A QoS Management System for Adaptive Applications Supporting Mobility and End-to-End Guarantees

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Abstract

Motivated by the current integration of radio access networks and the IP-based high-speed data communication in core networks, we have developed a new quality-of-service management concept for mobile environments. Following the IntServ service model, it provides resource reservation, control and signaling mechanisms and is able to interwork with RSVP in the backbone. The most important new feature is its capability to cooperate with adaptive applications that can adjust their traffic generation processes according to the varying conditions in a mobile environment. We have implemented and validated the concept in a testbed provided by an IEEE802.11b compatible wireless LAN with Mobile IP. The stated experiments with a new adaptive version of the video conference tool Vic reveal the feasibility and performance gains of our approach.

1 Introduction

Considering radio access networks, a variety of parameters have a substantial influence on the perceived quality of data transmission in high-speed packet-switched communication systems. In particular, the fast dynamics of a mobile environment requires an advanced management system to analyze, allocate and maintain resource reservations of applications that have specified their required quality-of-service (QoS) configurations. A corresponding mobile QoS (MQoS) management system should be able to respond to the dynamic changes of the conditions in a mobile environment. To provide end-to-end QoS between hosts, an interworking between the concepts applied for resource reservation and QoS-management schemes in the access and backbone domains and related interfaces are required. Particularly, mappings between the QoS requirements of mobile hosts (MH) to those mechanisms used in the backbone and vice versa have to be developed. Currently, both IntServ and DiffServ are used as service architectures supporting end-to-end QoS guarantees in IP-backbones. Furthermore, mobile communication networks of the third generation (3GPP, UMTS) can also be applied as backbone infrastructure. Therefore, appropriate QoS-mappings have to be designed.

In previous studies we have investigated the efficiency of TCP-based packet-switched communication in mobile environments [11, 12]. The studies helped us to identify those terms of a mobile environment having the most important impact on IP-based communication between hosts. Using these terms, we have developed a MQoS management system for the radio access network (RAN) that is able to adapt to dynamically varying conditions of mobile networks [1, 2].

In addition applications must be capable to adjust their behavior according to the dynamics of mobile environments, especially due to mobility patterns of MHs and perceived transmission conditions.

In this paper we propose a concept of a mobile QoS management system providing resource reservations within RANs and in the backbone to support end-to-end communications with respect to varying conditions in mobile environments. The concept also includes the interworking between the network and adaptive applications. Its feasibility is demonstrated by a prototype implementation in a wireless LAN (WLAN) with Mobile IP for mobility support and IntServ/RSVP for resource reservation. Its performance has been studied in a series of experiments with an enhanced version of the Mbone videoconferencing tool "Vic".

2 Issues of QoS Management and Related Work

Current research efforts mainly focus on the mobility management of mobile hosts and the support of their resource reservations [5, 8, 21]. If mobility is supported at the network layer, specific protocols like Mobile IP have to be applied which use tunneling for the transport of datagrams. For this reason the specific features of corresponding IP tunnels have to be considered carefully if RSVP signaling is used for resource allocation [17, 20]. For instance, proactive QoS reservation mechanisms are proposed to accelerate handover processes with QoS re-negotiation. Furthermore, extensions of RSVP that support the interworking with Mobile IP are discussed [6, 19]. The simulation ex-

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periments stated in these papers suggest the development of a new more general QoS reservation scheme tailored to mobile environments.

However, in a mobile environment MHs must be prepared to change their granted QoS reservations dynamically due to their own roaming, but also due to the roaming of other hosts. Hence, an optimization of signaling efforts is not sufficient. A QoS management system has to be provided in the radio access area – for serving the needs of mobility – together with a resource management supporting end-to-end guarantees – for resource reservations in the backbone. Such a management system must also provide interfaces for the interworking of the RAN and the backbone.

Dynamic changes of the available network capacity also require the capability of applications to adjust their behavior accordingly [3]. Regarding transport and quality control of real-time multi-media traffic, the Real Time Protocol (RTP) and Real Time Control Protocol (RTCP) [16] are often used. The latter allow an application to analyze the transmission quality to a certain extent. However, these protocols do not provide resource reservation mechanisms and respond mainly to changes of the network conditions. A direct coupling of network entities and the application layer is necessary to adjust data traffic in a pro-active manner. For this reason an appropriate integrated mobile QoS management and resource reservation system is required.

