An Admission Control Framework Integrating Radio and IP-Transport in 3GPP-based Networks

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Abstract- *Within the context of Beyond 3G (B3G) wireless networks, there is a clear migration towards the usage of IP/MPLS transport networks within the backhaul part of the radio access network (RAN). Despite expected cost savings and ease of maintenance, such a migration imposes new challenges on the IP QoS provisioning. These new challenges are fuelled by, on one hand, the traffic increase in the RAN due to the more efficient air interfaces, and on the other hand, potential bandwidth limitations likely to exist in typical backhaul network deployments. This paper develops a call admission control (CAC) framework that considers both the radio interface and also the IP transport network. This leads to a new paradigm where transport resources are considered not only at the network dimensioning stage but are included in an integrated resource management scheme. The CAC framework is validated by analysing a specific CAC algorithm in the context of UTRAN with IP-based transport.*

I. INTRODUCTION

It is widely recognized that B3G networks will migrate to all-IP architectures in the medium-term. This migration to all-IP architectures has different components, being one of them the migration of legacy transmission infrastructures based mostly on TDM and ATM technologies onto a more flexible, efficient IP/MPLS packet infrastructure for the core network but also for the backhaul[1] part of the radio access network. Such a migration would converge the core and radio access networks (RANs) and also would facilitate the integration and coexistence of different heterogeneous Radio Access Technologies (RATs) over the same infrastructure. On the other hand, it is also apparent that such a migration creates the challenge to support QoS over such IP networks since, even though over-provisioning can be the most straightforward way to manage QoS in the core network, it may not be the case for the backhaul network where one can find a predominance of relatively low-speed leased lines and microwave radio links. In fact, one of the biggest cost challenges facing wireless service providers today is the backhaul infrastructure that uses to be very expensive to maintain and difficult to scale. Furthermore, limitations in the backhaul can become more evident with the progressive deployment of new high speed technologies like HSPA (High Speed Packet Access) that will ultimately turn into a higher bandwidth provisioning in the backhaul network [1][2]. Hence, in this context, the development of

appropriate resource management techniques to support QoS in a RAN with IP-based transport (IP RAN) can result in big savings.

In this paper we develop an integrated call admission control (CAC) for IP-RANs that considers both radio and transport resource occupancy in its decision-making process. The framework is able of handling potential bottleneck situations in the IP transport part of a RAN. This leads to a new paradigm where transport resources are considered not only at the network dimensioning stage but are included in an integrated resource management scheme. This new paradigm allows to dynamically capture within the CAC framework multiple situations where the capacity or occupation of the transport network can vary over time (e.g. routing changes due to link failure/congestion, a radio cell exceeding its dimensioned transport capacity to the detriment of other cells, etc). The CAC framework is validated by analysing a specific CAC algorithm in the context of UTRAN R'99 with IP transport. The CAC algorithm is able to consider not only "if" a particular QoS bearer request can be admitted or not, but also "how" it can be admitted (e.g. by properly selecting the radio access bearer capabilities) so that higher network utilisation can be achieved. Existing work on admission control in the UTRAN has mainly focused on transport networks based on ATM and less attention has been paid to IP transport solutions. Furthermore, previous research work has been exclusively addressed by focusing on the transport itself, that is, without exploiting the possibilities of integrating the admission approach among the radio and the transport [3][4].

The paper is organised as follows. Section II identifies the coordination of the radio and IP transport among the key drivers within B3G and 4G architectural network frameworks. Then, in Section III, a novel resource management model that enables the IP and radio coordination for the QoS provision is presented and the proposed CAC identified as one of the building blocks of such framework. Over such a basis, Section IV develops the proposed CAC framework and details a specific algorithm for UTRAN with IP-transport. Results are included in Section V and finally Section VI concludes de paper.

