Network-Controlled Cell-Breathing
for Capacity Improvement
in Heterogeneous CDMA/TDMA Scenarios

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Abstract.-This paper proposes a new Common Radio Resource Management (CRRM) methodology which allows increasing the capacity of heterogeneous CDMA/TDMA. This is achieved by controlling the effective cell radius of the CDMA-based system (i.e. a network-controlled cell-breathing) through appropriate initial RAT selection and vertical handover strategies, so that the interference level in the CDMA-based RAT is reduced while at the same time the target coverage area is assured by means of the cooperation of the FDMA/TDMA based RATs. The proposed approach is evaluated by means of system level simulations in a detailed scenario including UTRAN and GERAN as examples of CDMA and FDMA/TDMA-based access technologies. Results reveal that throughput improvements up to 24% can be achieved with respect to other CRRM strategies based on load balancing principles.

I. Introduction

In general, cellular wireless systems become interference-limited and, consequently, any engineering technique devoted to either reduce interference or to improve the robustness of the system to bear interference will readily increase network capacity and operator's revenue. Managing interference has been a recurrent topic of interest for many years and the problem has been coped from many different perspectives. Channel coding, power control or antenna beamforming are only some examples. Conceptually, the ultimate objective of the proposal presented in this paper also pursues a reduction in the interference level in the scenario and, consequently, targets an overall improvement in the radio resources usage. Nevertheless, a different approach is followed, as described in the following.

The framework considered in this paper is that of heterogeneous radio access networks (RANs), also known as Beyond 3G (B3G) systems. The heterogeneous network concept is intended to propose a flexible and open architecture for a large variety of wireless access technologies, applications and services with different QoS demands, as well as different protocol stacks. Radio access networks include cellular networks and also other public non-cellular access networks (e.g. WLAN). Cellular networks may in turn be subdivided into different layers (e.g. macro, micro or picocells). In these new scenarios, different Radio Access Technologies (RATs) will coexist and will operate in a coordinated way.

Wireless networks differ from each other by air interface technology, cell-size, services, price, access, coverage and ownership. The complementary characteristics offered by the different radio access technologies (RATs) make possible to exploit the trunking gain leading to a higher overall performance than the aggregated performances of the stand-alone networks. Clearly, this potential gain of B3G systems can only turn into reality by means of a proper management of the available radio resources. Common Radio Resource Management (CRRM) refers to the set of functions that are devoted to ensure an efficient and coordinated use of the available radio resources in heterogeneous networks scenarios [1]-[3] . More specifically, CRRM strategies should ensure that the operator's goals in coverage and QoS are met while providing as high as possible overall capacity (i.e. the sum of the capacities achieved in every single RAN). Within CRRM, the initial RAT selection, i.e. the allocation of connections to specific RANs at session initiation, and the vertical handover (VHO), i.e. the capability to switch on-going connections from one RAN to another, are the key enablers to properly manage the heterogeneous radio access network scenario and become then key CRRM functions [4].

In this context, this paper intends to exploit the different sensitivity that diverse RATs may exhibit to interference so that a smart CRRM follows. In particular, in FDMA/TDMA-based access systems (e.g. GSM/GPRS) there is no intra-cell interference. In turn, inter-cell interference is caused by a single user in every co-channel cell. In contrast, in CDMA-based systems (e.g. UMTS) the intra-cell interference is caused by every single user transmitting in the cell. Furthermore, inter-cell interference is also originated by all simultaneous users in all neighbouring cells, since a complete frequency reuse is considered. Consequently, CDMA systems are much more sensitive to multi-user interference than FDMA/TDMA ones.

The underlying idea of the CRRM approach developed in this paper is to take advantage of the coverage overlap that several RANs using different access technologies may provide in a certain service area in order to improve the overall interference pattern generated in the scenario for the CDMA-based systems and, consequently, improving the capacity of the overall heterogeneous scenario. This can be achieved by controlling the effective cell radius of CDMA-based systems (i.e. a controlled cell-breathing effect) through appropriate initial RAT selection and vertical handover approaches, so that the interference level in CDMA-based RATs is reduced while at

the same time the target coverage area is assured by means of the cooperation of the FDMA/TDMA-based RATs.

