Inter-system Handover Parameter Auto-Tuning in a Joint-RRM Scenario

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Abstract— **In this paper, an auto-tuning scheme based on a fuzzy logic controller (FLC) is proposed for a standard inter-system handover (IS-HO) algorithm. A heterogeneous network scenario is considered, comprising GSM and UMTS radio access technologies. FLC modifies IS-HO parameters to perform load sharing between technologies based on network congestion statistics. To validate the proposed scheme, a system-level simulator with a joint radio resource management (JRRM) module has been developed. FLC adaptation capabilities are checked through changes in the time-space traffic distribution in a realistic scenario. Results show that call blocking rates can be significantly reduced, while keeping connection quality almost unaltered, at the expense of increasing network signaling load.**

Keywords: auto-tuning, heterogeneous networks, inter-system handover, optimization, fuzzy logic controller.

I. INTRODUCTION

Wireless communication networks are rapidly increasing in complexity due to the introduction of new services and technologies. Thus, several Radio Access Technologies (RATs) can be found in the same geographical area. In this heterogeneous scenario, it is crucial for network efficiency that all network segments do not compete, but cooperate closely to cover user needs seamlessly and transparently. For this purpose, a Joint Radio Resource Management (JRRM) entity is needed. As shown in Figure 1, JRRM deals with algorithms and policies that aim at integrating those distinct radio interfaces to support the different service data rate and user mobility requirements [1]. Such algorithms have to manage radio resources in each individual technology, where technical specifications are quite different, which makes their design a challenging task. Despite its complexity, 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 achievement of the previous advantages relies on a good mobility management in JRRM. For circuit-switched services, this is accomplished by Joint Admission Control (JAC) and Inter-System HandOver (IS-HO). While the former takes charge of the initial RAT selection, the latter is the basic mechanism to provide a global coverage, handling the user over distinct technologies and assigning the user to the RAT that, at every moment, can give the best QoS.

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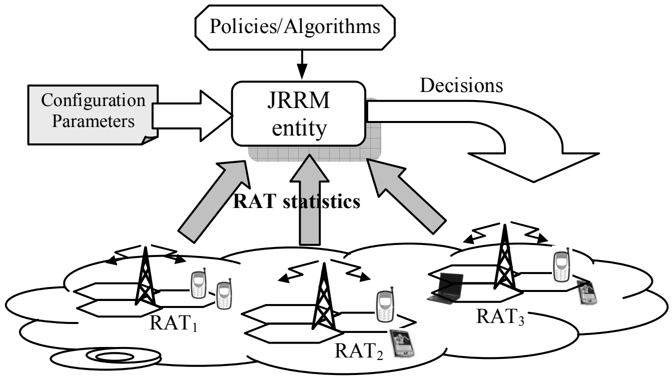

Figure 1 JRRM decision process

The design of JRRM algorithms has recently received considerable attention in the literature [2]-[7]. As these algorithms must deal with information of very dissimilar nature, fuzzy decision making algorithms have usually been proposed for JAC [8][9] and IS-HO [10]. Unfortunately, such advanced algorithms are not available in current vendor equipment. Moreover, for efficiency reasons, performance assessment has traditionally been based on simplistic network models. Alternatively, traffic sharing can be performed by controlling the user flow between RATs through parameter settings in a classical IS-HO scheme, instead of designing advanced JRRM algorithms.

In this paper, an auto-tuning algorithm is proposed to tune several parameters in a classical IS-HO algorithm for traffic sharing between GSM and UMTS. The adaptation rules are implemented in a fuzzy logic controller, which modifies IS-HO parameters based on statistical network indicators. Assessment is based on a test case in a dynamic system-level simulator including most current network capabilities. The rest of the paper is organised as follows. Section II describes the IS-HO algorithm to be optimized. Section III proposes the auto-tuning method and Section IV discusses the simulation scenario and results. Finally, conclusions are presented in Section V.