II. E2E QOS APPROACH FOR EVOLUTIONARY 3GPP-BASED NETWORK ARCHITECTURES

A plausible scenario for B3G networks in the medium term consists of a heterogeneous access network encompassing UTRAN, GERAN and WLAN RATs deployed over a fully migrated IP transport infrastructure [5]. Under this scenario, network architecture and interfaces between radio equipment (e.g. Iub) would be still compliant to 3GPP releases 5 or 6. In this context, the scope of end-to-end QoS management solutions over this architecture is illustrated in Fig. 1 and encompasses two main aspects: (1) Common

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[1] *the part of the network including the cellular base station at the edge, the base station controller or radio network controller, and all other Layer 1-3 transport, aggregation, and switching elements in the access and metro networks*

Radio Resource Management (CRRM), devoted to coordinate and optimise the usage of the several heterogeneous radio access interfaces, and (2) radio and IP transport coordination, that is, the deployment of QoS control mechanisms (e.g. admission control) considering both radio and IP transport resource availability. The second aspect is especially relevant for the RAN part since overprovisioning in the backhaul is not seen as a suitable solution.
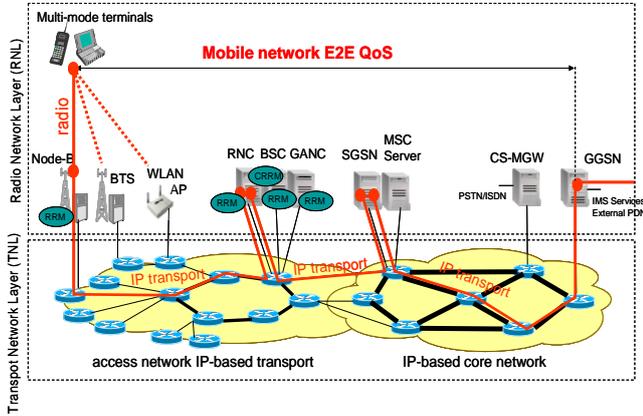

Fig. 1 Reference E2E QoS architecture

On the other hand, 3GPP is currently specifying an evolved network architecture that will ensure continued competitiveness of the 3GPP technologies in a long-term scenario. These efforts are mainly coordinated by the "Long Term Evolution" (LTE) and "System Architecture Evolution" (SAE) [6]. The new network model is pursuing a more distributed and packet-optimised RAN that can ultimately benefit from the adopted migration to IP infrastructures. However, even though the LTE network will avoid the need to support interfaces with stringent delay requirements (e.g. Iub in UTRAN) over the IP-based transport network by confining RRM at the base stations, the mobile network will always show a high degree of capillarity to inter-connect a lot of access points to the core network, so that the problem of achieving an efficient usage of resources in the transport network will persist in the long-term evolution. Thus, bottlenecks may appear in the IP transport in both network scenarios due to backhaul limitations and we aim at handling them dynamically through resource management functions.
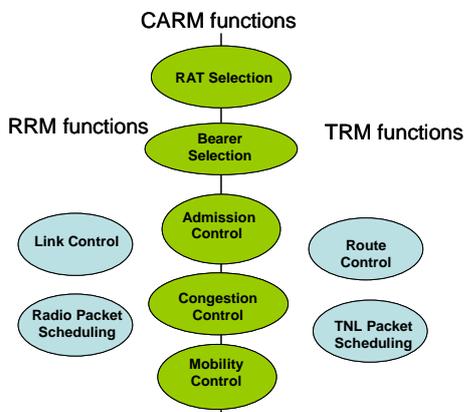

Fig. 2. Proposed QoS management functions.

III. A FUNCTIONAL REFERENCE QOS FRAMEWORK

This section highlights the main characteristics of a functional framework for a coordinated management of radio and transport resources that leads to efficient resource utilization and to better support of QoS guarantees. This framework has been introduced in [7] and it is referred to as CARM (Coordinated Access Resource Management).

The main QoS management functions likely to be deployed in an IP-RAN, summarized in Fig. 2, are split in three categories: CARM, RRM-specific functions and TRM-specific functions. CARM refers to those functions where a strong interaction between radio and transport segments can be predicted, and includes RAT Selection (RS), Admission Control (AC), Congestion Control (CC), Bearer Selection (BS) and Connection Mobility Control (MC). RRM-specific refers to those functions only related to the radio segment which only make sense within their own scope (or pool of resources)., and includes Radio Link Control (LC) and Radio Packet Scheduling (RPS). Similarly, TRM-specific refers to those functions only related to the IP segment, and includes TNL Route Control (RC) and TNL Packet Scheduling (PS). In the next paragraphs the objectives of each of the envisaged functions in the QoS architecture are described.

-*RAT selection*: This function is in charge of selecting the most appropriate RAT, either at call establishment or during the session life-time through the so-called vertical handover procedure, given the requested service and QoS profile.

