End-to-end QoS provisioning across heterogeneous domains

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Abstract

Heterogeneity with respect to networking technology is increasing, for example, considering QoS support. Different QoS have been developed for the Internet and for ATM networks. In the context of the Internet, integrated services (IntServ) as well as differentiated services (DiffServ) are considered. As a result, networking scenarios with different QoS models being applied in different domains are very probable. Within this paper a Inter Domain QoS router is introduced and its functionality is outlined with respect to RSVP based domains and to ATM domains. Reduced signaling of RSVP, connection establishment and connection re-negotiation is supported within the ATM domain in order to follow the dynamic QoS changes of RSVP. A local testbed has been established and simulation experiments have been conducted in order to evaluate the performance of the Inter Domain QoS router.

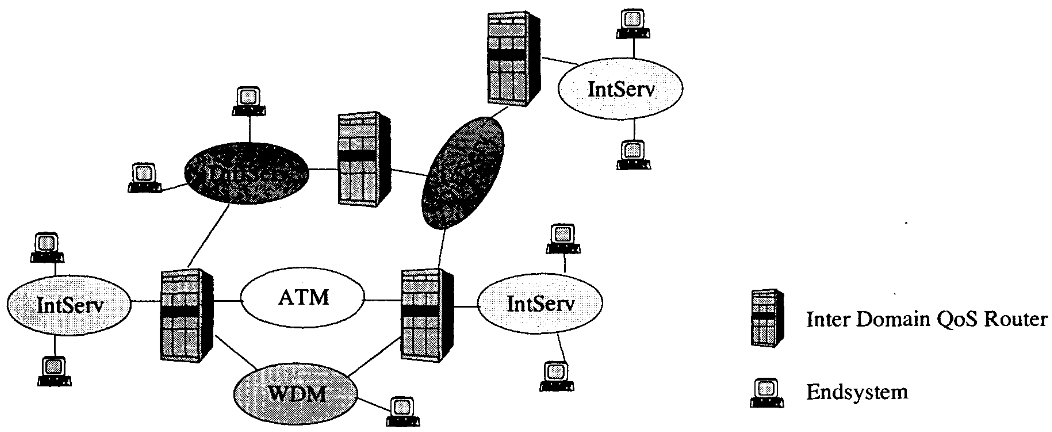


Figure 1: Basic Scenario

1 Introduction

In the last years, the communication environment has drastically changed. Today various network technologies exist and will continue to exist. As a result, different domains in the network may use very different technology, such as ATM, SONET and WDM, all of them with IP being used on top. Generally, it appears that IP may be the only common factor in future heterogeneous networking environments. On the other hand, applications have evolved from simple text-based Email's and file transfer to complex multimedia applications consisting of realtime and non-realtime data streams (e.g., audio, video and whiteboard). They require enhanced functionality including, among others, support for quality of service (QoS) and group communication. QoS support is needed on an end-to-end basis and, thus, across domain boundaries. The usage of different network technologies in these domains may result in different QoS models being used. Currently various QoS models are being developed, including integrated services

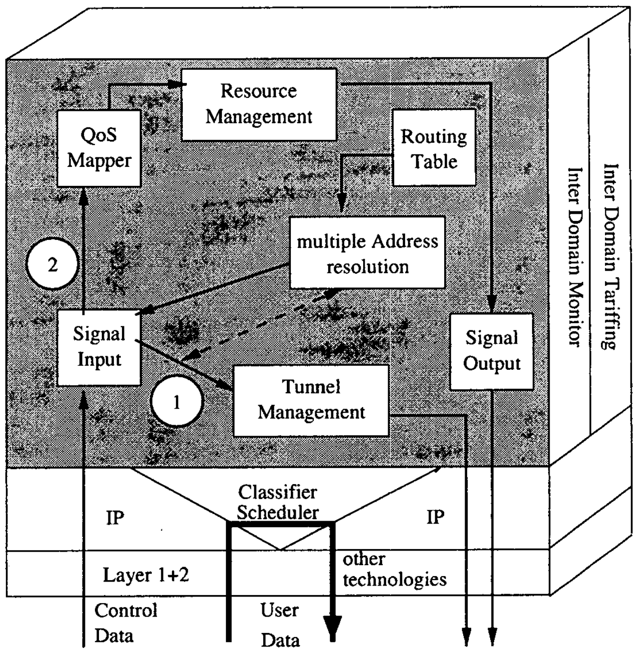


Figure 2: Inter Domain QoS Router

(IntServ, [7]) and differentiated services (DiffServ, [5]). Each of these models may be implemented at proper places on the Internet. Furthermore, ATM provides native QoS support including the required signaling protocol. WDM-based domains may even use other models. As a result, a communication path between interacting end systems may include various sub paths with different QoS models. In order to provide end-to-end QoS at a high quality and efficiency [3], a proper interworking is required. Therefore, we equip IP routers with additional functionalities for QoS interworking among domains with different QoS models. In the following, these routers are called *Inter Domain QoS Routers* (see Figure 1).