3 Mobile QoS Management

Our approach to provide end-to-end QoS guarantees on the application layer for roaming mobile hosts distinguishes the following aspects:

- a resource mangement supporting mobility that is capable to change existing reservations due to modifications of link allocations and transmission paths dynamically.
- a system to support the allocation and management of resources both in the access and backbone domain.
- the capability of applications to adapt to changes in available network capacity.

The corresponding components of our new concept are discussed subsequently in more detail.

3.1 Resource Reservation in the RAN

The layout of our system is motivated by the concept of mobility agents as introduced by Mobile IP (MIP) [15]. A so-called *resource management* component (RSM) is responsible for managing available resources within an IP subdomain providing allocation and adaptation. Mobile hosts contain a *data stream management* component (DSM) that allows applications to signal requests for resources to the RSM of the currently visited subnetwork [1].

Requests for resource reservations are characterized by relevant quality-of-service parameters specifying the tolerable variability of perceived QoS for a connection. The RSM informs the DSM about changes in previously granted resource allocations due to changes in the mobile environment. The DSM initiates the adaptation of all active data flows of the MH by notifying the involved applications and by adjusting the associated traffic controls in the network interface. A *network-interface control* component (NWIC) is used to adjust the traffic control settings of the network interface (see fig. 1) by means of a *class based queueing* scheme [7].

3.2 Resource Reservation in the Backbone

To support resource reservations not only in the radio access area but also in the backbone we have extended our MQoS system to interwork with an IntServ architecture. The required signaling and control protocol is provided by RSVP [4]. We have used the IntServ/RSVP implementation of the Information Sciences Institute of the University of Southern California [22] which has the ability to handle and to control resource allocations in intermediate systems. Regarding the needs of mobile hosts we have developed enhancements to cope with the QoS requirements of mobile hosts. To support interworking of our MQoS system in the RAN and the IntServ architecture in the wired infrastructure, two basic extensions had to be integrated. Since we rely on Mobile IP to support transparent roaming of MHs, resource reservations for data flows must be mapped to associated Mobile IP tunnels. Further the managed reservation mechanism had to be adapted to cope with dynamical changes in mobile environments such as roaming of MHs between potentially different subnetworks (i.a. intra- and inter-domain handoffs).

The cooperation of the MQoS system and the IntServ implementation is accomplished through new RSVP components with adapted functionality in addition to the existing components (see fig. 1). The RSVP daemon is part of the used IntServ architecture and performs the reservation and QoS control tasks in the backbone. The DSM and RSM components of our MQoS system manage the signaling and control of the reservation parameters in the RAN. In order to map the resource requests for the RAN on a request for the backbone we have implemented an *RSVP management* component (RSVP-M) which serves as an interface to handle QoS requests between the access and the backbone domain.

3.3 Mobile IP Tunnel Reservation

If a transmission path of a connection includes one or more IP tunnel segments spanning several intermediate nodes, resource reservation by RSVP signaling cannot be applied. While traveling through the tunnel the orignal headers and payloads of the data packets cannot be evaluated due to en-