It is worth mentioning that CRRM has been identified as an important issue by the 3GPP, which defines some recommendations and architectures for CRRM operation [1][2], as well as by the research community. For example, literature has covered the effects of load balancing in inter-RAT handover procedures. In particular, in [5], the effect of tuning the load-based handover (HO) thresholds depending on the load of inter-system/inter-layer/inter-frequency cells is studied. In [6], a force-based load balancing approach is proposed for initial RAT selection and vertical HO decision making. In turn, in [7] the authors compare the load balancing principles with respect to service-based CRRM policies. Similarly, Lincke discusses the CRRM problem from a more general perspective in e.g. [8] and references therein, comparing several substitution policies and evaluating them by means of simulations. This paper advances state-of-the art developments in this field by exploiting the concept of network-controlled cell-breathing through CRRM strategies, proposing specific algorithms and evaluating them in detailed system level simulations in order to proof the concepts.

According to the above framework, this paper is organised as follows. In section II the network-controlled cell-breathing concept is introduced. Then, section III presents the proposed RAT selection and VHO strategies to achieve the desired cell-breathing control. Section IV describes the simulation model considered to evaluate the performance, where UTRAN (UMTS Terrestrial Radio Access Network) and GERAN (GSM/EDGE Radio Access Network), as examples of CDMA and FDMA/TDMA-based RATs, respectively, coexist. Results are presented in section V and finally conclusions are summarized in section VI.

II. NETWORK-CONTROLLED CELL-BREATHING CONCEPT

The proposed controlled cell-breathing strategy is illustrated in Figure 1 for a situation where CDMA and FDMA/TDMA cells are co-sited. R_T denotes the planned cell radius in FDMA/TDMA and R_C denotes the variable effective cell radius in CDMA. Notice that, for a given service, the FDMA/TDMA cells ensure coverage in the whole area. In turn, by an appropriate control of the effective cell radius R_C (e.g. in the figure by changing from R_{C2} to R_{C1}) in CDMA cells through CRRM strategies, the required transmitted power levels and the inter-cell interference will be reduced, thus improving the capacity for the considered service in the CDMA RAT. Notice that, depending on the existing load conditions as well as the robustness of the specific services to interference, the CDMA radius could be eventually set equal to R_T. Similarly, Figure 2 illustrates the situation in which no co-siting exists between FDMA/TDMA and CDMA cells, reflecting that the proposed concept would also be applicable in this case.

In practice, due to the shadowing effects, the cell radius is controlled by setting the maximum propagation loss that can be allowed for a given RAT. Taking this into account, this paper

proposes a CRRM strategy that allocates users to RATs according to their propagation losses. Then, users with low propagation loss will be allocated to the CDMA cells and users with high propagation loss will be allocated to the FDMA/TDMA cells. It will be shown that, by setting a suitable maximum path loss threshold, the CDMA-based RAT achieves the desired network-controlled cell-breathing effect and the corresponding increase in performance.
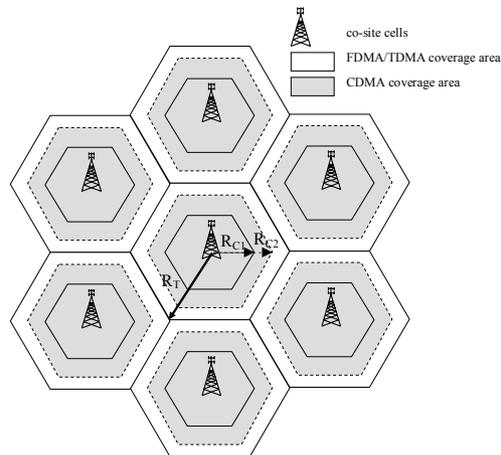