-*Bearer Selection*: Bearer selection is in charge of selecting the most appropriate radio access bearer service configuration according to the requested QoS profile. The selection can rely on radio and transport network load information.

-*Admission Control*: maintains information of available/allocated resources in both the radio and the IP transport network and performs resource reservation/allocation in response to new service requests, at call establishment or during vertical/horizontal handover, with a given QoS profile.

-*Congestion Control*: It is in charge of taking the actions required to handle overload events in the radio or transport network side.

-*Mobility Control:* This function is in charge of assuring a proper distribution of mobile terminals among radio cells through the appropriate traffic steering mechanisms (e.g. handover).

-*Radio Link Control:* It is in charge of dynamically adjusting the radio link parameters of the mobile terminals in order to preserve the QoS for established sessions (e.g power control and link adaptation).

-*Radio Packet Scheduling:* This function is in charge of maximizing resource occupation by scheduling packets for established sessions.

-*TNL Route Control:* This QoS management function is in charge of selecting the optimum routes in the transport network to guarantee the efficient use of TNL resources and the QoS requested by the TNL IP bearers.

-TNL Packet Scheduling: This function is in charge of implementing, at the IP transport network nodes, the appropriate QoS queuing decisions so the different flows (or aggregates of flows) receive the right QoS treatment at every node.

It is worth mentioning that the CARM framework fits both the envisaged medium-term architecture for B3G networks with IP transport in the RAN [5] and the long-term 3GPP vision where IP infrastructure is also deployed between evolved NodeB (eNB) and access gateways (AGWs) [6].

IV. COORDINATED ADMISSION CONTROL

In an heterogeneous network environment offering flexible services, the admission control should consider, not only "if" a particular QoS bearer request can be admitted or not, but also under which conditions, that is "how", it can be admitted (by allowing only certain transport formats, for example, in the case of UTRAN) and in which RAT and radio access point, that is "where", it could be admitted (assuming that there are several candidates of the same or different RAT). And in the case of an admission control mechanism integrating radio and transport parts, this decision would be influenced by at least (1) the radio resource occupation in the candidate radio access points and the (2) transport resource occupation in the path between the candidate radio-access points are their corresponding network controllers or access gateways (that is, the next anchor point in the network behind the access point for user plane processing).
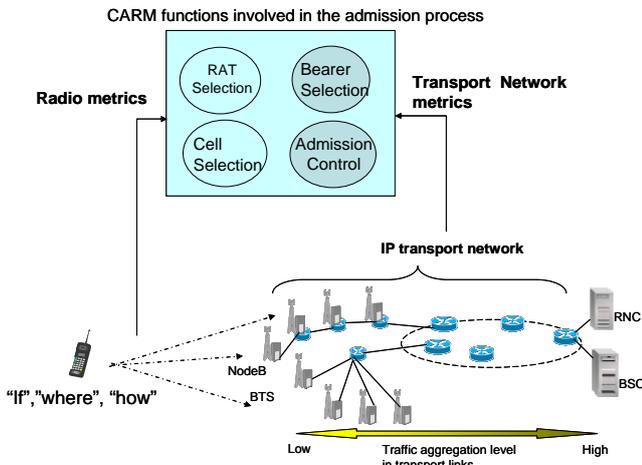

Fig. 3 CARM functions involved in the admission process

Fig. 3 illustrates the scope of the admission process integrating radio and IP segments in a heterogeneous RAT scenario. As shown in the figure, the whole admission control decision is eventually related to the CARM functions RAT selection, cell selection and bearer selection (the first two functions related to "where" and the last one to "how" admit the connection). In this paper the focus is mainly targeted to analyse the impact of considering the status of the transport network in the admission process. Then, over such a basis, optimisation of this admission process by dynamically adapting the radio bearer configuration (i.e. Bearer Selection) is also addressed. On the other hand, the benefits of using RAT and cell selection considering transport aspects in the admission process are out of the scope of this work.

In the following subsections we first describe the QoS model assumed for the RAN transport network and afterwards develop an integrated CAC for IP-based UTRAN scenarios.

A. QoS model of the RAN transport network

A differentiated services (Diffserv) model is considered in the IP transport network. Thus, several Per Hop Behaviours (PHBs) would exist and radio equipment (i.e. NodeB and RNC) will perform the mapping between radio traffic categories and the PHBs. No bandwidth reservations are done per NodeB, that is, traffic from several NodeBs traversing a given IP router compete for the same resources. Notice that this model does not exclude the utilisation of MPLS for path management but in any case QoS differentiation within the forwarding functionality is entirely handled by Diffserv.