Inter Domain QoS Routers (see Figure 2) consist of two or more different network interfaces. It can be differentiated between control data and user data. *User data* has to be forwarded to the outgoing interfaces through a *Packet Classifier* and a *Packet Scheduler*. *Control Data* such as RSVP signaling has to be handled by the Inter Domain QoS Router. First, it has to be decided by the *Tunnel Management*, if the Control Data (i.e., signaling data) is to be forwarded to the next Inter Domain QoS Router. This is the case if one of the next areas has the same technology as the last one. Signaling messages may be forwarded across foreign domains, but they are never interpreted inside these domains. The Inter Domain QoS Router, however, needs to implement the signaling protocols of the different domains that it interconnects. It also needs to map incoming signaling data from one domain to outgoing signaling data in a different domain, if applicable. This means, a mapping between the involved signaling protocols is required.

Additionally, the signaling data may carry QoS information that is needed for end-to-end QoS provisioning. However, different domains may use different QoS parameters, thus, necessitating a QoS mapping. This is the task of the QoS mapper located inside each Inter Domain QoS Router.

Furthermore, the output interface(s) need to be determined. The address resolution component is responsible for this.

The *Resource Manager* of the Inter Domain QoS Router is also involved. It needs to determine whether the required resources are available. Furthermore, the Packet Classifier and the Packet Scheduler are informed to handle the corresponding user data accordingly.

In addition to the functionality discussed above, monitoring and tariffing components are needed within each Inter Domain QoS Router. The Inter Domain Monitor collects information needed for accounting and policing. The information may need to be transferred from technology dependent data to technology independent data. Inter Domain Tariffing applies the information collected by the Inter Domain Monitor. It charges different connections based on this.

Within this paper, we present an approach for interworking among IntServ domains using RSVP as signaling protocol and ATM domains. A likely scenario could be the interworking of RSVP domains across an ATM backbone. It is not desirable to simply configure RSVP on top of ATM. This is especially underlined by the fact that RSVP has some serious scaling problems with respect to state holding and periodic signaling. Related work [2], [4], [8] and [10] shows some enhancements of RSVP signaling, to reduce this overhead in the entire Internet.

Since Inter Domain QoS Routers isolate RSVP domains and ATM domains, state holding with respect to RSVP is not required within ATM domains. Only the Inter Domain QoS Router keep information about RSVP reservations. Furthermore, RSVP signaling overhead is reduced across the ATM domain, i.e., RSVP messages are not simply forwarded periodically into an ATM domain.

The paper is structured as follows. Some basic principles of interworking RSVP and ATM domains are discussed in section 2. The specific solutions with respect to RSVP signaling and ATM connection establishment are outlined. A prototype implementation of an Inter Domain QoS Router is presented in section 3 along with some experimental results considering the processing load. Further results gained through simulation experiments are included in section 4. Section 5 summarizes the paper and gives an outlook on future work.

2 Interworking RSVP and ATM domains

Although Integrated Service with RSVP and ATM do have the common goal of providing QoS to its users, they function quite differently. Since these differences highly influence the design of a proper Inter Domain QoS Router, they are briefly outlined in the following. For a more detailed discussion, the reader is referred to [8].

The resource reservation protocol RSVP ([6], [16]) is responsible for signaling quality of service (QoS) requirements and it supports receiver-initiated dynamic reservations for multicast and unicast data flows. Basically three types of services are suggested for IntServ: best-effort, controlled-load [15] and guaranteed service [14]. RSVP is based on a soft-state approach. Signaling messages (PATH message and RESV message) are send periodically in order to prevent state information inside RSVP-capable routers from being deleted if they are further needed for active RSVP flows. State information is kept per flow which presents a scalability problem in large networks with millions or billions of users. Therefore, solutions are favored that do not require RSVP state holding within the entire network. The proposed Inter Domain QoS Router represents such a solution since no RSVP-related state information needs to be kept in non-RSVP domains even if they interconnect RSVP domains.

