On Managing Multiple Radio Access Congestion Events in B3G Scenarios

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Abstract— Among the Common Radio Resource Management (CRRM) functions that are responsible for the proper allocation of resources in a multi-access network, congestion control is the one devoted to overcome potential QoS failures due to the inherent dynamics of the network. In this paper we address the problem of congestion control in a scenario considering the GSM/EDGE Radio Access Network (GERAN) and the UMTS Terrestrial Radio Access Network (UTRAN). In particular, we face the problem where the two available Radio Access Technologies (RATs) undergo simultaneous congestion situations. For this case, a congestion resolution scheme based on Vertical (inter-system) Handover (VHO) jointly with a bit-rate reduction (BRR) scheme is proposed and evaluated for a mixed services scenario considering voice and data users.

Keywords- Common Radio Resource Management (CRRM); Congestion Control; GERAN; UTRAN; Beyond 3G.

I. INTRODUCTION

The heterogeneous network concept for Beyond 3G (B3G) systems proposes a flexible and open architecture where a large variety of Radio Access Technologies (RATs) will coexist and operate in a coordinated way supporting several services, applications and Quality of Service (QoS) classes interfacing through a common core network [1][2]. In this way, not only the user can be served through the RAT that fits better to the terminal capabilities and/or service requirements, but also a more efficient use of the total amount of available radio resources can be achieved. This potential gain offered by B3G systems may be exploited by the introduction of new Radio Resource Management (RRM) strategies which operate from a common perspective taking into account the overall resources in all the available RATs, and therefore are referred to as Common RRM (CRRM). In this way, the heterogeneous network may become transparent to the final user and the so-called ABC (Always Best Connected) paradigm [3], which claims for the connection to the RAT that offers the most efficient radio access at each instant, can be achieved.

Among the existing RRM functions devoted to ensure a proper utilisation of the available resources, congestion control (CC) faces situations in which the system has reached an overload status and therefore the QoS guarantees are at risk due to the evolution of system dynamics [4]. Although the term congestion may be used in other contexts, in this paper congestion affects the radio interface level. In this sense, few efforts have been devoted to analyse and evaluate radio congestion control in B3G scenarios [5]. Congestion control has been extensively covered in the literature in the area of fixed computer networks, e.g. [6]. Also at the radio access level it has also been addressed in a number of papers, e.g. [7] and [8], although considering one single RAT. In [9], the authors presented a framework for common congestion control taking into account a scenario where CDMA and TDMA technologies were deployed. Some congestion resolution methodologies were presented taking advantage of the CRRM concepts. In particular, a congestion resolution method using inter-system (vertical) handover (VHO) was presented and evaluated. This method proved to be suitable in scenarios where only one of the RATs was in a congestion state.

The work presented in this paper provides a new congestion control algorithm combining VHO and bit-rate reduction (BRR) techniques so as to lessen congestion status in scenarios with a CDMA-based (e.g. UTRAN, UMTS Terrestrial Radio Access Network) and a TDMA-based (e.g. GSM/EDGE Radio Access Network) network, in which both RATs are undergoing congestion.

In the following, section II presents some notions on CC in GERAN and UTRAN scenarios. In section III, the proposed congestion resolution mechanism is shown. Section IV deals with the implementation issues related to congestion resolution in both systems. Simulation setup is given in section V and simulation results are provided in section VI. This paper ends with some concluding remarks in section VII.

II. RADIO CONGESTION CONTROL IN GERAN/UTRAN

Three main procedures must be taken into account when dealing with congestion situations, [4], namely congestion detection (CD), congestion resolution (CR) and congestion recovery (CRV). CD is responsible for monitoring the network status in order to correctly identify a congestion situation by means of RAT-specific measurements. On the other hand, CR actuates over a set of RAT-specific parameters in order to reduce the load and consequently the congestion situation. Finally, some time after the congestion has been solved CRV will attempt to restore the transmission parameters that were set before the congestion was triggered.