On the other hand, the Diffserv model lacks of a standardised control plane although different approaches have been proposed in the literature [8][9]. In this work we assume a model similar to the Bandwidth Broker concept [8] in the sense that bandwidth management functions (e.g. admission control) are not integrated within diffserv routers but are located in a separate entity which relies on network topology knowledge and measurements monitoring to control the use of the network domain.

B. Algorithm formulation

To show the feasibility of the proposed integrated approach, we develop a CAC algorithm to regulate the amount of interactive traffic supported over a UMTS R99 network. Transport channel type switching is used in the air interface so that active users are assigned Dedicated Channels (DCH) as soon as they have data for transmission and there are available codes [9]. If not, they remain connected through the Forward Access Channel (FACH) in downlink and Random Access Channel (RACH) in uplink. We have decided to focus on this kind of data traffic because of its high variability, thus making the admission control process a difficult problem when targeting to obtain high link utilisations in the transport network without connection performance degradation. Furthermore, due to the bursty nature of this traffic, there is a lack of appropriate traffic descriptors that prevent the usage of parameter-based admission control (PBAC) algorithms in front of measurements-based admission control (MBAC) solutions. Moreover, MBACs schemes relying only on aggregated bandwidth information in contrast with using per-session knowledge is appealing from an implementation viewpoint.

The main objective of the proposed algorithm is to regulate the number of admitted data sessions so that specific QoS indicators of on-going connections can be still satisfied. Over such a basis, a complementary objective is added to the integrated algorithm so that the dynamic selection of the radio bearer capabilities can be exploited. In particular, the maximum allowed transmission rate while being in DCH mode is dependent on the occupancy of radio and transport resources. Let's assume that the Radio Access Bearer (RAB) under consideration allows configuring K different maximum data bit rates for the DCH channel. Let's R_i, $i=1..K$, denote the set of possible rates for DCH configuration so that $R_i<R_{i+1}$. According to this notation,

Fig. 4 illustrates the proposed admission control approach where a an admission request is initially checked with the highest R_K but, if radio and/or transport limitations exists, a lower R_i, $i \leq K$, can be finally decided.
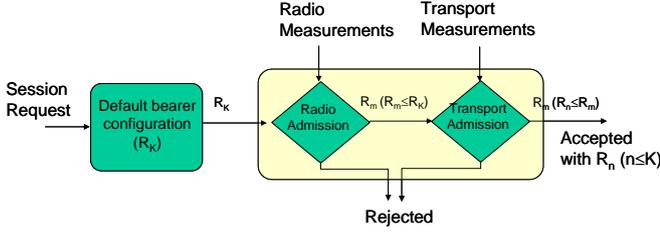

Fig. 4. Coordinated Admission Control approach.

With respect to the radio part, downlink admission control strategies are usually based on Node-B power consumption, since it is the main resource shared between the users connected to the node B. As a result, admission control strategies based on power estimation must take into account whether or not the Node-B has enough power to ensure the agreed QoS requirements of both the new user and the already accepted users. The general expression of an admission control based on power estimation that occurs in the i-th frame can be represented by [10]:

$$P_{AV}[n] + \Delta P_k \leq P_T^* \qquad \text{(Eq. 1)}$$

where $P_{AV}[n]$ is the averaged Node-B transmitted power in the n-th frame, ΔP_k is the estimated power increase due to the acceptance of the new user with rate R_k and P_T^* is a certain admission threshold. On the other hand, uplink admission control is typically based on cell load factor monitoring. Assuming that a given number of users are already admitted in the system, the admission control algorithm considers the increment in the load factor that the new acceptance would originate. Therefore, the condition to be checked for the admittance of the request would be:

$$\eta_{UL} + \Delta \eta \leq \eta_{max} \qquad \text{(Eq. 2)}$$

η_{UL} being the current estimation of the uplink cell load factor, $\Delta \eta$ being the estimated contribution demanded by the user.