ATM [13] is a connection-oriented transfer mode that supports different types of QoS (with services ranging from hard guarantees to best-effort services). ATM supports bidirectional point-to-point and unidirectional point-to-multipoint connections. For the establishment of an ATM connection, signaling protocols are required at the UNI [9] as well as inside the ATM network itself. The QoS requirements are signaled within the connection establishment phase. Resource reservations are also made per flow, i.e., per virtual channel which leads to a considerable overhead in large networks.

Major differences between RSVP and ATM that influence the design of a corresponding Inter Domain QoS Router are summarized in Table 1. RSVP provides a connection-less soft-state approach whereas ATM implements a connection-oriented approach with hard states with respect to QoS guarantees. Resource reservations are receiver-initiated in RSVP and sender-initiated in ATM. However, this can easily be mapped. With respect to multicast communication, RSVP provides heterogeneous QoS whereas ATM is solely based on homogeneous QoS (i.e., each member of the group receives the same QoS). Moreover, QoS requirements can dynamically change during an on-going RSVP session. In contrast, QoS in ATM is statically provided throughout the lifetime of a connection. Especially the dynamics of RSVP need to be supported through an ATM domain.

With respect to ATM, Inter Domain QoS Routers form end points of ATM connections which are established through ATM signaling. No specific functionality is needed for that purpose. RSVP control traffic, however, cannot simply be terminated at an Internet Domain QoS Router. Furthermore, the Inter Domain QoS Router has to implement the exact

	RSVP	ATM UNI signalling
Service	unreliable	reliable
State keeping	soft state	hard state
Reservation	Receiver initiated	Sender initiated
Multicast	heterogeneous QoS	homogeneous QoS
QoS	dynamic	static

Table 1: Major differences between RSVP and ATM

interaction between an RSVP domain and an ATM domain. The following tasks need to be considered and are outlined further below:

- Reduced RSVP signaling across ATM domain
- Point in time of ATM connection setup
- QoS re-negotiation

2.1 Reduced RSVP signaling

RSVP messages are send periodically in order to keep soft state in the corresponding RSVP capable routers. Since no RSVP state information is kept in ATM switches inside the ATM domain, it is not necessarily required that all RSVP messages traverse the ATM domain. This reduces control traffic load in the ATM domain as well as processing time inside Inter Domain QoS Routers.

Increasing the refresh period of RSVP messages is a simple but not desirable approach to reduce signaling traffic. It basically delays QoS re-negotiations. In [2] it is proposed to mark unchanged RSVP messages. This can reduce processing requirements in RSVP routers in general. It also could be used to filter these messages in Inter Domain QoS Routers and, thus, reduce signaling overhead across the ATM domain.

Filtering RSVP messages at the Inter Domain QoS Router is the basic approach followed for interworking of RSVP domains across ATM domains. However, filtering of RSVP messages can only take place, if the corresponding ATM connection is already established and if the QoS requirements of the receiver did not change since the last RSVP message. Resource establishment takes place in different steps: in RSVP domains through periodic RSVP messages. In ATM domain, a connection can be simply established for each RSVP session. In order to reduce the overhead within the ATM domain, multiple RSVP sessions can also be aggregated into one ATM connection. This ATM connection interconnects two or more Inter Domain QoS Routers. It lasts until an explicit termination message is issued by an Inter Domain QoS Router. The ATM connection is not dependent on soft state information and, its management (i.e., establishment and termination) is completely under the control of the Inter Domain QoS Router.