Figure 1 Network controlled cell-breathing when CDMA and FDMA/TDMA cells are co-sited
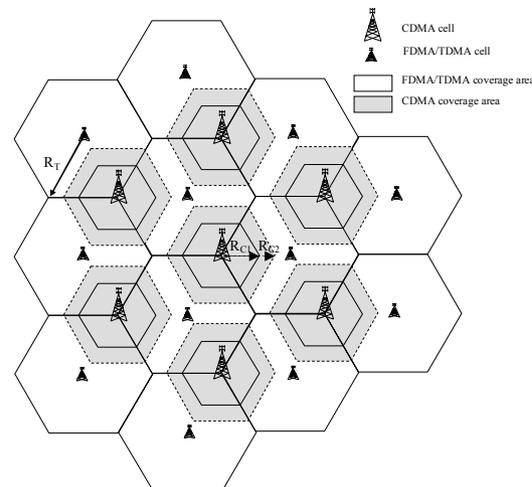

Figure 2 Network controlled cell-breathing without co-siting between CDMA and FDMA/TDMA cells

III. RAT SELECTION STRATEGIES

RAT selection strategies are devoted to decide the adequate access technology that each connection should be connected to. This decision is taken at session initiation, this case denoted as Initial RAT selection procedure, as well as during session lifetime, which can trigger a Vertical handover procedure in case the current RAT must be changed. RAT selection strategies may respond to different principles, like e.g. service-based policies (i.e. allocating the RAT according to the service characteristics) or load balancing principles (i.e. try to keep similar load levels in the different RATs). As described in section II, the approach considered in this paper intends to achieve an overall improvement by reducing the amount of

interference generated by users allocated in CDMA-based RATs through the regulation of the maximum allowed path loss, turning into a cell-breathing control. Therefore, the proposed CRRM strategy will be referred to as Network-Controlled Cell-Breathing (NCCB) strategy. For comparison purposes, a load balancing (LB) strategy will also be considered.

At this stage, it is worth mentioning that, in order to introduce the potentials of the network-controlled cell-breathing concept introduced in this paper, the feasibility of a suitable mapping between equivalent bearers in the considered RATs will be assumed (e.g. a voice service supported with a given bearer in RAT#1 can be supported with similar QoS with a given bearer in RAT#2). The extension of the proposed strategy to multi-service scenarios with some services not having equivalent bearers (e.g. a 384 kb/s bearer supporting an interactive service in WCDMA does not have the counterpart in 2G TDMA-based system) is considered out of the scope of this paper and is left for future work.

A. Network-Controlled Cell-Breathing (NCCB) strategy

Figure 3 illustrates the flow diagram of the initial RAT selection part in the proposed NCCB strategy. The decision is taken according to the path loss measurements in the best CDMA cell, provided by the terminal in the establishment phase. The path loss is computed by measuring the received downlink power from a common control channel whose transmitted power is broadcast by the network. Measurements are averaged in periods of T seconds. In case that the resulting path loss is higher than a given threshold PLth, the selected RAT will be FDMA/TDMA, while if the path loss is below the threshold the selected RAT will be CDMA. In case that there is no capacity available for the new session in the selected RAT (i.e. the admission control is not passed), the other RAT will be selected instead. Finally, if no capacity is neither available in the other RAT, the session will be blocked.

The corresponding vertical handover decision procedure is shown in Figure 4. The idea behind this procedure is to keep the high path loss users connected to FDMA/TDMA and the low path loss users to CDMA depending on how the propagation conditions vary along the session lifetime. Nevertheless, and in order to avoid undesired ping-pong effects leading to continuous RAT changes for users with path loss close to the threshold PLth, an hysteresis margin Δ (dB) is introduced together with a number of consecutive samples that each condition must be fulfilled before the VHO decision is triggered. This number is M_{up} when the condition is the path loss being above the threshold and M_{down} for the path loss below the threshold. On the other hand, it should be mentioned that the VHO is only executed in case that there is capacity available in the target RAT (i.e. if the admission control is passed).