II. IS-HO ALGORITHM DESCRIPTION

A detailed description of the HO algorithm from UMTS to GSM (U2GSM) is given in 3GPP standards [11]. Figure 2 summarizes this process. As in intra-RAT handovers, an IS-HO is triggered when: a) a low signal quality/level is experienced at the original RAT (i.e., E_c/N_o pilot channel in UMTS, bold line in the figure), and, b) the target RAT has enough signal quality/level (i.e., *RxLEV* in GSM, gray line). On the time axis, two events are clearly identified. Event 2D starts the collection of GSM measurements and event 3A starts the HO process. Event 3A is triggered when UMTS connection quality is below some threshold, T_{3A_U2GSM}, and GSM signal level is above T_{U2GSM}. These conditions can be formulated as

$$\frac{E_c}{N_o}(i) < T_{3A\_U2GSM}(i) - \frac{H_{3A\_U2GSM}(i)}{2} \qquad for\ TTT_{3A\_U2GSM}\ \text{sec}, \tag{1}$$

$$RxLEV(j) + OFFcell_{U2GSM}(i,j) > T_{3A\_GSM}(j) + \frac{H_{3A}(j)}{2} \qquad for\ TTT_{3A\_U2GSM}\ \text{sec}, \tag{2}$$

where i and j indicate the origin and destination cells, T_{3A_U2GSM}, and T_{3A_GSM} are quality (UMTS CPICH E_c/N_o) and signal-level (GSM *RxLEV*) thresholds, H_{3A_UMTS} and H_{3A_GSM} are hysteresis parameters, TTT_{U2GSM} is a temporal window, and $OFFcell_{U2GSM}$ is an offset term defined on a per-adjacency basis to bias HO decisions in favor of any of the RATs.

As already shown in [2], T_{3A_U2GSM} have a strong influence on IS-HO call flow. Generally speaking, T_{3A_U2GSM} controls the overall call flow between RATs, as only calls satisfying (1) will be evaluated by (2). A large T_{3A_U2GSM} value makes HO easier (i.e., most calls, even with acceptable UMTS signal quality, could be redirected to GSM). Subsequently, $OFFcell_{U2GSM}$ can be used to redirect calls to the desired target cell. It is worth noting that T_{3A_U2GSM} is defined on a per-cell basis, while $OFFcell_{U2GSM}$ is defined on a per-adjacency basis.

In current vendor equipment, the IS-HO algorithm from GSM to UMTS (GSM2U) may differ from its U2GSM counterpart. For simplicity, a symmetric algorithm has been assumed in this work, since a direct translation can easily be made by a proper setting of existing parameters.

From the previous explanation, it can easily be deduced that the threshold and offset parameters T_{3A_U2GSM}, $OFFcell_{U2GSM}$, T_{3A_GSM2U} and $OFFcell_{GSM2U}$ can be used to perform load sharing between RATs, and will thus be the main focus of the auto-tuning process.

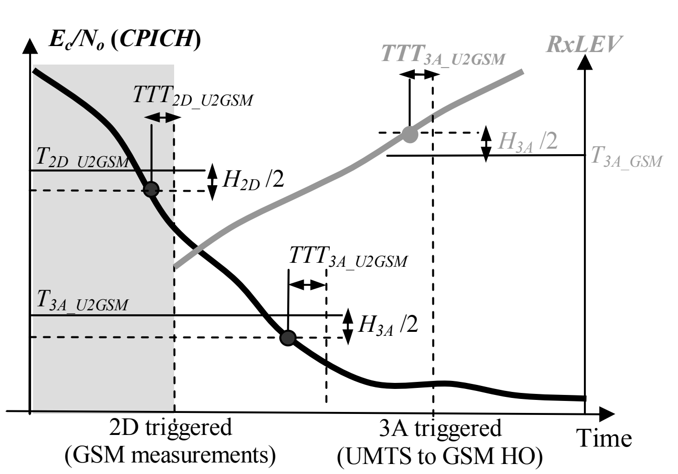

Figure 2 U2GSM IS-HO algorithm

III. AUTO-TUNING SCHEME

The auto-tuning algorithm is presented in this section. The proposed algorithm is implemented by a Fuzzy Logic Controller (FLC). FLCs [12] have been successfully applied to automatic network parameter optimization in single-RAT networks due to their ability to translate human knowledge into rules.

In the proposed scheme, FLCs compute the increments in $OFFcell_{U2GSM}$ and T_{3A_U2GSM} for each cell based on past congestion statistics. GSM2U FLCs compute $OFFcell_{GSM2U}$ and T_{3A_GSM2U} modifications in a similar way. For simplicity, all FLCs are implemented based on the Takagi-Sugeno approach [12]. For brevity, the following explanation is restricted to only one direction in IS-HO (i.e., from UMTS to GSM).

