Network Controlled Cell Breathing in Multi-service heterogeneous CDMA/TDMA scenarios

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Abstract.- **This paper proposes a new Radio Access Technology (RAT) selection algorithm for multi-service scenarios which allows increasing the capacity of heterogeneous CDMA/TDMA systems by controlling the effective cell radius of the CDMA-based system (i.e. a network-controlled cell-breathing), so that the interference level is reduced. The strategy is evaluated in a scenario including voice and interactive traffic and combined with service-based RAT selection strategies.**

I. INTRODUCTION

The heterogeneous radio access networks (RANs) concept proposes 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. 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 Beyond 3G (B3G) systems requires 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]. They 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].

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, the 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. In [9] a framework for defining initial RAT selection policies combining service-based criteria and radio networks considerations is presented.

This paper focuses on a heterogeneous scenario where interference-limited CDMA-based access systems (e.g. UMTS) coexist with FDMA/TDMA-based access systems (e.g. GSM/EDGE). The underlying idea of the CRRM approach developed in this paper is to take advantage of the coverage overlap that these systems 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, to improve the capacity of the overall heterogeneous network. This can be achieved by controlling the effective cell radius of CDMA-based system (i.e. a controlled cell-breathing effect) through appropriate initial RAT selection and vertical handover approaches. This concept, denoted as Network-Controlled Cell-Breathing (NCCB) was originally proposed by the authors in [10] and [11], where it was evaluated in a scenario with a single voice service, revealing that it achieves a significant throughput gain with respect to a classical load balancing approach. In turn, this paper focuses on the case when several services are considered, in which the CRRM solutions should also take into account that not all the existing RANs may have the same abilities to handle all the services, resulting in different perceived QoS. For example, in GSM/GPRS systems interactive traffic is handled by means of shared channels while in UMTS dedicated channels can be used instead, thus allowing lower transmission delays. In this sense, this paper advances state-of-the art developments in the CRRM field by exploiting the concept of NCCB through CRRM strategies in multi-service scenarios, proposing specific algorithms and evaluating them with detailed system level simulations in order to proof the concepts.

The rest of the paper is organised as follows. Section II describes the Network Controlled Cell Breathing concept as the basis for developing several RAT selection strategies, as explained in Section III. Section IV describes the simulation model and performance results are presented in section V. Finally, conclusions are summarised in Section VI.

II. NETWORK CONTROLLED CELL BREATHING

The controlled cell-breathing strategy is illustrated in Fig. 1 for a situation where CDMA and FDMA/TDMA cells are co-sited, although it could be also applicable in situations when no co-siting exists. 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 the coverage in the whole area. In turn, by an appropriate control of the effective cell radius R_C in CDMA cells (e.g. in the figure by changing from R_{C2} to R_{C1}) 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 to R_T. 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. 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.

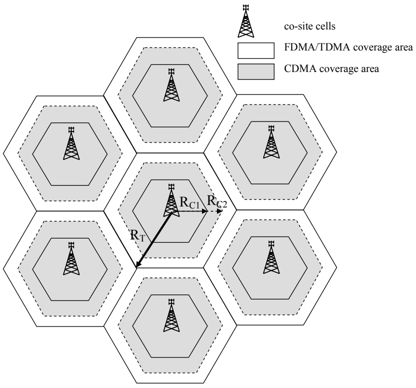

Fig. 1 Network controlled cell-breathing

III. RAT SELECTION STRATEGIES

RAT selection strategies decide the adequate access network that each user 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). In the following, several strategies combining the Network Controlled Cell Breathing concept explained in the previous section with service characteristics are presented for a scenario with conversational (i.e. voice) and interactive (i.e. www) services. The UMTS Terrestrial Radio Access Network (UTRAN) and the GSM/EDGE Radio Access Network (GERAN) are considered as examples of the CDMA and the FDMA/TDMA RATs.

1) NCCB strategy: In this case, the CRRM strategy is based only on the NCCB concept, without taking into account service information, so that the same RAT selection condition is applied to both voice and www users. Specifically, at session initiation, the RAT selection decision is taken according to the path loss measurements in the best UTRAN 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 PL_{UTRAN} is above a given threshold PLth, the selected RAT will be FDMA/TDMA (i.e. GERAN), while if the path loss is below the threshold the selected RAT will be CDMA (i.e. UTRAN). In case that there is no capacity available for the new session in the selected RAT (i.e. admission control is not passed), the other RAT will be selected instead. Then, if no capacity is neither available in the other RAT, the session will be blocked. The corresponding vertical handover decision procedure is shown in Fig. 2. 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.

