1. Executive Summary

The main objectives of the project DIANA (AC-319), that is part of the closing ACTS Programme, are to develop, integrate, validate and demonstrate resource reservation, signalling mapping, and traffic control functionality which seamlessly inter-operate between ATM and IP networks to achieve QoS.

DIANA is studying several scenarios for QoS provisioning including RSVP-over-ATM, Differentiated Services and Scalable Resource Reservation Protocol (SRP). In all the above scenarios, the IP QoS flows can be encapsulated in ATM VCs. ATM is merely providing transport to IP packets without interpreting the packets or services provided by those packets. However, the Differentiated Services and Scalable Resource Reservation Protocol scenarios are independent of the used link layer technologies.

In the RSVP over ATM proposal the SVC ATM QoS parameters are correlated to those of RSVP. Similar flows are aggregated to the same existing or newly created SVC. When new flows are accepted or old ones terminated, the SVC bandwidth may be renegotiated. Because of the connection setup delay, the bandwidth is increased well before a calculated threshold is reached. The primary applications for this scenario would be high-end IP telephony, video and dataconferencing applications.

In the Differentiated Services (SIMA) proposal Access Nodes at the domain boundaries define a priority level for each packet. They calculate the Drop Preference using the ratio of Momentary Bitrate to purchased Nominal Bitrate. The Core Nodes simply discard the packets according to outgoing link congestion or schedule real-time packets before non-realtime ones, making the network scalable and adaptive. This is suitable for any scenario where strict QoS is not absolutely necessary. DiffServ Networks can interwork even with regular best effort networks because they require no reservations or strict QoS.

In the SRP proposal the routers between sender and receiver receive packets that either are best effort traffic, request for bandwidth or have a reserved bandwidth. Routers may forward packets unchanged, downgrade or discard them according to the status of the outgoing link. Receiver gives direct feedback to the sender so it knows the network status. SRP is best suited for wide scale reserved non-realtime flows with extra restrictions at the ingress routers, such as bulk residential ISP customer accounts with bandwidth quotas.

Project DIANA - Converging and integrating IP and ATM for real-time applications

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Abstract

The evolution of IP and ATM share some common drivers. Both of them are addressing efficient network resource utilisation. In order to evaluate the options and combinations offered by these technologies the DIANA project is looking into the areas where ATM and IP both overlap and complete each other, that is *QoS interworking between ATM and IP*. This is achieved by investigating RSVP-over-ATM approach. This solution is compared with two IP level approaches: Differentiated Services and Scalable Resource Reservation Protocol (SRP).

The RSVP over ATM proposal creates RSVP flow aggregates with similar QoS requirements and sets up a SVC for each aggregate. This approach is best suited for end-to-end per flow QoS provisioning. The relatively complex RSVP over ATM connection set up is inefficient has for short-lived flows in a wide scale network, and the assumption of end-to-end RSVP support may be too strong. DIANA project has developed a dynamic bandwidth management solution to reduce the signalling overhead in RSVP over ATM case.

The Differentiated Services framework covers a set of per hop behaviour (PHB) schemes where priority levels are set in the headers of each individual packet at domain boundaries. Packet discarding and scheduling are done in the subsequent routers. DIANA has been working on a solution called Simple Integrated Media Access (SIMA). The mechanism is very scalable and adaptive but offers only relative QoS for sender originated flows. Although SIMA is easy to manage with only two parameters, it is flexible enough to be used as an end-to-end solution in wide scale networks.

The Scalable Reservation Protocol (SRP) proposal has two priority values that can be set in each packet by the sender or any subsequent router to reflect the flow status in the next link. Receivers give feedback to the senders. SRP offers adaptive and scalable reservations but can not differentiate between

similar priority levels. It is best suited for wide scale reserved non-realtime flows with extra restrictions at the ingress routers, such as bulk residential ISP customer accounts with bandwidth quotas.

This article describes briefly the implementations of the studied QoS mechanisms and summarises their applicability.

2. Introduction

DIANA is a EU 4th Framework project. Its goal is to evaluate different ways of providing IP QoS over ATM and compare the results in order to identify the scenarios where each mechanism is at its best. The adopted technical approach of the project relies on practical implementations and experiments with the studied QoS mechanisms. The partners participating in the project are Telscom, Flextel, EPFL, UST, ASPA, NetModule, Finsiel, Nokia, Telenor and Swisscom.