B. Load Balancing (LB) strategy

As a reference, the above algorithm has been compared with a CRRM strategy based on load balancing, which aims at keeping the same load in both CDMA and FDMA/TDMA, similar to those in [5][7]. To this end, the initial RAT selection

process consists in allocating the user to the RAT with the lowest load level. For CDMA, the load is measured as the uplink load factor [9], given by the ratio between the intercell and intracell received power with respect to the total received power including background noise. In turn, in FDMA/TDMA the load is measured as the fraction between the occupied slots with respect to the total number of existing slots. Both load measurements are averaged in periods of 10s to smooth load fluctuations and are obtained from the base stations having the lowest path loss among those of each RAT. Furthermore, the vertical handover algorithm is also based on load balancing. To this end, and whenever a horizontal handover is required in the current RAT, the suitability of executing a vertical handover instead is evaluated, so that the mobile is again served by the lowest loaded RAT.
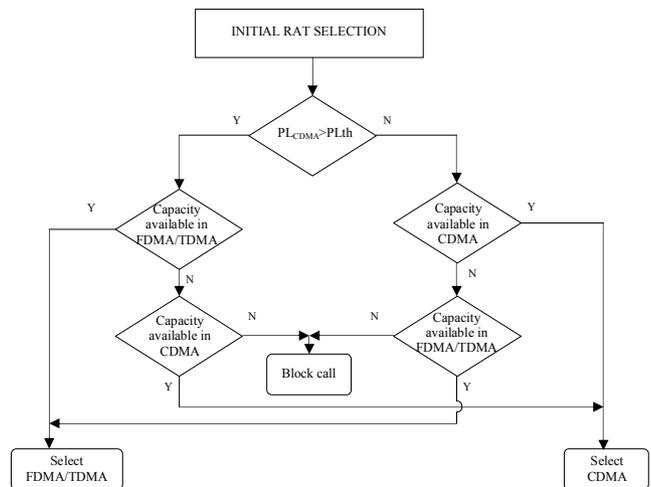

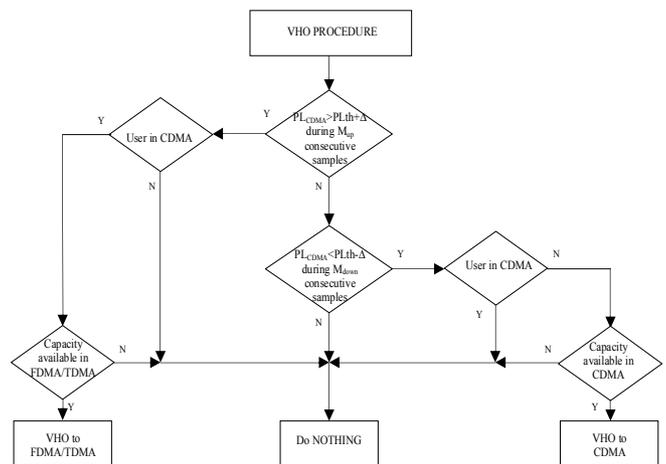
Figure 3 Initial RAT selection in the NCCB strategy

Figure 4 VHO process in the NCCB strategy

IV. SIMULATION MODEL

The considered approaches have been evaluated by means of system level simulations that take into consideration in detail the characterisation of the different RANs. Specifically, UTRAN and GERAN are considered as examples of CDMA-based and FDMA/TDMA-based RATs. The scenario considers 7 omnidirectional cells for GERAN and 7 for UTRAN. The cells of both RANs are collocated. The separation between

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base stations is 2 km. In case of GERAN, it is assumed that the 7 cells represent a cluster so that all the cells operate with different carrier frequencies. The parameters of the UE and the UTRAN and GERAN cells are summarised in Table I and Table II, respectively. It is assumed that all terminals have multi-mode capabilities, i.e. they can be connected either to UTRAN or to GERAN. Three carriers per cell in the 1800 MHz band are assumed in GERAN and a single UTRAN FDD carrier is considered in UTRAN. In this way, the total bandwidth available in the cluster of seven GERAN cells is approximately the same as the bandwidth used by UTRAN. The urban macrocell propagation model in [10] is considered for both systems, with the path loss as a function of the distance d to the base station given by:

$$Lp(dB)=128.1+37.6\log(d(km))+S(dB) \qquad (1)$$

where S(dB) corresponds to the log-normal shadowing with s=10 dB standard deviation. The mobility model described in [11] is considered with mobile speed 3 km/h and shadowing decorrelation distance 20 m.