Now focusing on the transport admission part, given a RB request, the transport admission is sucessfully passed with the highest R_i that satisfies the following condition:

$$avBW_{path}[n] \geq \delta \cdot \tilde{R}_i \qquad \text{(Eq. 3)}$$

where $avBW_{path}[n]$ is the estimation of the available bandwidth in the I_{ub} interface for the interactive traffic class at time instant n in the path between a NodeB and its controlling RNC and $\delta \in [0,1]$ is a factor used to obtain an admission rate constraint based on the peak rate $\tilde{R}_i$ of the RB in the transport network (i.e. DCH data rate plus transport protocol overheads). It is worth noting here that this admission rate constraint, even being conservative if δ values close to 1.0 are used, only affects the admission decision of a new RB because, once it has been accepted, the dependence of future admission decisions on this RB is only through its contribution to the measured aggregated bandwidth.

The estimation of the available bandwidth in the path RNC-NodeB is based on the following assumptions. Measurements of the traffic load are conducted by the routers in the transport network on each output interface. In particular the number of dequeued bits during a sampling_*period* (T_s) normalised to the available capacity C_i in bits/s is used to calculate the traffic load. These measurements are distributed by TNL routers (using e.g. SNMP) each reporting period (T_p). If multiple samples are taken in the same reporting period, the maximum value is reported. Possible ranges for T_s and T_p could be respectively 100-500ms and 500ms-10s. From an implementation point of view, measurements could be collected in a central entity or directly delivered to the RNCs. In any case, the entity monitoring the measurements can calculate an available bandwidth per link i according to the following expression:

$$avBW_i[n] = C_i(1 - \mu_i[n] - \beta \cdot \sigma_i[n]) \qquad \text{(Eq. 4)}$$

where μ_i and σ_i are, respectively, estimations for the mean and standard deviation of the reported traffic load in link i, and β is a parameter used in order to relate Eq. 4 to the probability of not exceeding the maximum link utilization. Notice that many studies have only concentrated in the measured mean value and do not consider the variance. In our case, as suggested in [11], due to the bursty nature of the considered traffic, the standard deviation allows to account for the appropriate spare of bandwidth needed to absorb fast traffic fluctuation components that can not be compensated by the admission or departure of new sessions. Moreover, notice that when the number of connections traversing a link is large, by applying the Central Limit Theorem, the link utilisation resulting from the aggregation of multiple statistically independent traffic connections can be modelled as a Gaussian random variable and the, in that case, the β factor can be analytically obtained by limiting the probability of reaching full link utilisation p according to:

$$Q\left(\frac{1-\mu_i}{\sigma_i}\right) \leq Q(\beta) = p \qquad \text{(Eq. 5)}$$

where $Q(.)$ is the complementary cdf of a N(0,1) Gaussian random variable.

The averaging process used in the computation of the mean and standard deviation is related to the time scale of the traffic fluctuations we are interested to follow by means of the admission process. According to [11] if we want the session admission control to be able to follow session dynamics, there is a critical time scale dictated by how fast sessions depart from the system. This critical time scale depends on the mean session duration and on the number of simultaneous sessions concurring in a given link. In particular, the mean and standard deviation estimators used to track the admission process are based on the Exponential Weighted Moving Average (EWMA) mechanism and can be defined as follows:

$$\mu_i[n] = \omega_\mu \cdot load_i[n] + (1-\omega_\mu) \cdot \mu_i[n-1] \quad \text{(Eq. 6)}$$

$$\sigma_i[n] = \omega_\sigma \cdot |load_i[n] - \mu_i[n-1]| + (1-\omega_\sigma) \cdot \sigma_i[n-1] \, \text{(Eq. 7)}$$

where the corresponding exponential averaging weights can be calculated in terms of a given averaging period (T_{av}) as follows:

$$w_\mu = \frac{2}{1+\dfrac{T_{av}}{T_p}} , \quad w_\sigma = \frac{2}{1+\dfrac{K \cdot T_{av}}{T_p}} \qquad \text{(Eq. 8)}$$

where K>>1 is used to obtain a more accurate estimation of the standard deviation over several mean averaging periods. Finally, from the available bandwidth computer per link, an estimation of the available bandwidth per path can be obtained by making the limitations of a potential bottleneck link to prevail over others by means of the following expression:

$$avBW_{path}[n] = \min_{\text{link } i \in \text{path}} \left(avBW_i[n] \right) \qquad \text{(Eq. 9)}$$

From an implementation point of view, notice that the information about which links traverses a RNC-NodeB path can be obtained by listening to OSPF routing protocol messages (RFC2328) to know network topology.