As shown in Figure 3, three main blocks are identified in an FLC: fuzzifier, inference engine and defuzzifier. In the *fuzzifier*, FLC inputs (i.e., network performance indicators) are classified according to some so-called *linguistic terms*. In this work, congestion rates in the uplink and downlink for both RATs are used as inputs (denoted as CR_{UL_GSM}, CR_{DL_GSM} CR_{UL_UMTS} and CR_{DL_UMTS}) For UMTS, CR is understood as the percentage of time during which all channel codes are assigned or maximum power is reached at the base station. To tune $OFFcell_{U2GSM}$, an additional input, $DEVoff_{U2GSM}$, indicates the deviation of the current offset value from the default one as

$$DEVoff_{\text{U2GSM}}(i,j,t) = OFFcell_{\text{U2GSM}}(i,j,t) - OFFcell_{\text{U2GSM}}(i,j,t_0). \tag{3}$$

The fuzzyfier translates input values into a value in the range [0,1] indicating the degree of membership to a linguistic term, x, according to several input membership functions, μ_x. For instance, $\mu_{low}(CR_{UL\_GSM})$ function indicates how low is the uplink CR in GSM with a value between '0' (i.e., CR_{UL_GSM} is not low at all) and '1' (i.e., it is definitely low). For simplicity, the selected input membership function are triangular or trapezoidal, as shown in Figure 4a. It should be pointed out that CR membership functions are similar for GSM or UMTS and uplink or downlink, i.e.,

$$\mu_x(CR_{y\_GSM}) = \mu_x(CR_{y\_UMTS}) \tag{4}$$

$$\mu_x(CR_{DL\_z}) = \mu_x(CR_{UL\_z}), \tag{5}$$

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

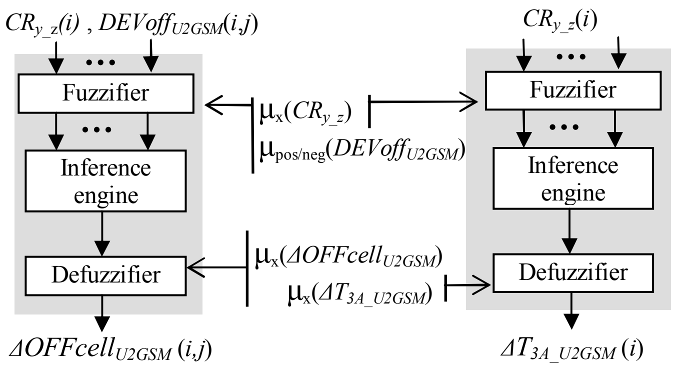

Figure 3 Fuzzy controller diagram

In the *inference engine*, a set of IF-THEN rules define the mapping of the input to the output in linguistic terms. Table I describes the set of rules in the U2GSM tuning process. Briefly, the parameter $\Delta T_{3A\_U2GSM}(i)$ is positive (i.e., $T_{3A\_U2GSM}(i)$ quality threshold in (1) increases) when CR_{UL_UMTS} or CR_{DL_UMTS} are high in cell *'i'*. Likewise, FLC rules for GSM2U parameters are similarly defined.

Finally, the *defuzzifier* obtains a crisp output value by aggregating all rules. As shown in Figure 4b, the output membership functions for $\Delta OFFcell_{U2GSM}$ are constants. The output membership functions for ΔT_{3A_U2GSM} are similar to those in Figure 4b, but only with 'negative', 'null' and 'positive' values (i.e., -2, 0 and 2 dBs, respectively). The centre-of-gravity method is applied here to compute the final value of the output.

To avoid network instabilities due to excessive parameter changes, T_{3A_U2GSM} and $OFFcell_{U2GSM}$ values are restricted to a limited variation interval. This is aligned to usual operator policies, which avoid, if possible, significant changes in network configuration for safety reasons.