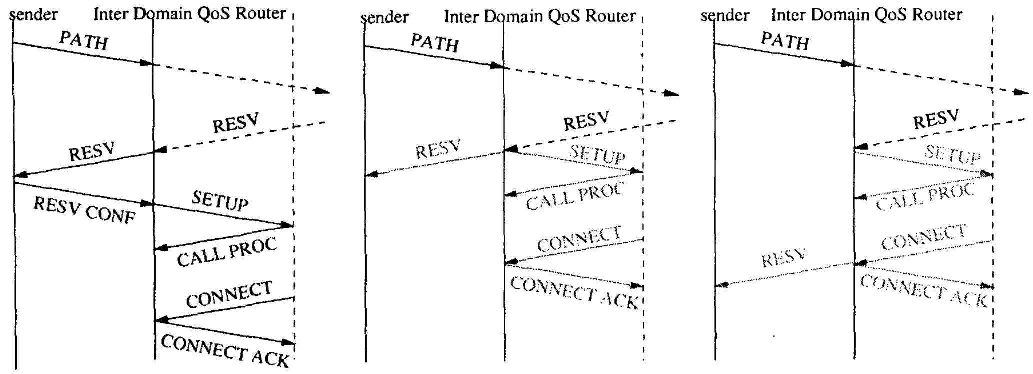
For the purpose of the establishment of end-to-end resource reservations or the re-negotiation of such reservations (i.e., the reception of a modified RSVP message), RSVP messages need to be forwarded across the ATM domain. In case of a modified RSVP message it needs to be decided whether a change with respect to the ATM connection and its associated QoS is needed.

Generally, this approach does not require any changes inside the different domains. Only the Inter Domain QoS Router need to provide the required functionality.

Inter Domain QoS Router are also capable to make use of RSVP extensions proposed in [2]. For instance they may use the Bundle message to aggregate multiple RSVP messages destined for the attached RSVP domain, make use of the Summary Refresh message to reduce the amount of delivered information or participate in the Procedures of Exponential Back-Off of retransmitted messages, to reduce the number of unnecessary retransmissions. In combining the reduction over the ATM domain with this other methods, the Inter Domain QoS router is well suited for the use of end-to-end QoS provisioning.

2.2 ATM connection setup

If an ATM domain is involved in the path of communicating end systems, then an ATM connection needs to be setup among the corresponding Inter Domain QoS Routers. This decision is, for example, derived from the RSVP messages received by such an Inter Domain QoS Router. If it receives a PATH message with no corresponding ATM connection through the



(a) RSVP first

(b) Concurrent

(c) ATM first

Figure 3: Alternative connection setups

ATM domain being available it first periodically forwards the PATH message on a best-effort ATM connection through that domain. This best-effort connection can be established with IP over ATM (e.g., CLIP [11]). Basically, Inter Domain QoS routers will establish such a best-effort ATM connection to all other Inter Domain QoS routers attached to the same ATM domain. If a RESV message is issued in response to that PATH message, it travels the same way back to the origin Inter Domain QoS Router of the PATH message. At the time of reception, both Inter Domain QoS Routers being involved know the ATM addresses of each other. Thus, a direct ATM connection with the required QoS support can be established. This establishment could be initiated by either Inter Domain QoS Router. However, since we are considering multicast communication, the origin Inter Domain QoS Router needs to initiate this setup due to the unidirectional communication in case of multicast.

Basically three alternatives with different time consumption exist for the establishment of the ATM connection (see Figure 3):

- *RSVP first* (see Figure 3(a)), i.e., start the ATM setup only after an RSVP confirmation message has been received
- *Concurrent setup* (see Figure 3(b)) within the RSVP domain and the ATM domain
- *ATM first* (see Figure 3(c)), i.e., RSVP setup is started after ATM setup has been confirmed

2.3 QoS Re-negotiation

As stated above, one of the major differences between RSVP and ATM is the fact that dynamic QoS changes are enabled with RSVP but are not supported by ATM. As a result, an Inter Domain QoS Router may receive a modified RSVP message indicating different QoS requirements for the corresponding RSVP session. This can either be a PATH message or a RESV message. Modified messages generally need to be transferred across the ATM domain in order to properly inform the next RSVP domain on the way. This transmission takes place periodically until the receipt is acknowledged by the corresponding Inter Domain QoS Router. Such an acknowledgement is not available in RSVP. Currently, we use an implicit acknowledgement were the establishment of a new ATM connection indicates the receipt of the modified RSVP message. Thereafter, periodic retransmissions of that message are stopped.