TABLE I
UTRAN BS AND UE PARAMETERS

BS parameters	
Cell type	Omnidirectional
Maximum transmitted power	43 dBm
Thermal noise	-104 dBm
Common Control Channels Power	33 dBm
Maximum DL power per user	41 dBm
BLER target (UL)	1%
Eb/No target (UL)	9 dB
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-100 dBm
BLER target (DL)	1%
Eb/No target (DL)	10.9 dB
DL Orthogonality factor	0.4

TABLE II
GERAN BS AND UE PARAMETERS

BS parameters	
Cell type	Omnidirectional
DL transmitted power	43 dBm
Thermal noise	-117 dBm
Number of carriers	3
Sensitivity (UL)	-108 dBm
UE parameters	
Maximum transmitted power	33 dBm
Minimum transmitted power	0 dBm
Thermal noise	-113 dBm
Sensitivity (DL)	-104 dBm

In UTRAN, an iterative power control procedure is considered to simulate the inner loop power control aiming at achieving the target (Eb/No) that ensures the required Block Error Rate (BLER), thus determining the transmitted power in the uplink and in the downlink directions as well as the measured (Eb/No). On the other hand, the loss in orthogonality due to multipath in downlink transmissions of a given base station using OVSF (Orthogonal Variable Spreading Factor) codes is modelled by means of an orthogonality factor equal to 0.4.

With respect to GERAN, a slow power control is simulated in the uplink, so that the transmitted power is changed in steps of 2 dB every measurement period of 0.48s in order to reach a specific sensitivity level. No power control is simulated in the downlink, and all the channels are transmitted with maximum power. The sensitivity values and link layer characterisation is taken from [12].

Only the voice service is considered. Calls are generated according to a Poisson process with an average call rate of 10 calls/h/user and exponentially distributed call duration with an average of 180 s. In UTRAN, the Radio Access Bearer (RAB) for voice users is the 12.2 kb/s speech defined in [13], considering a dedicated channel (DCH) with spreading factor 64 in the uplink and 128 in the downlink. In turn, in GERAN, voice users are allocated to a TCH-FS (traffic channel full-rate speech), i.e. one time slot in each frame.

TABLE III
RRM PARAMETERS

UTRAN RRM PARAMETERS	
UL admission threshold (η_{max})	1.0
DL admission threshold (P_{max})	42 dBm
Measurement period	1s
Active Set size	1
Replacement hystheresis	3 dB
Time to trigger handover	0.64 s
Minimum Ec/Io	-16 dB
Dropping condition	1 dB below target during 20 s
GERAN RRM PARAMETERS	
Measurement period	0.48s
Minimum access power	-105 dBm
Minimum UL received power to trigger handover (L_RXLEV_UL_H)	-100 dBm
Minimum DL received power to trigger handover (L_RXLEV_DL_H)	-100 dBm
Number of consecutive samples below L_RXLEV_UL_H or L_RXLEV_DL_H to trigger handover	3
Dropping condition	5 dB below sensitivity during 20 s
NCCB ALGORITHM PARAMETERS	
Measurement interval (T)	1s
Hysteresis margin (Δ)	1 dB
Mup	3
Mdown	3
PLth	120 dB

The parameters of the NCCB CRRM algorithm and a summary of the main RRM parameters in UTRAN and GERAN is given in Table III. Regarding the admission control procedure in UTRAN, three conditions are checked [3], namely the uplink load factor should be below the threshold η_{max}, the downlink transmitted power below P_{max} and there must be available OVSF codes in the base station. With respect to GERAN, voice users are accepted provided that there are available time slots. With respect to the admission control for horizontal handovers, the availability of OVSF codes for UTRAN or time slots for GERAN is checked in the new cell. If admission is not passed, a vertical handover will be tried. If the vertical handover is not possible, then the call will be dropped. Vertical handovers will also be tried before dropping a call when the dropping conditions in Table III occur.