The project is developing an integration unit that allows the investigation of different solutions for the convergence of QoS support in IP and ATM levels. The convergence of IP and ATM is addressed by investigating RSVP-over-ATM architecture. This solution is compared with two purely IP level approaches: Differentiated Services and Scalable Resource Reservation Protocol. The integration unit is exploited in a test network that has been constructed on the basis of the ATM infrastructure stemming from previous ACTS and RACE projects. A number of experiments, trials, and measurements are being conducted to provide an insight into the feasibility and efficiency of the emerging techniques.

Flextel provides the hardware of the integration unit. Software implementations of the various queuing mechanisms are based on the Linux Traffic control. EPFL, UST, Telenor and Nokia have developed and implemented parts of the queuing mechanisms. The other partners have been active in applications side: a Windows based videoconferencing application, ARMIDA, is used for demonstrating QoS in real life context.

3. RSVP over ATM

As mentioned above, DIANA implements a RSVP over ATM architecture [RFC 2205, RFC 2209, RFC 2210, RFC 2215, AF96-0258, RFC 2380, RFC 2381, RFC 2382] as an example of a traffic descriptor and QoS parameter based resource reservation that strictly guarantees end-to-end QoS. In order to address scalability issues, a concept of massive aggregation of flows to VCs similar to [BeVi 97, GBH 97] is applied to reduce the control overhead induced by signalling and the maintenance of per-flow state information in the core network.

Therefore, DIANA's RSVP over ATM traffic control architecture is implemented in a router that represents the border between an IP network and an ATM network, at a point where a sufficiently large number of IP flows can be aggregated and transferred on a common VC towards the egress of the ATM network. The implementation unifies RSVP signalling; Integrated Services traffic control, flow-to-VC mapping, CLIP IP over ATM address resolution and UNI4.0 signalling in a working ensemble, see Fig. 1.