This paper will concentrate on the CD and CR mechanisms. Due to different access schemes used in TDMA/FDMA-based GERAN and CDMA-based UTRAN, these mechanisms will

have to be RAT-specific. The following sub-sections present these particular CD and CR mechanisms.

A. Congestion Detection

In GERAN, radio resources (i.e. timeslots) are shared between voice and data users. While voice users demand a fixed and constant amount of resources during the entire call, data services make use of the concept of "capacity on demand" where resources are dynamically allocated whenever packets are waiting to be delivered. In this way, several data users may share the same timeslot by means of a proper scheduling algorithm [10]. In this context, overload situations may occur due to the excessive resource sharing among data users over the same timeslot. Bearing this in mind, it was proposed in [9] that the reduction factor (RF) could be useful to account for the congestion effect of timeslot sharing among users. This parameter takes values between 0 and 1, meaning a high timeslot reuse in the former and a low timeslot reuse in the latter. At a given time, the RF can be computed, in both uplink (UL) and downlink (DL), as:

$$RF = \begin{cases} 1 & \text{if } 0 \leq N_d \leq C_d \\ C_d / N_d & \text{if } N_d > C_d \end{cases} \tag{1}$$

where C_d is the number of channels devoted to data users and N_d is the number of assigned data timeslots over the C_d channels. Then, fixing a reduction factor threshold RF_{CD} linked to some QoS parameter (e.g. a minimum bit rate), if $RF < RF_{CD}$ during a certain number of frames, the CR mechanism is triggered.

In UTRAN, overload situations may be detected using the load factor η which can be measured, for UL and DL, as [11]:

$$\eta_{UL} = 1 - \frac{P_N}{I_{total}} \quad (2) \qquad \eta_{DL} = \frac{P_{total}}{P_{max}} \quad (3)$$

with P_N the background thermal noise, I_{total} the total received power at the Node-B, P_{total} the total transmission power and P_{max} the maximum Node-B transmission power. Then, the criterion to decide whether we have entered a congestion situation consists in checking if $\eta_{\{UL,DL\}} > \eta_{CD}$ during a certain percentage of frames within a given period of time.

B. Congestion Resolution

After a congestion situation is detected by the CD procedure, a congestion resolution (CR) algorithm is triggered. The CR procedure will then actuate over a set of parameters or procedures in order to reduce the load and consequently overcome the congestion situation. It is necessary that these actions consider the current network status, the cause of the congestion situation and service/user-type mixings, among other issues. A set of possible actions aiming to reduce the load in each of the RATs are:

- Blocking of new connections: users demanding admission in the system may be forbidden of doing so as long as a congestion status remains.
- Transmission rate control: in UTRAN, load factor can be reduced by effectively managing users' data rates at the radio interface by modifying the allowed transport formats.
- Handover (HO): attempt handover to neighbouring cells

(i.e. Horizontal HO) or to other RATs (Vertical HO) in order to lessen the load in the congested RAT.
- Call/Session dropping: terminate ongoing calls or sessions managed by the congested cell/RAT.

In order to reduce the load in the system and, consequently, mitigate congestion, load reduction algorithms may be devised by making an efficient use of one or more actions defined above. Note that some of these actions will only apply to specific RATs while other may be used seamlessly.

III. PROPOSED CONGESTION CONTROL MECHANISM

In a multi-RAT environment, to perform a VHO should be the preferred option since it may solve the congestion situation without degrading the quality perceived by users [9]. However, given a scenario where both GERAN and UTRAN RATs are in a congestion state, solely performing VHO among RATs will not solve the congestion. This is because a VHO to congested cell/RAT will usually not be allowed. An approach that aims to solve the congestion under these circumstances consists in reducing the congestion in UTRAN by means of reducing the users' bit-rate demands so that not only the congestion in UTRAN is solved but it also enables the allocation of VHO users from GERAN and, in this way, congestion is also solved in GERAN. This two-step procedure combining BRR technique with VHO is depicted in Fig. 1 and explained in the following.