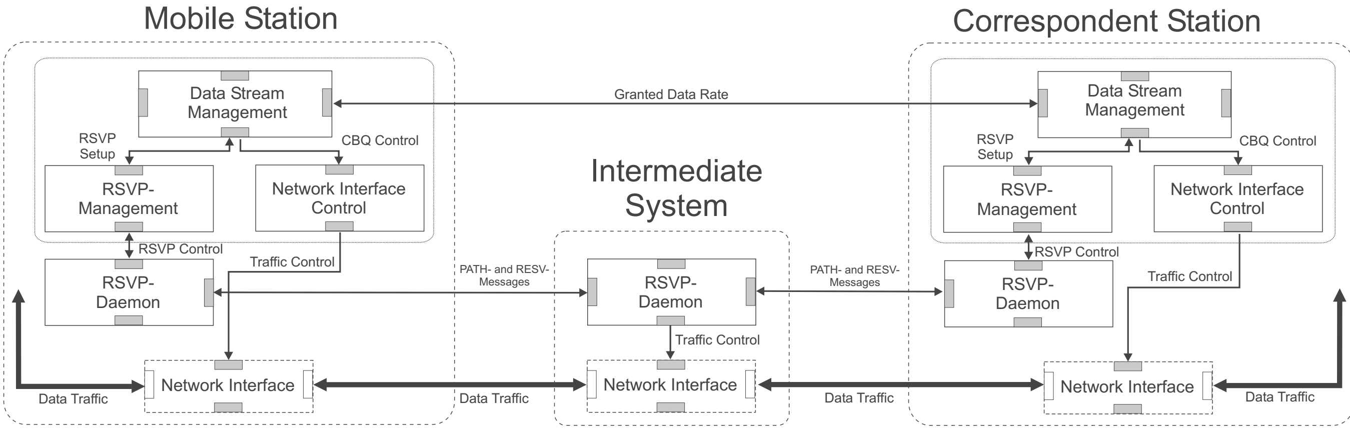

Figure 1. *RSVP components in the RAN and in the backbone.*

capsulation. Hence, RSVP path and reservation messages cannot be recognized within the tunnel [14].

To cope with reservations of resources along IP tunnels and to support the end-to-end QoS guarantees a new mechanism for resource reservations over IP tunnels has been developed in RFC 2746 [18]. The basic idea is to apply RSVP recursively over the tunnel segments of the path. Based on this mechanism we extended our MQoS concept. Therefore, the RSVP components had been adapted at the endpoints of Mobile IP tunnels to perform the reservations for encapsulated packets of the tunneled data flows.

In general, the following tunnel configurations can be distinguished in a Mobile IP environment:

- *foreign agent care-of-addresses*: tunnel from home agent to foreign agent.
- *co-located care-of-addresses*: tunnel from home agent to mobile node.
- *reverse tunneling*: tunnel from foreign agent to home agent.

In our prototype implementation Mobile IP with foreign agent care-of-addresses and without reverse tunneling is used. Hence, only tunnels from home agents to foreign agents must be taken into consideration. The QoS reservation along Mobile IP tunnels is provided by the RSM components of our MQoS system with enhanced signaling and resource management functionality.

When registering in an RSM domain an MH has to announce its home agent address to the RSM. With requesting resources for a specific data flow by an MH the RSM is able to recognize – using the IP address of the sender and the receiver of a data flow – whether the corresponding transmission path includes a Mobile IP tunnel. This happens if the MH resides in a foreign subnetwork and receives a flow from a remote host. Then the RSM in the home network of the MH is informed that a reservation for an MIP tunnel must be established. In this case, the mobility agent of the home network is the tunnel entry and the local mobility agent of the foreign network the corresponding exit. In fig. 2 we have depicted the relevant connections between the associated components of our MQoS management system that are required for the signaling of reservations and the following data transfer.

In our approach the resources for flows across a Mobile IP tunnel are reserved in an aggregated manner. If several flows pass a tunnel between two mobility agents, the corresponding aggregated reservation on the tunnel is established by combining the separate reservation requests. In this way the tunnel mechanisms used in the Dynamics implementation of Mobile IP, for instance, had not to be modified. For this reason no additional UDP header is necessary which usually identifies individual flows in a tunnel [18]. If a tunnel reservation is not possible, then the last flow registered at the tunnel is released and all stations associated with the corresponding connection are informed by their DSMs.

3.4 QoS Roaming

If a MH moves to another radio access area while any connections with QoS guarantees are active, new reservations have to be negotiated after attaching to the new access point. In this respect, two cases have to be studied:

- data flows whose receiver is the moving MH,
- data flows whose sender is the moving MH.

After negotiating new resource reservations in the new domain the RSM in the home network is informed about those flows whose receiver is the roaming MH. On the basis of the flow description the RSM recognizes a change of a tunnel endpoint. The new tunnel endpoint is the foreign agent of the new registration domain. Therefore, it is required to adjust the tunnel reservation accordingly in the home network. Reservations are removed from the old tunnel by