V. RESULTS

Results are provided in this section to demonstrate the benefits of the proposed CAC framework in IP-RAN scenarios with bottleneck links in the transport network. In particular the following simulation cases are considered:

- No CAC in the transport. Only radio-aware CAC is performed at session set up.

- CAC A: Coordinated CAC at session set up. Admitted sessions make use of 384 kbps data rates in DCH mode.

- CAC B: Coordinated CAC done at transport channel type switching level. In this case, interactive sessions are always admitted at call set up but the activation of DCH channels during activity periods is controlled by the coordinated admission control. Only 384 kbps DCH channels are granted.

- CAC C: Similar to CAC B with the addition of the bearer adaptation functionality. Thus, in this case, unlike CAC B, the rate of the DCH channel is adapted to transport load status according to the algorithm illustrated in Fig.4. Besides 384kbps data rate, 256 kbps and 128 kbps DCHs can be assigned.

Regarding network topology, we consider a basic deployment scenario consisting of seven hexagonal cells connected to a IP-based transport network with two traffic aggregation points between each NodeB and its controlling RNC. This configuration allows us to define different network scenarios depending on the placement of the bottleneck link. Results provided in this paper correspond to a bottleneck link located between the central NodeB and the first IP router for traffic aggregation. The simulation of the Iub model has been done according to guidelines provided in [5]. In particular, a layer 3 multiplexing scheme has been considered along with a packetiser that can retain a data fragment as long as 5ms to avoid sending IP packets with a short payload. The maximum size of IP packets is 1500bytes and the buffer sizes in the routers are configured so that a maximum queuing delay of 50ms is tolerated since, if network buffers are dimensioned too large (e.g. to ensure that no packets are dropped at any transport element), then packets can be finally dropped at the destination node because they have exceeded a maximum transfer delay [12]. With respect to the air interface settings, cell radius and NodeB power level are set so that radio admission blocking is negligible [10]. Thus, admission rejections are exclusively due to transport limitations.

Results have been obtained for a range of 320-420 interactive users uniformly distributed in the overall scenario and a bottleneck link capacity of 1 Mbps in the Iub transport of the reference NodeB. Interactive users follow the web browsing model, with 5 pages per session, an average reading time between pages of 15s, an average of 25 objects (packets) per page, and inter-arrival packet time of 6.1ms. The average packet size is 366 bytes. This leads to an average bit rate feeding the RNC buffers during activity periods of around 480 kb/s and a mean session bit rate around 4.8kbps. The mean session duration is around 75s and a session arrival rate of 40 sessions/h/user is assumed. Figure 5 shows the ratio of lost transport frames due to buffer overflow in the bottleneck link. As shown in the figure, if no transport-aware CAC is used, unacceptable packet dropping can be caused in the transport network due to the high variability of the considered traffic. On the other hand, according to Figure 6, mean packet delay observed by interactive traffic is not too much affected by this dropping ratio due to the relatively fast retransmission recovery procedure conducted at the RLC (Radio Link Control) layer. However, this dropping ratio has repercussions directly on the amount of extra traffic that the RNC is injecting into the transport network to recover from transport losses and, as a consequence, there is a traffic increase equivalent to the bottleneck dropping ratio in all the links located upstream between the bottleneck and the RNC controller. Moreover, if no traffic differentiation is done at the transport network (e.g. best-effort IP transport network) and real-time traffic (e.g. voice) is sent in unacknowledged mode along with data traffic, the dropping ratio produced in the transport would be directly translated into frame loss ratio of the real-time service. It is important to stress here that this high dropping probability is observed even for very low link utilisations (e.g. 35% for 320 users in the overall scenario) due to the bursty nature of the web traffic.