(a) Before CC procedure   (b) Solve UTRAN congestion by means of BRR

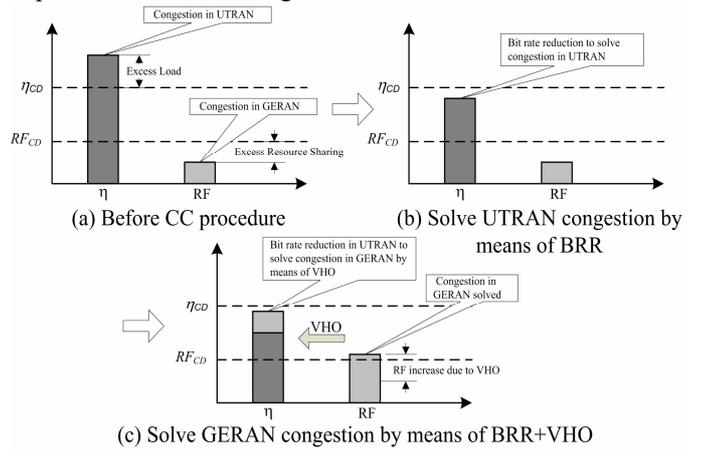(c) Solve GERAN congestion by means of BRR+VHO

Figure 1.   Congestion resolution in a UTRAN/GERAN congested scenario.

Given that congestion events may arise independently in the uplink and/or downlink, congestion resolution mechanisms should face the problem specifically in each link.

A. Uplink Congestion Resolution

1) Step 1: Congestion Resolution in UTRAN

The UL load factor reduction needed to solve the congestion in UTRAN by means of iteratively performing BRR over n users, $\Delta\eta_{UL,BRR_n}$, may be computed as:

$$\Delta\eta_{UL,BRR_n} = \eta_{UL,measured} - \eta_{CD} \tag{4}$$

where $\eta_{UL,measured}$ is the measured UL load factor.

It can be shown, [11], that η_{UL} in (2) may be re-written as a load factor contribution of the N users in the system, i.e.:

$$\eta_{UL} = (1 + f_{UL}) \sum_{i=1}^{N} \left[A_i / R_{b,i} + 1 \right]^{-1} \tag{5}$$

with f_{UL} the estimated inter-to-intra-cell interference ratio, $R_{b,i}$ the bit rate requirements of user i and $A_i = W/(E_b/N_o)_i$ the ratio between the total bandwidth (W) and the bit-energy-to-noise-density ratio requirement for user i. Then, the load factor reduction achieved after reducing a user i from bit-rate $R_{b,i}^{(old)}$ to bit-rate $R_{b,i}^{(new)}$ with $R_{b,i}^{(old)} > R_{b,i}^{(new)}$ is:

$$\Delta\eta_{UL,BRR_i} = \frac{1+f_{UL}}{A_i/R_{b,i}^{(old)}+1} - \frac{1+f_{UL}^*}{A_i/R_{b,i}^{(new)}+1} \qquad (6)$$

where f_{UL}^* is the estimated inter-to-intra-cell interference ratio that results from the bit-rate reduction over the given user. As we will see further on, the estimation of f_{UL}^* is critical to the effective performance of the proposed load reduction scheme.

An iterative user-per-user approach over the set of users in the congested cell may be adopted. In each iteration, one user is modified in terms of its bit-rate requirements and the resulting load factor reduction computed. Then, at the *K-th* iteration, the cumulative load factor reduction, $\Delta\eta_{UL,BRR}^{(K)}$, can be written as:

$$\Delta\eta_{UL,BRR}^{(K)} = \Delta\eta_{UL,BRR}^{(K-1)} + \frac{1+f_{UL}}{A_i/R_{b,i}^{(old)}+1} - \frac{1+f_{UL}^*}{A_i/R_{b,i}^{(new)}+1} \qquad (7)$$

Bit-rate reductions will be possible as long as a minimum bit-rate requirements are satisfied, i.e. $R_{b,i}^{(new)} \geq R_{b,i}^{(min)}$. Then, the iterative procedure will stop whenever $\Delta\eta_{UL,BRR}^{(K)} \geq \Delta\eta_{UL,BRR_n}$, meaning that congestion has been solved in UTRAN, or alternatively, when no further bit-rate reduction is allowed, meaning that the congestion cannot be solved.