The new QoS requirements signaled through a modified RSVP message may lead to changes with respect to the QoS associated with the ATM connection. The decision about an update of the ATM connection is subject of the Inter Domain QoS Router. Basically, three alternatives can be distinguished:

- Continue operation with old connection and its QoS
- Modification of ATM QoS parameters
- Establishment of a new ATM connection

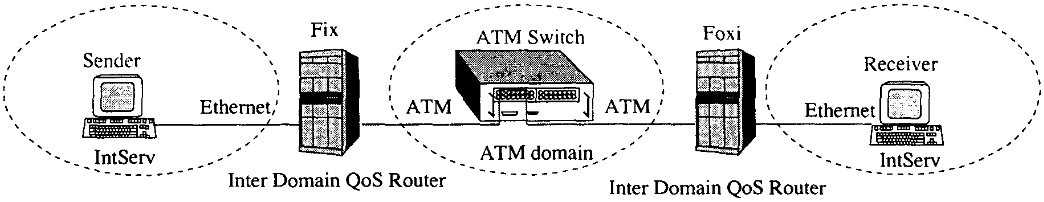


Figure 4: Inter Domain QoS Router testbed

- Termination of the old connection before establishment of the new connection (Alternative 1)
- Establishment of the new connection before termination of the old connection (Alternative 2)

The changes required in the QoS parameters might be very low compared to the currently provided QoS of a connection. In such a case, the old connection is continued to be operated with unchanged parameters and without the establishment of a new ATM connection. It is assumed that this does not have a major impact on the data stream flowing through the ATM domain. This way slight changes to the QoS are neglected.

Modification of QoS parameters belonging to the established ATM connection may be used, if available. This means, the QoS parameters of the ATM connection are re-negotiated. The peak cell rate (PCR) is an example for such a QoS parameter (see [1]).

If the new requirements cannot be served with renegotiation, the establishment of a new ATM connection becomes necessary. Two different ways for the establishment of a new ATM connection are possible considering the order of establishment and termination of the old connection. In the first case, the old ATM connection is terminated and the establishment of a new ATM connection is initiated afterwards. Until the setup of this connection, a best-effort connection is used for data transfer. In the second case, the old ATM connection remains open until the new connection is established. However, in case of scarce resources this alternative may not be available.

3 Prototype Implementation and Experiments

A prototype of the Inter Domain QoS Router has been implemented. The implementation is based on Linux 2.0.25 and the ISI RSVP release 4.1a4 for Sun OS ported to Linux. The Linux RSVP version supports unicast signaling of RSVP messages.

Our testbed (see Figure 4) includes two Linux Pentium PCs with 155Mbps ATM adapters from Efficient Networks. A CISCO Lightwave 1010 ATM switch is used as ATM network. Between both PCs Classical IP SVC connections are possible. This is realized by the Almesberger ATM package 0.31. Such a classical IP SVC connection is established and used for the transfer of RSVP messages across the ATM domain.

Reduced RSVP signaling as well as filtering of RSVP messages is included in the prototype. Currently, only best-effort ATM connections can be used for data transfer. However, this is sufficient to evaluate the processing load on Inter Domain QoS Routers.

In order to evaluate the load on Inter Domain QoS Routers related to RSVP message processing, the amount of system calls was determined over a time interval of 30 minutes. It is useful to count the system call, because it shows why the system is loaded. During this time, an RSVP session transferring data from Fix to Foxi was operational. The amount of system calls decreases considerably if the reduced signaling was applied. Foxi reported 15.5 % less system calls and Fix 62.2 % less system calls compared to normal RSVP signaling. In a second scenario, 100 active RSVP sessions were initiated. The observed reduction of system calls is somewhat comparable with the first measurement: 19.8 % less system calls at Foxi and 58.5 % less system calls at Fix.

Generally, it can be seen that the reduction of system calls at the origin Inter Domain QoS Router is lower than at the receiving Inter Domain QoS Router. The reason is, that at the origin Inter Domain QoS Router for every received PATH message a query to the routing interface is made, to gather the next hop for the RESV message. These queries form 40 % of the observed system calls in the case of one RSVP session and 45 % in the case of 100 RSVP sessions. Modify-

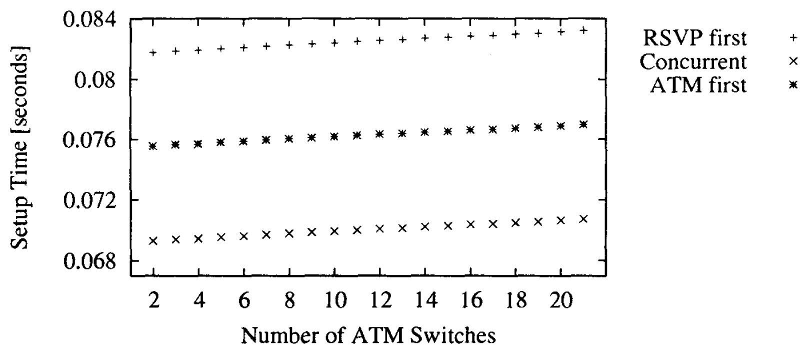


Figure 5: Result of establishment the end-to-end reservation

ing the implementation in a way that the route query is only issued if the PATH message is received by another interface or the PATH message has another last hop address will increase the performance gain in the origin Inter Domain QoS Router (Foxi in the testbed) to the same range observed with the receiving Inter Domain QoS Router (i.e., Fix in the testbed).