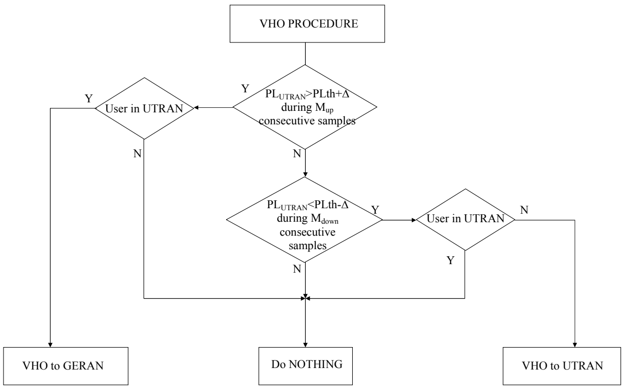

Fig. 2 VHO with the NCCB strategy

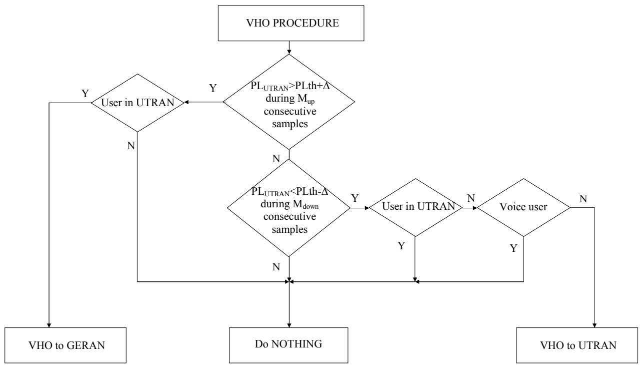

Fig. 3 VHO with the VG_NCCB strategy

2) NCCBvoice strategy: In this case, the NCCB strategy is applied only for voice users, while www users follow a service-based policy and they are allocated by default in UTRAN provided that there is enough capacity. Otherwise, they are moved to GERAN and they will try to return to UTRAN each time they need a horizontal handover.

3) VG (Voice GERAN) strategy: In this case, the RAT selection is done according to the service type, so that voice users are served through GERAN and www users through UTRAN, provided that there is enough capacity available in the selected RAT [9]. In case that there is not enough capacity the other RAT is selected instead. In such a case, the user will

try to return to the preferred RAT each time a horizontal handover is required.

4) VG_NCCB strategy: This case corresponds to the combination between NCCB and VG policy, so that for low path losses the VG policy is applied while for high path losses users are allocated to GERAN regardless the service. The corresponding flow diagram for the VHO condition is shown in Fig. 3. Also the convenience of executing a VHO is always checked when a horizontal handover is required. Notice that, according to this strategy, and for moderate traffic loads, voice traffic is mainly served through GERAN while www traffic is shared between UTRAN and GERAN depending on path loss.

IV. SIMULATION MODEL

The considered approaches have been evaluated by means of system level simulations in a scenario that considers 7 omnidirectional cells for GERAN and 7 for UTRAN. The cells of both RANs are collocated. The cell radius is 1 km. In case of GERAN, it is assumed that the 7 cells represent a cluster so that all of them operate with different carrier frequencies. The main parameters of the User Equipment (UE) and the Base Station (BS) are summarised in Table I. It is assumed that all terminals have multi-mode capabilities, i.e. they can be connected either to UTRAN or to GERAN. The urban macrocell propagation model in [12] is considered for both systems, corresponding to $Lp(dB)=128.1+37.6\log(d(km))$ with an additional shadowing with standard deviation 10 dB. The mobility model in [13] is considered with speed 3 km/h.

Voice 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 [14]. 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. Interactive users follow the www browsing model given in [13], with 5 pages per session, an average reading time between pages of 30s, an average of 25 packets per page, and interarrival packet time 0.125s for the uplink and 0.0228s for the downlink. The average packet size is 366 bytes. A session rate of 24 sessions/h/user is assumed. WWW browsing service is provided in UTRAN by means of dedicated channels (DCH) making use of the transport channel type switching procedure. The considered RAB assumes a maximum bit rate of 64 kb/s in the uplink and 128 kb/s in the downlink [14]. In turn, in GERAN, the www service is provided through a PDCH (Packet Data Channel) with a round robin scheduling algorithm to allocate transmissions to users sharing the same time slot. On the other hand, a link adaptation mechanism operating in periods of 1s is used to select, for each user, the highest modulation and coding scheme (MCS) that ensures the specific sensitivity requirements. The highest modulation scheme considered in this paper is MCS-7.