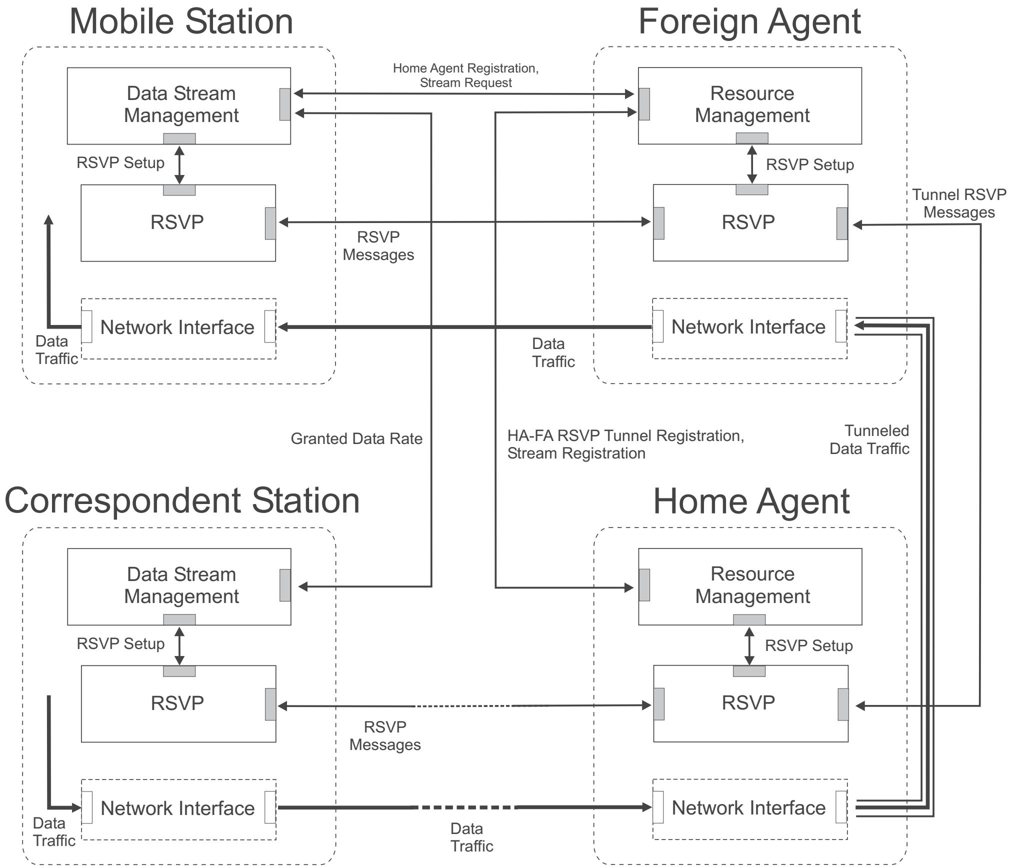

Figure 2. *Signaling connections for communication over RSVP tunnels.*

reducing the overall reservation capacity and added to the new tunnel successively.

It can be assumed that roaming between neighboring microcells result only in slight changes of the transmission path. For data flows originating from the roaming MH the reservations in the intermediate nodes, which are also part of the new transmission path, have not to be changed. New reservations have to be requested only for the new intermediate nodes of the new transmission path. This is performed by controlling the associated RSVP daemons.

4 Evaluating the Adaptation of Applications

4.1 Experimental Setting

We have implemented the MQoS architecture in a RAN testbed with two overlapping radio cells (see fig. 3). The RAN consists of an IEEE802.11b compatible wireless LAN with 11 Mbps transmission rate, two access points and several MHs. Mobility on the network layer is supported by the *Dynamics* Mobile IP implementation of the Helsinki University of Technology [9, 10].

Our MQoS management system copes with following effects:

- MHs can change their APs while actively communicating to other stations with granted resource reservations.
- Dynamic adaptation of overall provided resources within a subdomain is applied according to roaming MHs and their resource requests.
- Changing quality conditions of the radio link reflected by a varying signal-to-interference (SIR) ratio and changes of BER due to MH movement are taken into account.

As shown in figure 3 each subnet contains an RSM component to manage the resources in the subnet. On each station a DSM component must be present allowing applications to request network resources.