Over such a basis, the ultimate goal that the transport-aware CAC need to accomplish is the reduction of the packet dropping ratio in the transport network while keeping interactive service performance indicators (i.e. mean packet delay in our analysis). In this sense, as shown in figure 5, CAC A strategy applied at session level can lead to a reduced dropping ratio by limiting the number of admitted sessions in the system. A measurement reporting period T_p=1s and no admission rate constraint has been considered (δ=0) in this case. Moreover, this strategy can provide an improvement in terms of mean packet delay for admitted interactive users (see Figure 6). However, the penalty imposed by this strategy in terms of admission acceptance ratio is too high, as illustrated in Figure 7. Again, the reason behind such reduced admission acceptance ratio is the high variability observed in the web traffic in links with low traffic aggregation level such as the one addressed in this study.
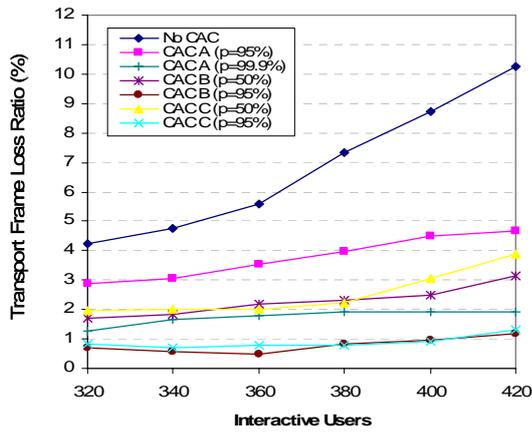
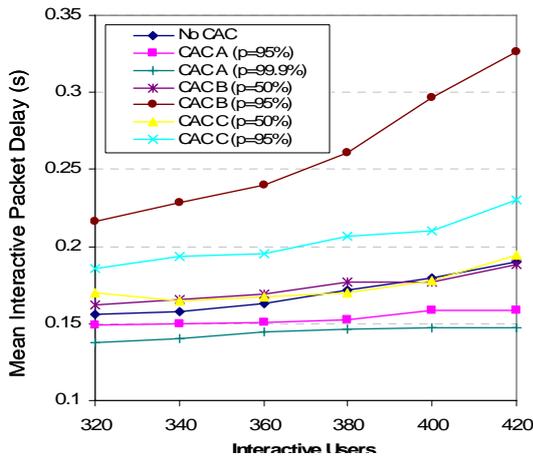**Fig. 5.** Transport Frame Loss Ratio in the bottleneck link.

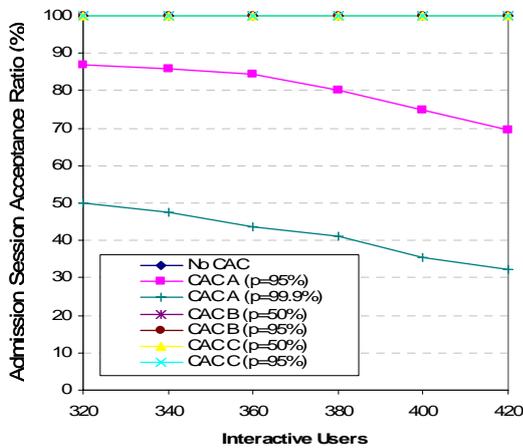**Fig. 6.** Mean packet delay for interactive traffic in reference NodeB.

Fig. 7. Admission acceptance ratio for web sessions.

On the other hand, when moving admission process at DCH level as proposed in CAC B and C, satisfactory results can be obtained in terms of mean packet delay and packet dropping while handling the same number of users as in the non CAC situation (e.g. sessions are always accepted at call set up). In this case, T_p has been reduced to 200ms to account for the fast variation of the DCH holding time and an admission rate constraint equal to half the peak rate is considered (δ=0.5). Notice that with both strategies dropping ratios below 1% can be achieved in the bottleneck link for p=95%. This reduction has associated an unavoidable cost in terms of interactive packet delay because DCH activation can be delayed due to transport

overload. However, when using the adaptive bearer selection strategy considered in CAC C, this cost can be minimised as shown in Figure 6. In particular, a CAC C strategy with p=90% and 380 users is able to reduce transport losses from 7.5% to 0.8% at expenses of a small mean packet delay increase from 170ms to 206ms. Moreover, a more aggressive CAC C strategy with p=50% can even reduce dropping in the transport from 7.5% down to 2.2% without affecting mean packet delay performance.

CONCLUSIONS

This paper develops a coordinated CAC framework that considers both the radio interface and also the IP transport network. This leads to a new paradigm where transport resources are considered not only at the network dimensioning stage but are included in an integrated resource management scheme. The rationale of such a framework is based in the impracticability of bandwidth overprovisioning solutions within the IP-based transport network infrastructures for the backhaul part of the radio access network. This situation is a reality in current 3G network deployments and is expected to persist in next generation networks. The CAC framework is validated by analysing a specific CAC algorithm in the context of UTRAN with IP-based transport.

ACKNOWLEDGEMENTS

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