2) Step 2: Congestion Resolution in GERAN

Once UTRAN congestion has been solved, we must perform additional BRR in UTRAN so as to accommodate VHO users coming from GERAN. In GERAN, if the measured RF at a given time, $RF_{measured}$, is below the RF threshold RF_{CD}, it is required to perform n VHOs such that the resulting incremental RF, $\Delta RF_{VHO,n}$, is at least:

$$\Delta RF_{VHO,n} \geq RF_{CD} - RF_{measured} \qquad (8)$$

An iterative user-per-user procedure is considered for attempting VHO from GERAN to UTRAN until reaching the desired increment $\Delta RF_{VHO,n}$. In addition, a VHO user in UTRAN will add an amount of load factor given by:

$$\Delta\eta_{UL,VHO_i} = \frac{1+f_{UL}^*}{A_i/R_{b,i}^{(min)}+1} \qquad (9)$$

where it is assumed that VHO users are granted with the minimum bit-rate requirement, $R_{b,i}^{(min)}$, in UTRAN.

Bearing in mind the load contribution of the VHO user in UTRAN, given in (9), along with the actual load in UTRAN, we may proceed, if necessary, with the iterative BRR procedure given in (7), in order to accommodate the VHO user in UTRAN and thus lessen congestion in GERAN.

Alternatively, it may occur that no further BRR can be applied in UTRAN and still congestion remains in GERAN. In this case, the proposed algorithm cannot solve the congestion and further actions should be taken (e.g. dropping users), which are however out of the scope of this paper.

B. Downlink Congestion Resolution

Solving congestion situations in the DL may be approached analogously considering that the reduction in the DL load factor needed to overcome congestion, $\Delta\eta_{DL,BRR_n}$, is now:

$$\Delta\eta_{DL,BRR_n} = \eta_{DL,measured} - \eta_{CD} \qquad (10)$$

where $\eta_{DL,measured}$ is the measured DL load factor. Bearing in mind (3), a given DL load factor reduction may be expressed in terms of a reduction in the transmitted power by n users in the congested cell, i.e. $\Delta P_{T,n}$. Consequently, an iterative procedure similar to what was done in the UL can be carried out so as to lessen the congestion in UTRAN/GERAN.

IV. IMPLEMENTATION ISSUES

In UTRAN, the effective election of users data rate, $R_{b,i}$, is managed by means of Radio Bearer (RB) control procedures [12]. Upon Radio Bearer setup, users allocated in UTRAN are granted with a Transport Format Combination Set (TFCS) for both the UL and DL according to the required service. This TFCS contains the possible Transport Format Combinations (TFC), which set the number of Transport Blocks (TB) of a given size that have to be transmitted within a Time to Transmit Interval (TTI) (see Table I) [11]. Note that each TFC is associated with a certain bit rate. Initially, users can be allocated with the highest allowed TFC within the TFCS, i.e. $TFC_{UL}^{(0)} = TFC_{UL,max}$ and $TFC_{DL}^{(0)} = TFC_{DL,max}$. If congestion is detected in UTRAN UL or DL, we may reduce the UL or DL TFC of a given user by an amount n_TFC in order to lessen the load and hence the congestion status. This way, after the reduction of n_TFC of a given user the new TFC becomes:

$$TFC_l^{(new)} = \max(TFC_l^{(old)} - n\_TFC_l, TFC_{l,min}) \qquad (11)$$

where we assume that there must be a minimum TFC in each link $l \in \{UL, DL\}$, $TFC_{l,min}$, that ensures some minimum bit-rate requirements. Note that $TFC_l^{(old)}$ and $TFC_l^{(new)}$ correspond to bit-rates $R_{b,i}^{(old)}$ and $R_{b,i}^{(new)}$ in (6) and (7).