4.2 Adaptive Video Communication

The high dynamics of a mobile environment not only requires an adaptive support by a QoS management system but also an adaptation at the application layer. The active applications must be able to adjust their codecs after changes to the admitted data rates during an active communication phase. A lack of this capability on the applica-

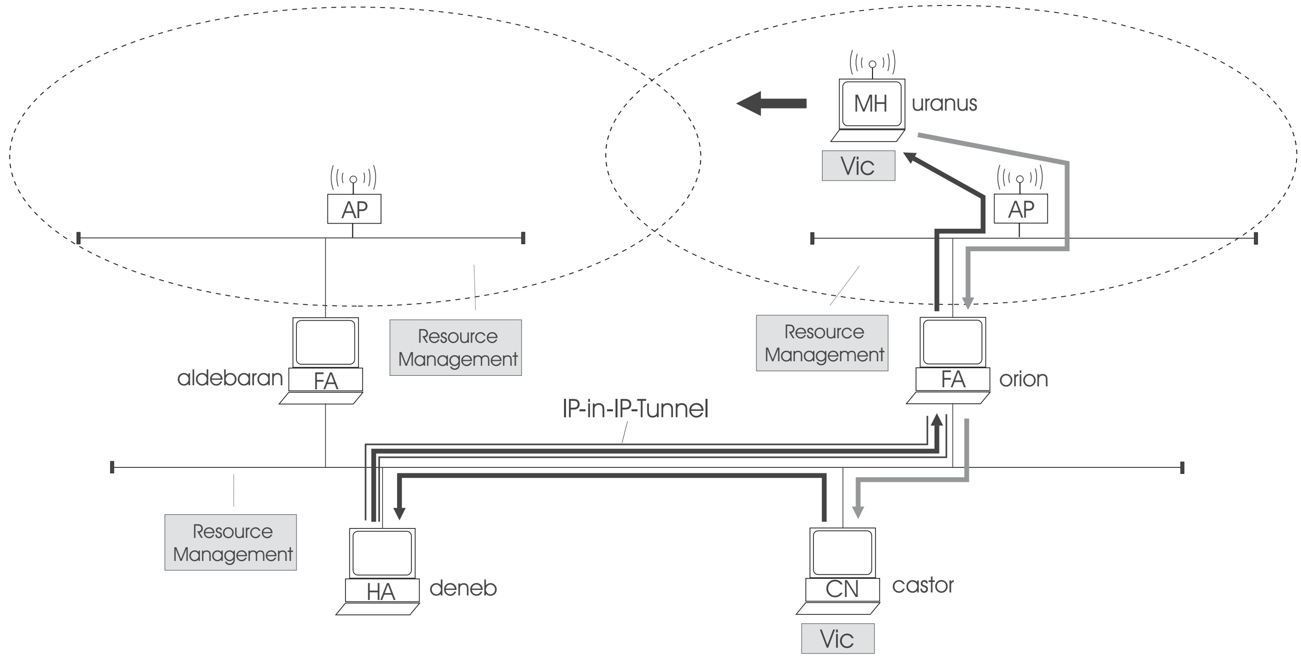

Figure 3. *Experimental Setting.*

tion layer can cause a significant degradation of the service quality of a connection, e.g., if an application generates a much higher data rate than admitted by the policing unit of the network interface. In our mobile QoS management system the non-conformant packets of a flow are discarded in such a case.

To validate our concept and to evaluate the performance of our MQoS implementation the MBone video conferencing tool "Vic" [13] has been enhanced by the capabilities to request QoS parameters and to respond dynamically to changes of the network environment. Flow descriptions and their QoS parameters can be specified in the corresponding enhancement of Vic (see fig. 4). To identify the flow, the IP source and destination addresses as well as the port numbers have to be specified. RSVP only sets up uni-directional reservations. Since in a video conference a bi-directional transport of data is required in general, the application layer internally requests resource reservations for both directions of a connection. Apart from the specification of flow identifiers it is necessary to determine minimal and maximal data rates for traffic characterization. The interworking with the MQoS system is performed by specifying the assigned DSM (see fig. 4: "Dama" parameter).

The MQoS system has to determine the data rate that can be granted within the specified lower and upper bounds. The active application has to guarantee that the generated data rate observes the granted rate. Since the MQoS system can change granted data rates at any time, Vic must be able to adjust its rate accordingly. The mechanism for dynamic adaptation has been integrated in the enhanced version of Vic. Hence, no manual setting is required to guarantee the rate adjustments.

To investigate how this new dynamic rate adjustment influences the perceived quality of real-time video transmission of roaming mobile hosts a series of experiments with point-to-point connections has been performed. We compared video transmissions with and without explicit resource reservations. Furthermore, experiments with variable background load have been performed, that is, in addition to the video transmission several other flows with QoS requirements have been registered in the MQoS System. As performance index the subjective perception of the transmitted video images has been used.