4 Simulation experiments

In addition to the prototype implementation, a simulator for Inter Domain QoS Routers was implemented and currently still is enhanced with additional features. The simulation is based on Opnet. Since Opnet does not provide any RSVP support, RSVP capable senders, receivers, routers as well as Inter Domain QoS Routers have been implemented.

Various simulative experiments have been conducted. Although until very recently, main focus was on the alternatives with respect to ATM connection setup as well as on re-negotiation of ATM connections.

Considering the alternatives with respect to ATM connection establishment, the resulting differences in setup time are presented in the diagram shown in Figure 5. The setup time refers to the end-to-end connection between two nodes that are connected to IntServ-domains that are interconnected through an ATM domain (see for example sender and receiver in Figure 4). More precisely, the establishment delay at the sender and Inter Domain QoS router is measured. With respect to the sender, the time interval between sending a PATH message and receiving a corresponding RESV message is measured. At the Inter Domain QoS router, the point in time, when an ATM connect is received is collected. The larger time of both dominates the establishment time and is considered in Figure 5. Different diameters of the ATM domain have been investigated, ranging from two to 21 ATM switches on the path. The diagram clearly shows that a concurrent setup of the reservations is advantageous with respect to setup time. The difference between the two approaches RSVP first and Concurrent is constant and refers to the time needed to send and receive the RESV message and to send and receive the RESV CONF message.

Since setup time is considerably short, the selection of the alternative should only have a minor impact on the costs being associated with the setup time of a connection. But there is an influence to the cost that are associated with an established ATM connection. The available resources in the ATM domain and the IntServ domain can trigger the selection of one of the alternatives. RSVP first should be selected in case of a shortage of resources in the IntServ domain and enough resources being available in the ATM domain. In such a case it is reasonable to defer ATM connection setup until it is clarified whether enough resources can be provided in the IntServ domain, i.e., until resource reservation in the IntServ domain has succeeded. However, a major drawback of the alternative RSVP first is, that the RESV Confirmation message is needed to confirm the reservation to the Inter Domain QoS router. According to RFC 1633 [6], an RSVP capable router is not required to return such a confirmation message. As a result, the alternative Concurrent setup is preferred. This is also the selected alternative in case enough resources are available in both, the IntServ domain as well as the ATM domain. There is a high probability that both setups may succeed. The Concurrent alternative is selected in heavily loaded IntServ