A summary of the main RRM parameters in UTRAN and GERAN is given in Table II. With respect to the admission control procedure in UTRAN, three conditions are checked [1], namely the uplink load factor after user acceptance should be below the threshold η_{max}, the downlink transmitted power below P_{max} and there must be code sequences available. With respect to GERAN, voice users are accepted provided that there are available time slots, while interactive users are always accepted at session initiation in idle state. Voice users have precedence over www users, so that slots occupied by www users are allocated to incoming voice users when there are not other free slots. All slots are reversible except the slot 0 of the carrier transmitting the broadcast channel.

TABLE I UTRAN BS AND UE PARAMETERS

BS parameters	**UTRAN**	**GERAN**
Maximum transmitted power	43 dBm	43 dBm
Thermal noise	-104 dBm	-117 dBm
Common Control Channels Power	33 dBm	43 dBm
Maximum DL power per user	41 dBm	N/A
Number of carriers	1	3
UE parameters	**UTRAN**	**GERAN**
Maximum transmitted power	21 dBm	33 dBm
Minimum transmitted power	-44 dBm	0 dBm
Thermal noise	-100 dBm	-113 dBm
DL Orthogonality factor	0.4	N/A
Multislot class	N/A	2 UL, 3 DL, 4 UL+DL

TABLE II RRM PARAMETERS

UTRAN	
UL admission threshold (η_{max})	1.0
DL admission threshold (P_{max})	42 dBm
Active Set size	1
Replacement hystheresis	3 dB
Time to trigger handover	0.64 s
BLER target voice	1%
BLER target interactive	10%
Dropping condition	1 dB below target during 20 s
GERAN	
Maximum number of TBFs per slot	UL: 8, DL:32
Minimum power to trigger handover	-100 dBm
Samples to trigger handover	3
Dropping condition	5 dB below sensitivity during 20 s
NCCB ALGORITHM PARAMETERS	
Measurement interval (T)	1s
Hystheresis margin (Δ)	1 dB
Mup	3
Mdown	3

V. RESULTS

V.A. Performance comparison

This section analyses the performance achieved by the different strategies under different situations regarding load and traffic mix. Fig. 4 plots the corresponding load in UTRAN and GERAN (i.e. the uplink cell load factor in UTRAN and the number of occupied time slots with respect to the total number of time slots in GERAN) as a function of the number of www users, respectively, for a situation with 600 voice users in the scenario and for the different strategies. PLth=120 dB is considered in NCCB. Clearly NCCB and NCCBvoice achieve a better load balancing among the two RATs, so that there is more room in GERAN to accommodate www users and therefore their delay will not increase so much (see the packet delay in Fig. 5). In turn, with the service-based strategies VG and VG_NCCB, GERAN is overloaded. Notice also that in all the cases, the highest load factor in UTRAN occurs with NCCBvoice because it is the strategy with the largest number of voice and www users in UTRAN (i.e. all voice users with path loss below PLth and all the www users will mainly be allocated in UTRAN).

