BLER) in UMTS larger than 5% is less than 0.1%. Moreover, the global Blocked Call Rate (BCR) obtained for both technologies is very low along the entire simulation. Such a low BCR is produced by the use of the joint admission control algorithm.

V. CONCLUSION

In this paper, an auto-tuning scheme based on fuzzy logic controller has been presented for an inter-system cell reselection algorithm. FLCs modify the offsets related with this algorithm to favor changes between radio technologies during the cell reselection process, instead of redirections calls during admission control process, which cause a significant delay in call establishment. A system-level simulator has been developed including standardized cell reselection and admission control algorithms.

Simulation results in an extreme scenario show that the number of call redirections in admission control is progressively reduced as cell reselection parameters are modified. In addition, the rejected call percentage in the cell and RAT selected by cell reselection algorithm decrease significantly, as a result of a more uniform traffic distribution between RATs. The price to be paid is an increase of the reallocations between RATs during the cell reselection process. Such benefits are obtained keeping a constant global Blocked Call Rate in network and ensuring connection quality.

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