The results in this section are obtained with the value of PLth=120 dB as indicated in Table III. This value corresponds to the 60-th percentile of the path loss distribution, which means that around 60% of the users will perceive a path loss below 120 dB and therefore will be normally allocated in UTRAN while 40% of the users will be allocated in GERAN. Results not shown here for the sake of brevity indicate that this setting of PLth=120 dB becomes a good threshold setting because it is able to achieve the desired network-controlled cell-breathing effect while at the same time keeping similar load levels in the two considered RATs.

Figure 5 and Figure 6 present the Block Error Rate (BLER) performance for uplink and downlink, respectively, obtained with the NCCB and the LB strategies in the two considered RATs. It can be clearly noticed that the proposed NCCB strategy achieves an important reduction in the BLER in both links for the CDMA-based RAT (i.e. UTRAN) with negligible increase in the BLER of the FDMA/TDMA-based RAT (i.e. GERAN). This reveals the effectiveness of the network-controlled cell-breathing concept, able to reduce the interference and therefore to improve the performance in CDMA.
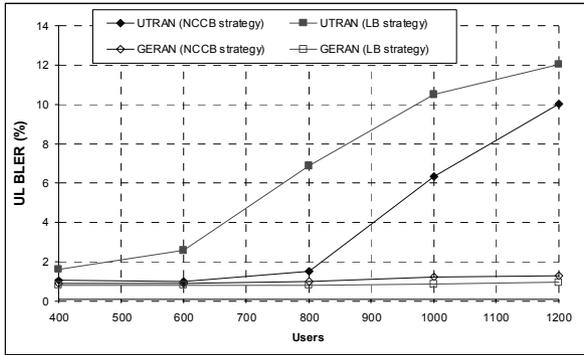

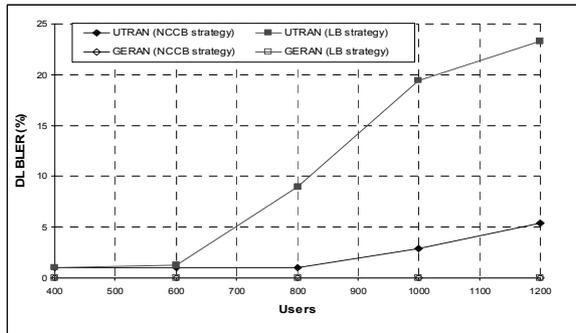Figure 5 Uplink BLER in UTRAN and GERAN

Figure 6 Downlink BLER in UTRAN and GERAN

The interference reduction in CDMA turns into a capacity increase, because, more users can transmit simultaneously, while on the other hand, transmissions are more effective since the BLER is lower. This is observed in Figure 7, which presents the comparison in terms of the total aggregated throughput in the scenario (i.e. including UTRAN and GERAN). The benefits of the proposed strategy can be clearly

observed with throughput increases of around 13% in the uplink and 24% in the downlink. Notice in Figure 8, which presents the uplink throughput in each RAT, that the capacity gain comes from UTRAN, while the throughput in GERAN remains similar to the one obtained with the LB strategy.

Similarly, Figure 9 illustrates the improvements obtained in terms of dropping and blocking probabilities, respectively, showing the better efficiency of the NCCB strategy to allocate the available resources in the two RATs among the different users.
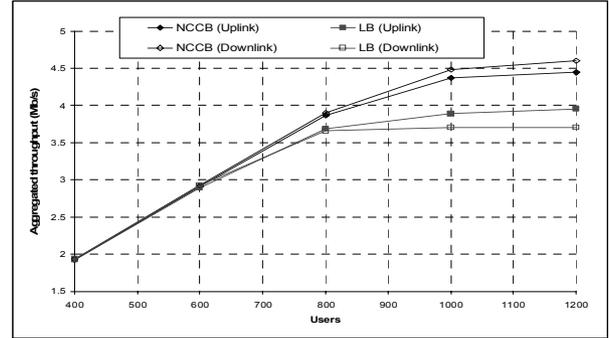