Note that the value of n_TFC_l will determine the pace of the BRR scheme. According to the TFC reducing pace in the system, we may classify these algorithms in fast and slow BRR algorithms [11]. Fast reduction algorithms try to execute high BRR to a reduced number of users. On the contrary, in slow reduction algorithms, low BRR are executed over a higher number of users. According to this, two BRR schemes are proposed in this paper:

TABLE I. PARAMETERS FOR UTRAN INTERACTIVE RAB 64/128 [13].

		UPLINK		DOWNLINK	

		UTRAN Interactive RAB UL64/DL128			
Payload size (bit)		320			
TTI (ms)		20			
		UPLINK		**DOWNLINK**	
		num TB x TB size	Data rate (bps)	num TB x TB size	Data rate (bps)
TFS	TF0 (bits)	0x320	0	0x320	0
	TF1 (bits)	1x320	16000	1x320	16000
	TF2 (bits)	2x320	32000	2x320	32000
	TF3 (bits)	3x320	48000	4x320	64000
	TF4 (bits)	4x320	64000	8x320	128000

a) Maximum BRR (MAX-BRR): Applying the maximum allowable transmission rate reduction on a given user, i.e. $n\_TFC_l = TFC_{l,max}$.

b) Minimum BRR (MIN-BRR): Where the reduction on each user is the minimum allowable reduction, i.e. $n\_TFC_l = 1$.

In GERAN, VHO tasks require base station (BS) selection procedures so that the user is directed to the most suitable UTRAN BS. In this paper it is assumed that the BS with the highest E_c/I_o among those that are above a given threshold is chosen. Furthermore, the VHO procedure should be aware of the congestion status of the destination BS. If the chosen BS undergoes a congestion state the VHO is not allowed.

Also note that each VHO user directed to UTRAN must request admission by means of the Admission Control (AC) procedure, which in UTRAN includes both UL and DL procedures [11]. Therefore, admission will be gained only if UL and DL admission algorithms decide so. In consequence, CC procedures must not only take into account the congested link but also should guarantee admission in both UL and DL links. In particular, after performing BRR in the UL to accommodate a VHO user it could happen that no free OVSF codes are available in the DL [11]. Then, CC may attempt to diminish DL resources by effectively reducing the DL TFC of some users already admitted in the system.

Another issue to consider when attempting VHO on a number of users is the prioritisation among users. Many implementations are possible according to service type, location, user type, etc. Without loss of generality, it is assumed that users are chosen randomly among those being served in the congested GERAN cell, so all the users have the same precedence.

V. SIMULATION SETUP

The proposed scenario considers GERAN and UTRAN RATs in 7 co-located sites with equal coverage over an area of 4.5 km by 4.5 km and with cell radius of 1km. The urban macrocell propagation model is assumed and omnidirectional antennas are considered in both systems. A mix of voice and interactive traffic users is considered with all terminals having multi-mode capabilities. In GERAN, voice users are allocated to full-rate channels, i.e. one timeslot in each frame, which offers a bit-rate per user of 12.2 kbps both in the UL and DL. In UTRAN, the RAB for voice users is the 12.2 kbps given in [13]. Interactive (web browsing) users in GERAN are allocated assuming multislot capabilities with up to 2 UL slots and 3 DL slots, with maximum number of 4 UL+DL slots. The assumed Modulation and Coding scheme (MCS) is MCS-7 [14], which offers a bit-rate of 44.8 kbps per time-slot. In UTRAN, the RAB for interactive users is shown in Table I.

Admission control procedure for voice and interactive users in UTRAN consider checking the UL load factor ($\eta_{UL,max}$=1), the DL transmitted power ($P_{DL,max}$=42dBm) and the availability of OVSF codes at the BS [11]. In GERAN, voice users are accepted provided there are free available time slots. Otherwise, they make use of voice priority by reducing the slot requirements of ongoing data users, or by dropping data users if necessary. Data users are accepted given that there are

free timeslots and that the maximum number of users sharing the same slot is at most 8 for the UL and 32 for the DL.