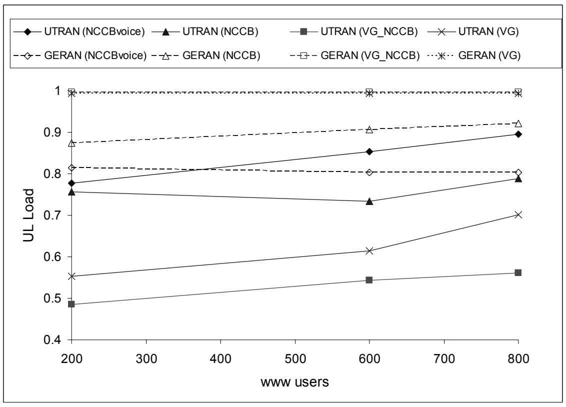

Fig. 4 Load in UTRAN and GERAN with the different strategies

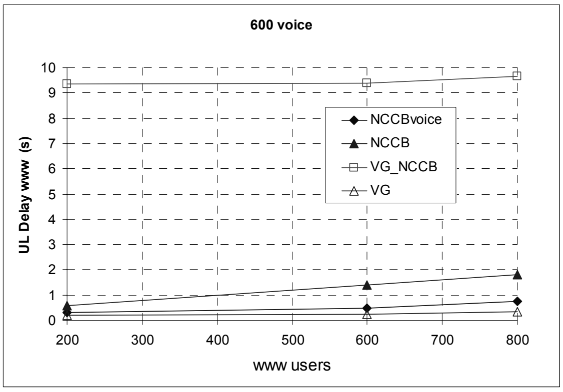

Fig. 5 UL average packet delay for www users

The results in terms of www packet delay are shown in Fig. 5. For the VG_NCCB strategy the average delay reaches very high values. The reason is that, with this strategy, GERAN is completely overloaded because it contains the voice users (according to VG policy) as well as the www users with path loss above PLth. As a result, there are few slots available for www users so they will experience very few opportunities to transmit their packets, thus increasing the delay. Among the rest of policies, the pure service-based policy VG achieves the lowest delay because in this case www users are mainly served through UTRAN. In turn, the performance with NCCB is worst because of the www users that are served through GERAN, which experience a higher delay. Finally, NCCBvoice achieves a delay performance closer to VG because www users are mainly served through UTRAN.

Fig. 6 and Fig. 7 plot the Block Error Rate (BLER) for voice users in UTRAN and GERAN, respectively, as a function of the number of www users for the case with 600 voice users in the scenario. While the differences in GERAN are small, the worst performance in UTRAN is achieved with the VG policy, which suffers a high BLER degradation for large path losses. Some BLER reduction is achieved with the VG_NCCB strategy, which reduces the load factor in UTRAN (see Fig. 4) by allocating high path loss www users to GERAN. In turn, the NCCB and NCCBvoice strategies achieve the best performance thanks to allocating the high path loss users in GERAN. In this case, a slightly worst behaviour is observed with NCCBvoice because of the larger load factor in UTRAN.

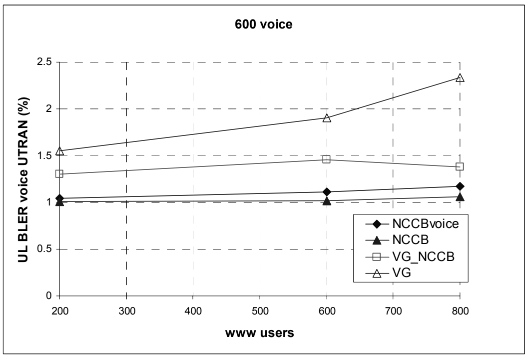

Fig. 6 UL BLER in UTRAN for the 600 voice users case

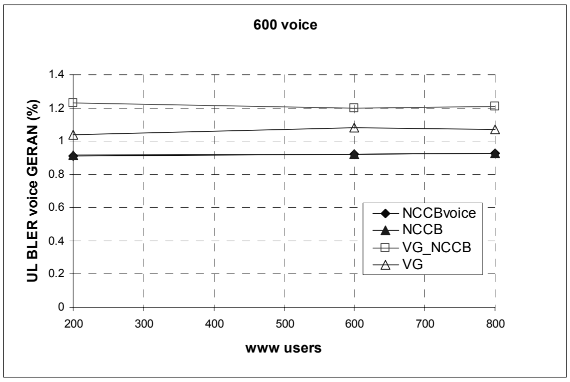

Fig. 7 UL BLER in GERAN for the 600 voice users case

V.B. Setting of the threshold PLth

The previous results have shown that from the delay point of view the best performance is achieved by the pure service policy VG, followed by NCCBvoice, while from the point of view of BLER, the best performance is achieved by NCCB and NCCBvoice, and the latter performs better in terms of delay. Consequently, NCCBvoice appears to have the best behaviour among the considered strategies. Taking this into account, in the following the appropriate setting of the path loss threshold PLth in this strategy is analysed. To this end, some simulations have been performed by considering different values of PLth according to the path loss distribution for several traffic mixes. They are PLth=110 dB (20-th percentile), PLth=115 dB (40-th percentile), PLth=120 dB (60-th percentile) and PLth=125 dB (80-th percentile). Fig. 8 and Fig. 9 plot the average www delay for the different values of PLth and for two voice loads, namely 400 and 800 users, respectively. Notice that, from the point of view of www users, it is better to have reduced values of PLth because the NCCB policy applies only to voice users while www users are allocated in UTRAN. As a result, increasing the number of voice users in UTRAN (i.e. by increasing PLth) turns into a higher load factor that degrades the performance of www delay. On the contrary, from the point of voice users, as discussed in [10], the appropriate setting is to select a PLth value that balances the load among RATs.