To evaluate the impact of resource reservations and the dynamic adaptations on the application and network interface layers, some roaming experiments were performed. In these cases the MH changed its position between two radio cells during a video communication. While there were enough resources to support the video connection in the first cell, in the second one only the minimal needed bandwidth has been provided. Hence, the data rate had to be adjusted accordingly during handoff. In the experiments two relevant scenarios were studied:

- Vic adjusts its data rate to the rate admitted by the resource management component after each handoff.
- No rate adjustment has been applied at the application layer. However, the network interface is controlled in such a way that the configuration is adjusted to the new granted data rate. Hence, frames transferred from the application layer to the network interface are discarded by policing if the granted rate is exceeded.

The results show that a video communication can be continued even with minimal bandwidth allocation if the

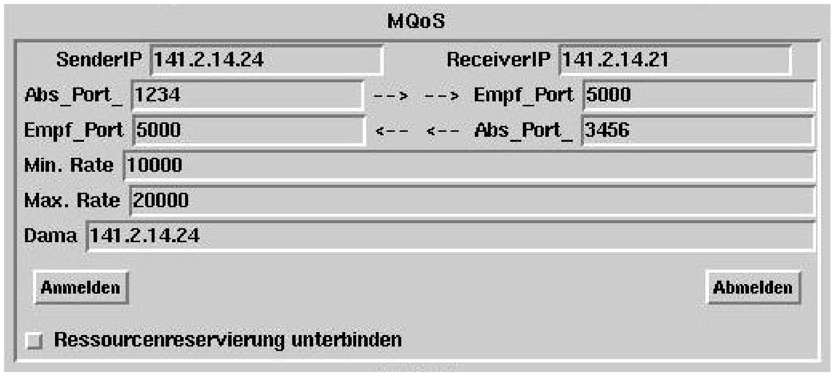

Figure 4. *MQoS extension of Vic (interface in German).*

Figure 5. *Transmission quality of an adaptive application with rate adaptation (lhs) and without rate adaptation (rhs).*

adjustment to the granted bandwidth is performed by the application itself after handoffs. The reason is that this adaptation causes a corresponding regulation of the frame rate. In our experiments an automatic throttling from 20 fps to 1.5 fps was triggered. Without frame rate adjustment to the spare capacity available in a subnetwork nearly all frames had been discarded at the network layer. Hence, an increase of transmission errors could be observed: only a few sections of the video frames had been transmitted successfully. After some time a significant degradation of the transmission quality with partial interruptions had been perceived (see fig. 5).

5 Conclusions

We have developed a new management system to support QoS adaptation of applications in mobile environments. The concept has been described, a prototype has been implemented and its feasibility has been checked by a series of experiments in a testbed provided by an IEEE802.11b compatible wireless LAN with Mobile IP and RSVP enhanced resource reservation.

The roaming experiments with our MQoS system have shown that a fast adaptation of application-generated traffic is required in mobile environments. Otherwise, inefficient resource consumption and significant degradation of transmission quality will occur. Our approach has shown that an improved control of the data rate generated by an application is an effective and feasible way to support efficient data transfer. The control is triggered by cooperating mobility and resource management components. This conclusion is valid not only for real-time multi-media streams where the adjustment can easily be achieved by appropriate parameter settings and changes of the codec scheme, but also for elastic bearer services like file transfer, advanced multi-media mail services and web applications that rely on the TCP suite. In this respect the investigations in [2, 11] and others have shown that standard TCP flow control responds in a very sensitive manner to the dynamics of a mobile environment.

The developed enhancement to RSVP provides the means of dynamic QoS resource reservations of mobile hosts. However, the RSVP based solution has only limited abilities to adapt to high dynamics of hosts in a mobile environment since the adjustment causes significant signaling traffic in the backbone. On the other hand, not all of the changes in the RAN have to be signalled to the backbone nodes with highest priority. The signaling load and the dynamics of changes resulting from the mobility of MHs can be reduced if threshold based capacity limits or elastic capacity ranges are specified for the reservations of flows in the backbone.

In the future we intend to develop a more general specification of the mapping of resource reservations between radio access domains based on arbitrary third generation technologies and the IP-based backbone domain following the outlined concept and implementation of our MQoS management system.

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