TABLE I. U2GSM FUZZY LOGIC CONTROLLER RULES

CR_{UL_UMTS}	CR_{DL_UMTS}			ΔT_{3A_U2GSM}
L	L			Neg
L	M			Null
M	L | M			Null
H	-			Pos
-	H			Pos
CR_{UL_UMTS}	CR_{DL_UMTS}	CR_{DL_GSM}	$DEVoff_{U2GSM}$	$\Delta OFFcell_{U2GSM}$
L	L	L	Pos	S-Neg
L	L	L	Neg	S-Pos
L	L	H	-	H-Neg
H	-	L	-	H-Pos
-	H	L	-	H-Pos
H	-	M	-	Pos
-	H	M	-	Pos
L | M	L | M	H		Neg
L | M	L | M	L		Pos
L | M	L | M	M	-	Null
H	-	H	-	Null
-	H	H	-	Null

"|" : Logical OR

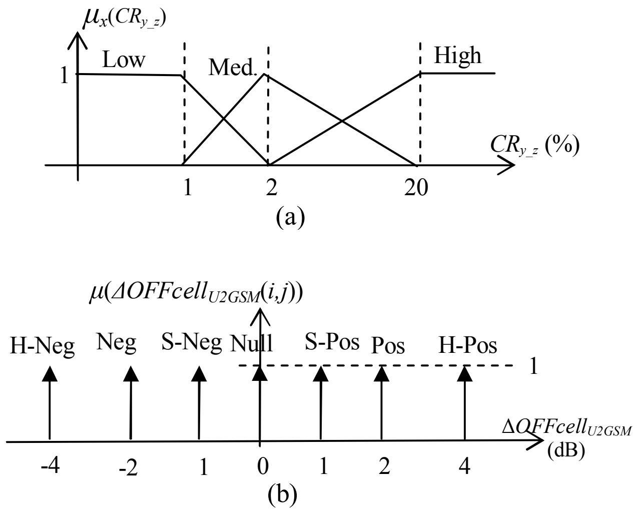

Figure 4 Example of input and output membership functions

To avoid unnecessary IS-HOs, T_{3A_U2GSM} and $OFFcell_{U2GSM}$ are not always modified. On the contrary, changes proposed by the FLC controlling in T_{3A_U2GSM} *(i)* are only implemented in the scenario when the average value $OFFcell_{U2GSM}(i,j)$ for all *j* cells is close to its variation limits (i.e., [-6 6] dB). As some situations of unbalanced traffic can be managed by only changing $OFFcell_{U2GSM}$, this approach tries to avoid unnecessary T_{3A_U2GSM} modification and, therefore, unnecessary IS-HOs. Thus, the network signalling load is only increased when needed.

IV. RESULTS

A. Simulation set-up

A dynamic system-level simulator has been developed in MATLAB©. GSM and UMTS technologies have been implemented and an IS-HO module from and towards both radio accesses is running in the platform. Admission control and Intra-system handover (i.e., between cells in the same RAT) have also been implemented.

The simulation scenario models a macro-cellular environment where full overlapping between GSM and UMTS coverage areas exists. The layout, shown in Figure5, consists of 19 tri-sectorized 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). Table II summarises the main models and default parameters in the simulator.

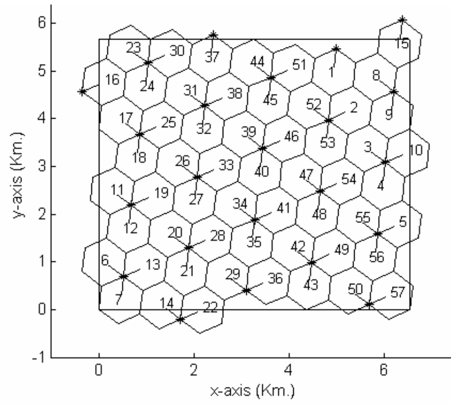

Figure 5 Simulation scenario

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, $_{SF}$=6dB
Mobility model	Linear with random turns, 3km/h (constant)
Service model	Speech, mean call duration 100s, activity factor 0.5
BS model	Tri-sectorized antenna, $EIRP_{max}$=43dBm 1 TRX (GSM), 1 channel code tree (UMTS)
Adjacency plan	Symmetrical adjacencies, 32 per cell
JRRM parameters	T_{3A_U2GSM} -28 dB T_{3A_GSM2U} -100 dBm ([-110 … -47]) $OFFcell$ 0 dB ([-6 ... 6])
Time resolution	480ms (GSM), 100ms (UMTS)
Simulation time	1h (per optimization step)