Users are non-homogeneously distributed over the scenario considering a 1km radius circular hot-spot around the central cell which includes 25% of the total users in the scenario.

Regarding user allocation in each RAT, i.e. GERAN and UTRAN, a service-based RAT selection policy presented in [14] is used. In brief, voice traffic is directed to GERAN and interactive traffic is directed to UTRAN provided capacity is available in each of the RATs. Otherwise, users attempt admission in the opposite RAT. If finally the admission is not possible, users are blocked.

Threshold values for congestion detection in UTRAN and GERAN are η_{CD}=0.6 and RF_{CD}=0.2 respectively.

Furthermore, MIN-BRR algorithm is used to reduce bit-rate requirements of UTRAN users (MAX-BRR was also simulated but no global significant differences were noticed).

VI. SIMULATION RESULTS

As mentioned in section III, to determine the convenient values for the intercell-to-intracell interference ratios in (7) and (9) is crucial for the effective operation of the proposed congestion resolution scheme. Fig. 2 shows the UL load factor in UTRAN before and after the presented CC scheme is applied. The values of f_{UL} and f_{UL}^* have been statistically estimated considering the 50th percentile of the CDF as suggested in [11]. In our case, the values for f_{UL} and f_{UL}^* were 0.4 and 1.0 respectively. The higher value of f_{UL}^* is justified bearing in mind that bit-rate reduction in UTRAN implies a lower transmitted power by these users. Consequently, there will be a reduction in the intracell interference while intercell interference remains at similar levels. For the sake of comparison, the case when both ratios are equal is also plotted, i.e. $f_{UL} = f_{UL}^* = 0.4$. It can be seen that for an adequate estimation of the load reduction obtained by BRR, f_{UL} and f_{UL}^* must be carefully estimated. Indeed, for the case of $f_{UL} = f_{UL}^* = 0.4$, the resulting load factor is still above the congestion threshold while as for $f_{UL} = 0.4$ and $f_{UL}^* = 1.0$, the estimation guarantees that the load factor resides below the threshold.
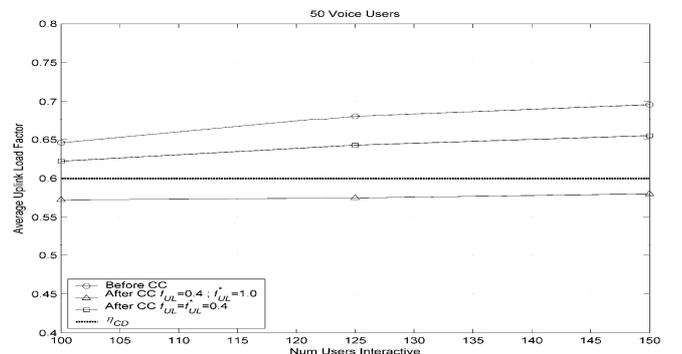

Figure 2. Intercell-to-intracell factor influence on BRR load estimation.

Fig. 3 shows the average RF in both links measured at the central cell before and after the CC procedure. Regard that the RF limitation, i.e. lower RF, is set on the DL due to the higher amount of resources allocated in this link according to the specified multi-slot capabilities. In any case, the CC algorithm will cause an increase in the RF over the defined threshold after attempting VHO of users from GERAN to UTRAN.

As for UTRAN, Fig. 4 shows the average load factor in both UL and DL for several traffic mixes before and after CC. Results indicate that, for UTRAN, the bottleneck is set on the UL, which will undergo load factor values exceeding the threshold η_{CD}. In the DL however, load remains below η_{CD} due to the higher power level available in the DL direction.

In terms of throughput, different behaviours are expected in each RAT. In GERAN, CC will reduce excessive timeslot sharing among users by performing VHO to UTRAN, thus throughput per user is expected to increase (Fig. 5). In UTRAN however, BRR will be carried out in order to diminish the load factor and to accommodate users arriving from GERAN, thus throughput per user is reduced (Fig. 6). As a result, after CC is applied, in both systems we can guarantee a minimum bit-rate of around 25 kbps per user as opposed to poorer performance if CC was not applied.