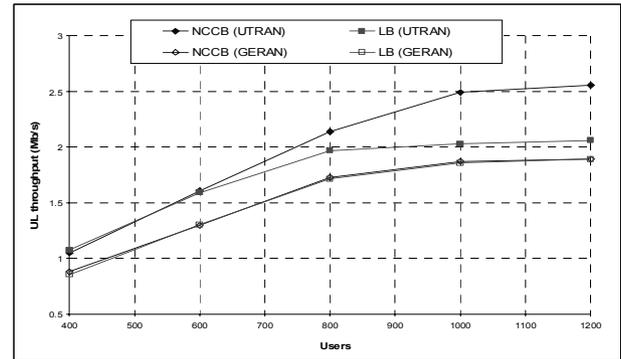Figure 7 Total throughput in uplink and downlink
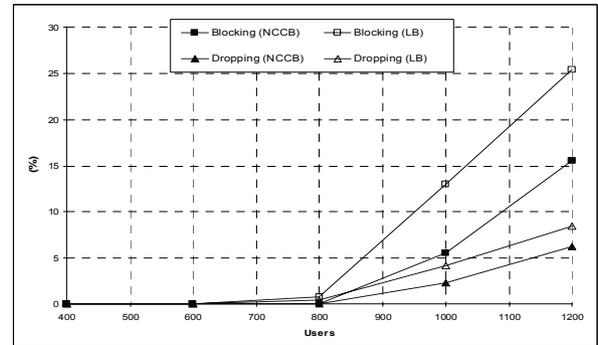

Figure 8 Uplink throughput per RAT

Figure 9 Blocking and dropping probabilities

Finally, in order to complete the study with some considerations regarding the required signalling, Figure 10 plots the ratio of vertical handovers per second with the NCCB and the LB strategies. Notice that LB requires less vertical handover executions because in this case the decision to make a VHO is only checked when a horizontal handover has been

decided in the current RAT (a part from the cases when a VHO is triggered because a dropping is about to occur), while in NCCB the VHO is triggered when crossing the limits imposed by PLth.
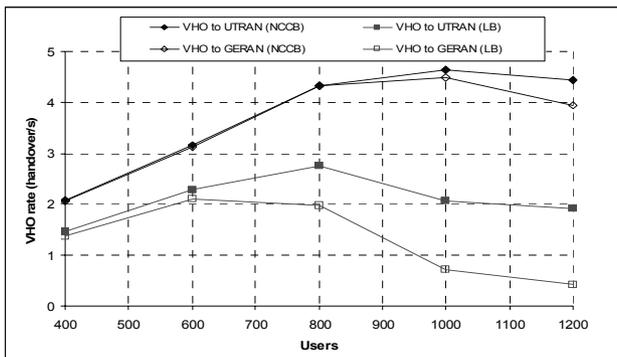

Figure 10 Vertical Handover rate

VI. CONCLUSIONS

This paper has presented the network-controlled cell-breathing (NCCB) strategy for CRRM in heterogeneous TDMA/CDMA scenarios that achieves a reduction in the interference level of the CDMA system by controlling the its effective cell radius through initial RAT selection and vertical handover policies. The strategy has been evaluated by means of system level simulations in a scenario with UTRAN and GERAN as two examples of access networks using the CDMA and FDMA/TDMA technologies. It has been compared against a classical load balancing strategy that tries to keep the same load level in both RATs. Results reveal that a significant improvement in terms of capacity for both uplink and downlink is achieved with the proposed strategy.

The present work has dealt with scenarios in which the same service can be provided with equivalent radio bearers in the considered access networks. Future work includes the extension of this strategy to multi-service scenarios in which there are not equivalent radio bearers in the two RATs for some of the services.

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