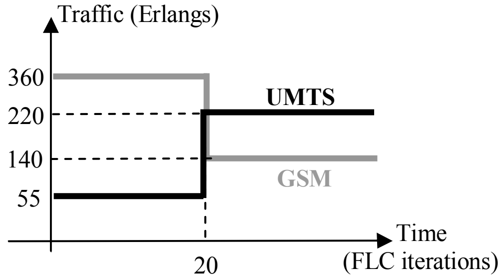

Figure 6 Time evolution of traffic demand in the scenario

Figure 6 shows the temporal traffic distribution (consisting of circuit-switched voice calls) configured in the simulations. To check the FLC auto-tuning capability, GSM and UMTS traffic sources are initially configured to result in a strongly unbalanced scenario. Thus, it is expected that parameter changes performed by the FLC manage to relieve congestion in any of the RATs. At some instant, the congestion situation is reversed to check the capability of the network to adapt to changes in the traffic distribution (e.g., population movements, new premises). For clarity, these two periods are hereafter referred to as first and second stage.

Assessment is based on three overall network performance indicators: (a) Blocked Call Rate (BCR) as a network capacity indicator, within a period; (b) IS-HO ratio (i.e., ratio of total IS-HOs to carried calls) as a signaling load indicator; and (c) Block and Frame Error Rates (i.e., BLER for UMTS and FER for GSM) as network quality indicators.

B. Simulation Results

Multiple iterations have been simulated under the traffic conditions described in the previous section. Since traffic spatial distribution is uniform in the scenario, $T_{3A\_U2GSM}(i)$ and $OFFcell_{U2GSM}(i,j)$ cell averages are statistically representative. Such averages are defined as

$$\overline{T_{3A\_U2GSM}} = \sum_i T_{3A\_U2GSM}(i) \Big/ N_{cell} \quad , \tag{6}$$

$$\overline{\overline{OFFcell_{U2GSM}}} = \sum_i \left(\frac{\sum_j OFFcell_{U2GSM}(i,j)}{N_{adj}(i)} \Bigg/ N_{cell} \right) \quad , \tag{7}$$

where $N_{adj}(i)$ in (7) represents the number of adjacent cells for i cell. Identical equations can be defined for GSM2U statistics.

Figure 7 shows the values of those indicators for both U2GSM and GSM2U handovers across iterations. It should be pointed out that confidence intervals for these averages are negligible, and are thus not shown. In the figure, it is observed that, in the first stage, when GSM is overloaded, FLC favors GSM2U IS-HOs by increasing $OFFcell_{GSM2U}(i,j)$ and $T_{3A\_GSM2U}(i)$. This trend is maintained until the 2nd stage, when the traffic distribution changes. At the same time, U2GSM parameters are set accordingly to prevent U2GSM HO.