VII. SUMMARY

In this paper the problem of congestion control in heterogeneous B3G networks has been addressed in a scenario where congestion arises in both GERAN and UTRAN. The envisaged solution exploits the higher flexibility offered in UTRAN systems so as to solve congestion in both systems by means of a combined resource reduction and VHO scheme. Results have been provided showing that such schemes succeed in solving congestion and still maintaining some minimum bit-rate guarantees.

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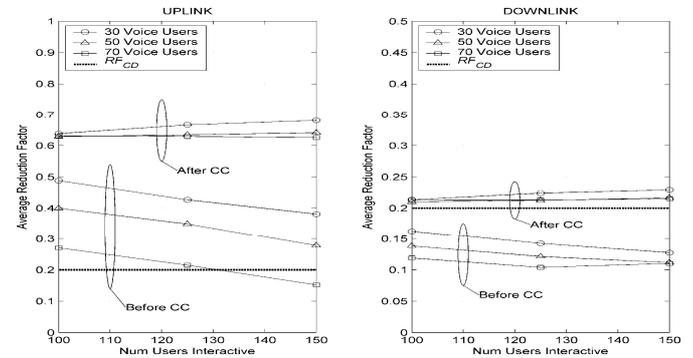
Figure 3.   Average RF in GERAN before/after applying CC.
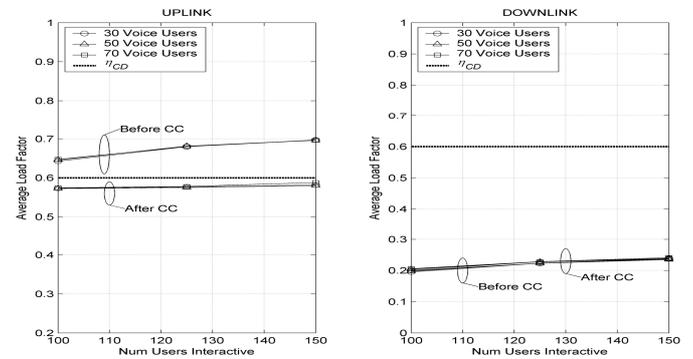

Figure 4.   Average load factor in UTRAN before/after applying CC.
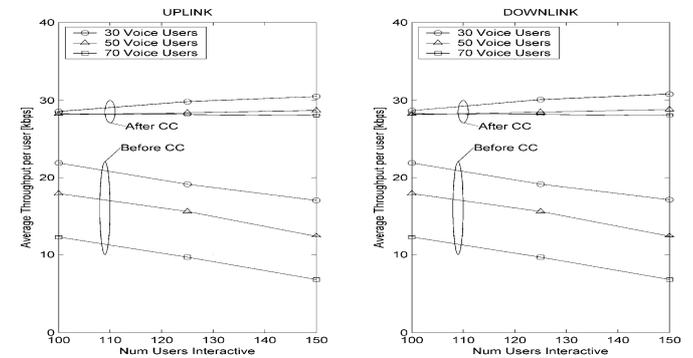

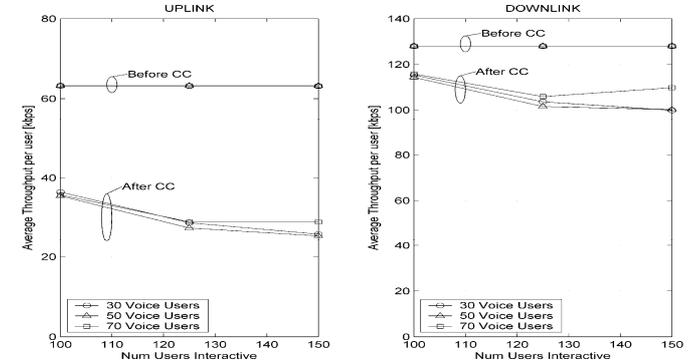Figure 5.   Average throughput per user in GERAN before/after applying CC.

Figure 6.   Average throughput per user in UTRAN before/after applying CC.