Fig. 10 and Fig. 11 plot the total aggregated throughput for the considered load levels. From the observation of this figure and the delay performances, it can be concluded that the setting of the PLth threshold depends on the existing traffic mix in the scenario. Particularly, the following cases can be distinguished:

- For moderate loads of voice and www (e.g. 400 voice and

200 www) there is not a high sensitivity to PLth.

- For moderate voice load and high www load (e.g. 400 voice and 1000 www) the best setting would be around PLth=110 dB, mainly because of the lowest delay achieved by www users, although the differences with PLth=115 dB are small.
- For high voice load and moderate www load (e.g. 800 voice and 200 www) the best performance is achieved with PLth=120 dB, like in the case with only voice users [10]. This value achieves a good trade-off between balancing the load among the two RATs and at the same time distributing users according to the path loss.
- For high loads of voice and www users (e.g. 800 voice and 600 www) the best performance is achieved by PLth=115 dB, which provides a good trade-off between balancing the load among the RATs while keeping a low delay for www users.

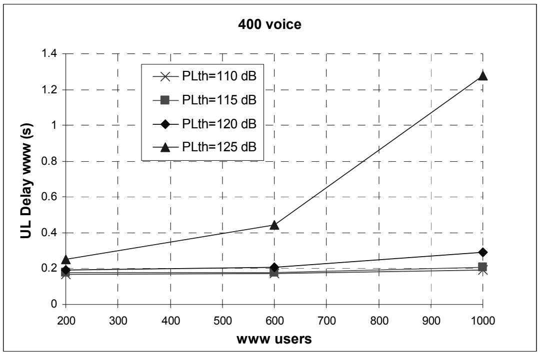

Fig. 8 UL www packet delay for different values of PLth with 400 voice users

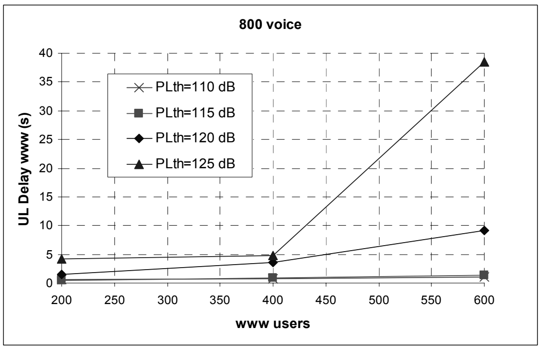

Fig. 9 UL www packet delay for different values of PLth with 800 voice users

VI. CONCLUSIONS

This paper has proposed a CRRM strategy based on controlling the effective cell radius of CDMA cells in heterogeneous scenarios with CDMA and TDMA/FDMA-based RATs, so that the CDMA interference can be reduced and the total capacity increased. This strategy has been analysed and compared against other possibilities including service-based concepts in a scenario with www and voice users. It has been observed that the best performance can be achieved when applying the proposed NCCB strategy to voice users while trying to allocate www users in UTRAN. Also the setting of the parameter PLth depending on the specific traffic mix has been discussed.

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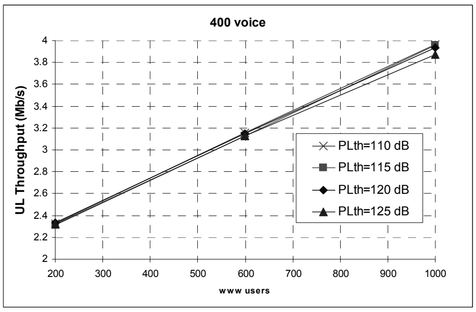

Fig. 10 UL throughput for different values of PLth for 400 voice users

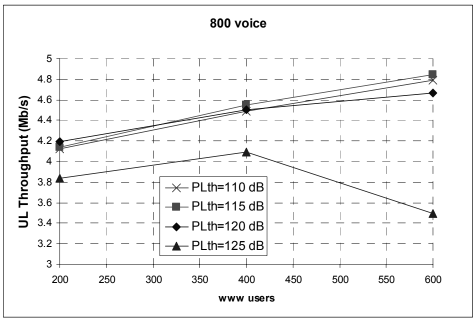

Fig. 11 UL throughput for different values of PLth for 800 voice users

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