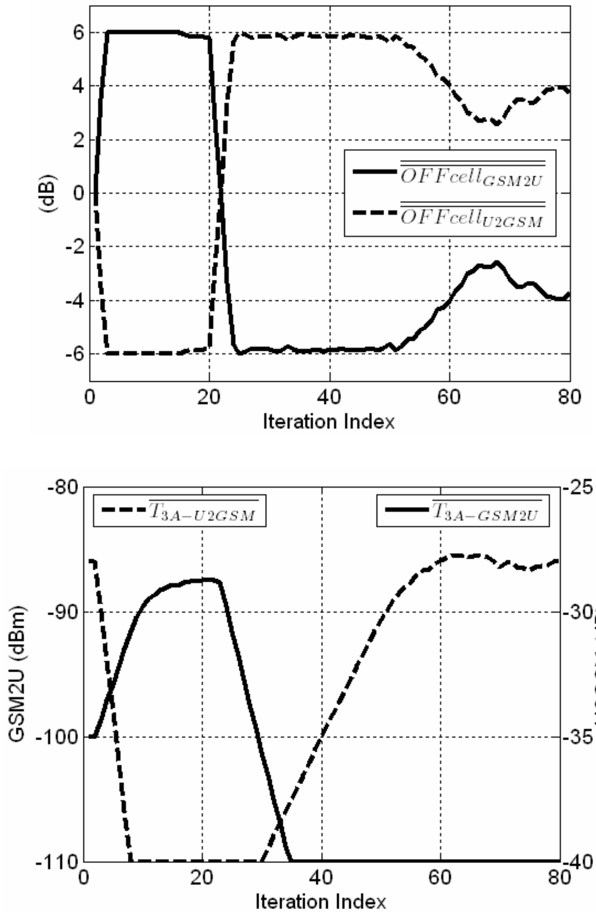

Figure 7 Offset and threshold time evolution

Once traffic distribution changes in the 2nd stage, FLCs change network parameters to cope with congestion in UMTS. Thus, T_{3A_GSM2U} is restricted to avoid GSM2U HOs, while T_{3A_U2GSM} is relaxed to favor U2GSM user flow. It is worth noting that changes in T_{3A_U2GSM} and T_{3A_GSM2U} start some iterations after traffic change in 20th iteration. As explained before, only when $OFFcell_{U2GSM}$ and $OFFcell_{GSM2U}$ parameters are close to their limit values (i.e., 25th iteration in Figure 7), changes in T_{3A_U2GSM} and T_{3A_GSM2U} are implemented in the scenario.

Figure 8 shows the Blocked Call Rate (BCR) in both technologies across iterations. In the figure, it is observed that, by sharing load between RATs, BCR in GSM is reduced in first stage up to 12% in absolute terms (i.e., from 16% to 4%), while keeping BCR in UMTS almost unaltered. As a result of congestion relief, network carried traffic increases in, approximately, 15% (not shown in the figure). In the second stage, the initial load imbalance between technologies is not so severe and BCRs are not as high as in the first stage. Therefore, the rules fired in the FLC inference engine suggest more subtle parameters changes. As a result, convergence to the equilibrium is slower and BCR balance between RATs is only reached after 35-40 iterations. In the limit, network traffic gain obtained by the tuning process is about 4%.

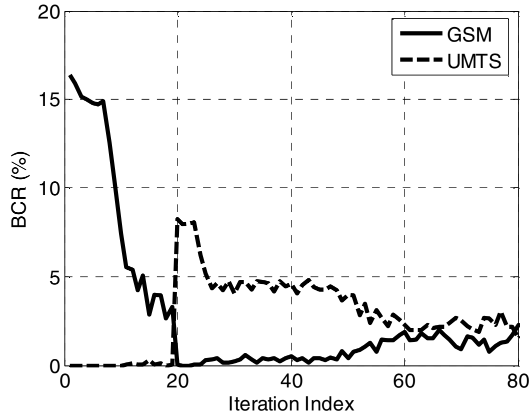

Figure 8 Blocked Call Rate (BCR) evolution

Figure 9 evaluates the influence of the tuning process on network signalling load by showing the IS-HO ratio. In the first simulation stage, a high IS-HO rate is experienced to balance traffic (up to 35% in 19th iteration). In the second stage, less ISHOs are needed and handover ratios are, then, lower (7-8%).

Yet not shown in the figures, enough call quality is always ensured at any iteration point and radio technology. More specifically, the probability of experiencing a Frame Error Rate (FER) larger than 5% in GSM is less than 0.01 (i.e., 1% of simulation time). Likewise, the probability of experiencing a Block Error Rate (BLER) in UMTS larger than 5% is below 0.001.

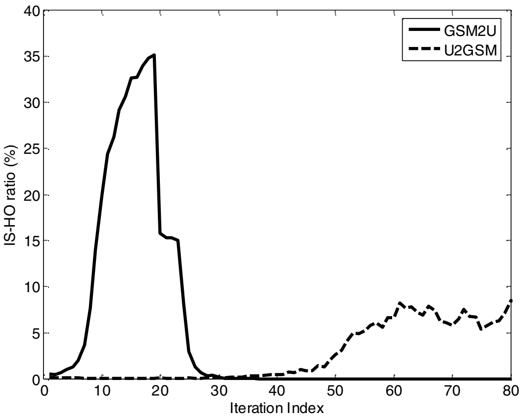

Figure 9 U2GSM and GSM2U IS-HO ratios

V. Conclusions

In this paper, an FLC-based auto-tuning scheme has been proposed for a standard IS-HO algorithm. FLCs perform traffic sharing between technologies by re-directing calls between technologies through changes in IS-HO parameters. A dynamic GSM-UMTS system-level simulator has been developed, including a standardized IS-HO algorithm.

Simulations have shown that, in the case considered, BCR can be reduced by a factor of 4 by tuning IS-HO parameters. Hence, it can be concluded that the proposed scheme is a cost effective method to increase network capacity. The price to be paid is a significant increase in network signaling load due to more IS-HOs. It is expected that such a negative effect can be counteracted by jointly tuning JAC and IS-HO parameters.

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