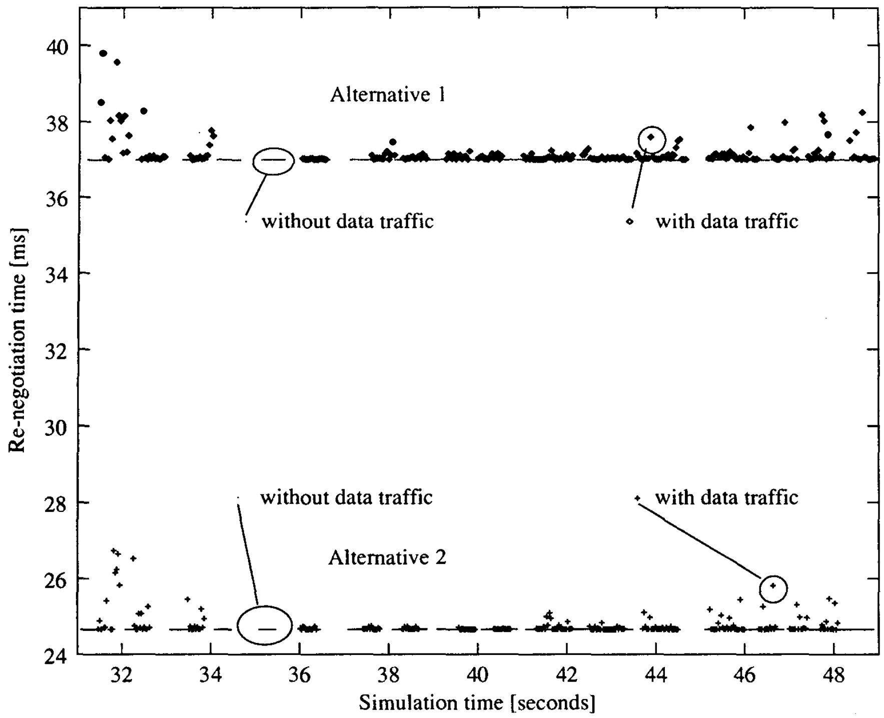


Figure 6: Result of re-negotiation

and ATM domains, because a failed setup is reported faster. The ATM first alternative is selected only, if the ATM domain is heavily loaded and the IntServ domain is lightly loaded. The selection of alternatives is summarized in Table 2.

	lightly loaded IntServ	heavily loaded IntServ
lightly loaded ATM	Concurrent	ATM first
heavily loaded ATM	Concurrent or RSVP first	Concurrent

Table 2: Alternative for Connection Setup

Furthermore, the duration of a QoS re-negotiation is of interest. For the test scenario two Inter Domain QoS Routers are considered 155 RSVP session are established between them. Every RSVP session is mapped to a rt-VBR ATM connection. All RSVP sessions have the same direction. The ATM domain consists of two Inter Domain QoS Routers which are connected through a 155 Mbit/s ATM connection. Each RSVP sender produces a data stream with a data rate of either 78.125 kbits/s or 39.0625 kbits/s. Re-negotiation takes place between these two data rates every 8 seconds. The start time of the RSVP session is constantly distributed over a time interval of 10 seconds. To get the ATM link heavily loaded, background traffic is generated. The background traffic uses one rt-VBR connection.

Two different traffic scenarios are distinguished, one with the above described characteristics and a second which simulates only the signaling data without user data and background traffic.

The diagram depicted in Figure 6 shows the observed duration of the re-negotiation process. On the x-axis the simulation time is shown, and on the y-axis the time of a re-negotiation. This refer to the time interval from start of the re-negotiation phase until the establishment of the new connection. Both alternatives (see section 2.3) have been investigated. With alternative 1, first the existing connection is terminated. Before that, all data queued for transmission are sent into the ATM network. Alternative 2 first establishes the new connection and then transfers the queued data across that connection.

The results show that alternative 2 is about 12 ms faster than alternative 1. Furthermore, it can be seen that the scenario without data traffic leads to nearly constant re-negotiation times. This is not the case if user data are sent. The queue length of the Inter Domain QoS Router is responsible for the variation in the re-negotiation time. The scenario with no data traffic can, then, be seen as lower bound for a re-negotiation. Alternative 1 has a variance of about 3 ms (8.4 %) and Alternative 2 about 2 ms (7.6 %). The lowest bound differs of about 12 ms. This is due to the termination of a connection and the associated data transfer.

Alternative 2 has the disadvantage that leads to a higher resource utilization for a short period of time. However, re-negotiation alternative 1 is faster. So the decision should be made with respect to the available resources inside the ATM domain. If many resources are available, alternative 2 should be used otherwise alternative 1.

5 Summary and Perspectives

In this paper Inter Domain QoS Routers were introduced in order to provide end-to-end QoS through domains with different QoS models, such as IntServ, DiffServ and ATM. The paper focuses on the interconnection of RSVP domains through an ATM domain. However, the general concept can be applied to other scenarios as well. Generally speaking, the Inter Domain QoS Routers try to isolate different domains as much as possible. Therefore, they provide an interworking between the corresponding signaling protocols, if applicable. Moreover, a mapping of QoS parameters is also provided. Furthermore, QoS aggregation can be used if possible and, thus, the scalability of the approach to large networks is increased.

Appropriate algorithms for handling RSVP messages in the Inter Domain QoS Router were presented along with mechanisms that deal with dynamic QoS modifications as they typically appear in the RSVP domains but are not directly supported within ATM networks. The performance has been investigated with simulative experiments.

Currently, the concept of Inter Domain QoS Routers is further applied to DiffServ domains. WDM and SONET networks will additionally be considered in the future. In [12] a tariffing model for Internet services has been developed that will be integrated in the presented Inter Domain QoS Routers.

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