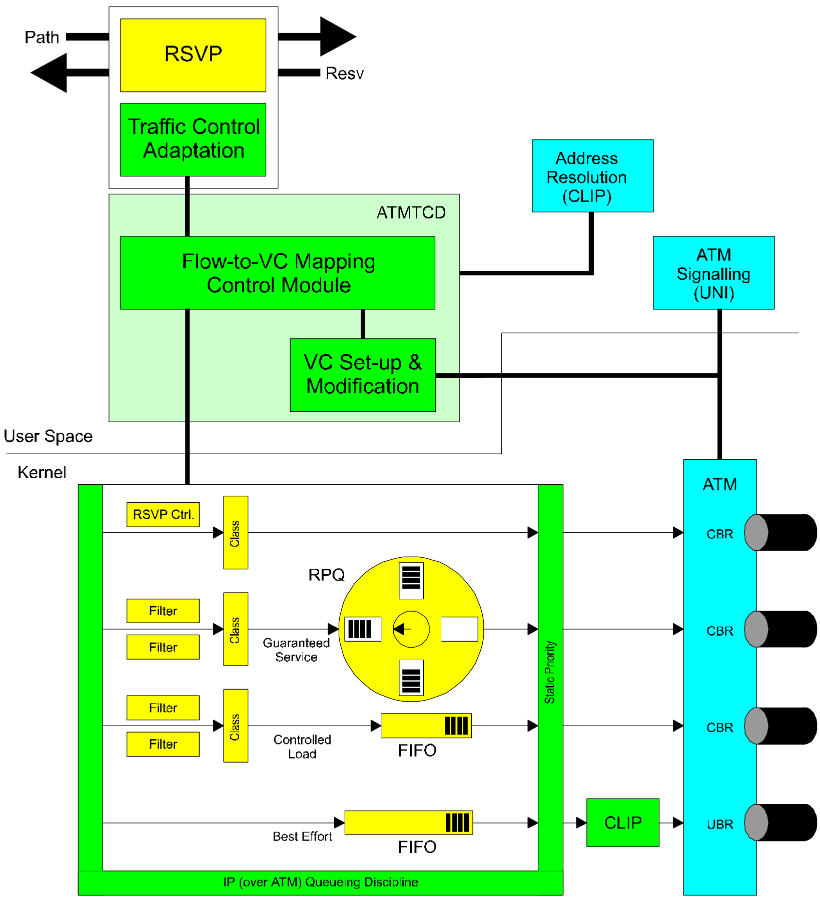

Figure 1 RSVP over ATM traffic control architecture

The controlling RSVP demon process starts interacting with ATM traffic control when traffic control related RSVP messages arrive. For this purpose, RSVP has been enhanced with an ATM specific Link Layer Dependent Adaptation Layer (LLDAL). DIANA's LLDAL implementation is separated into a traffic control adaptation to RSVP and a demon process ATMTCD that controls most of the interworking tasks (address resolution, signalling translation) and traffic management functions (flow-to-VC mapping, dynamic bandwidth management, queue management & schedulers). In this architecture, the core ATMTCD is not only in charge of handling communication with RSVP and the Linux kernel traffic control but also in controlling its subordinate modules. Flow-to-VC Mapping Control Module (F2VM) and VC Set-up and Modification Module (VSMM) implement the mapping from an IP flow to an ATM VC and the dynamic set-up and modification of VCs following the rules of the dynamic threshold based bandwidth management scheme.

The traffic control architecture comprises the following interworking and traffic control functions:

- Aggregation filters and flow records
- ATM address resolution and signalling translation
- Asynchronous ATM VC set-up and modification
- Queueing and scheduling.

In order to reduce the control overhead induced by signalling for a single flow with a possibly low bandwidth demand and short lifetime, a dynamic bandwidth management scheme re-negotiates reserved ATM bandwidth [Q.2963.1] of a record only when the resource calculation for the flows mapped to that record yields a bandwidth that crosses a re-negotiation threshold. Those thresholds will be tuned in a way that avoids re-negotiation to an extent that can be justified by economic considerations in terms of reserved bandwidth and signalling processing overhead. This means that new flows can often be granted prior to ATM level re-negotiation by exploiting the safety margins as realised with the threshold. In this case, ATM re-negotiation can be carried out asynchronously. Consequently, the VSMM is able to handle all set-up and modification requests asynchronously and is thus a pre-requisite for the dynamic bandwidth management scheme. The behaviour of the system is sketched in Fig. 2. It shows the release of ATM level reservation due to decrease of aggregate flow bandwidth .

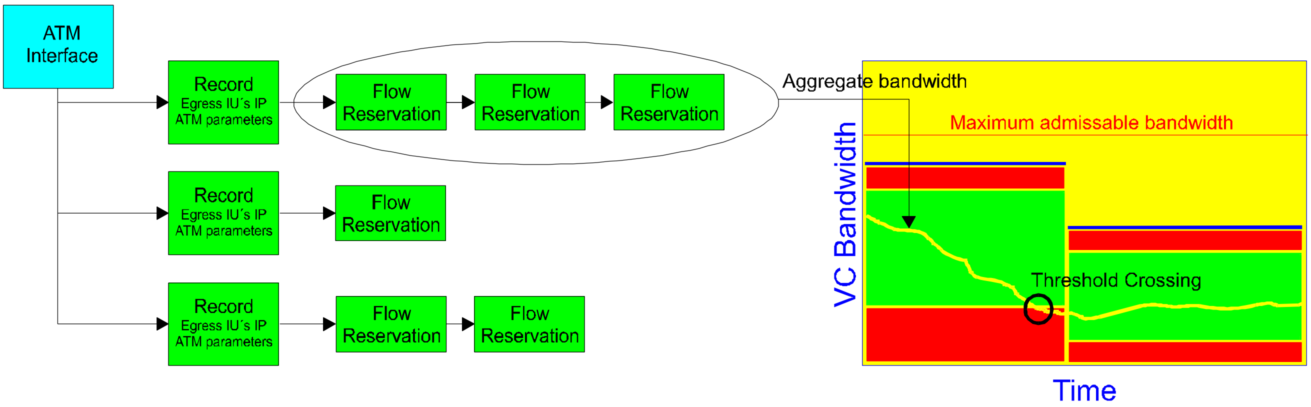

Figure 2 Flow to VC mapping and dynamic bandwidth management

The RSVP over ATM process ensemble introduced in Fig. 1 controls an IP over ATM queuing discipline that includes a RPQ scheduler [RPQ 96, RPQ 99] ensuring isolation of flows with different delay requirements although they are aggregated to the same VCs.

The RPQ scheduler maintains P + 1 priority ordered FIFO queues to handle P priorities. Those queues rotate at the end of a rotation interval Δ. This means that the queue with the previously highest priority is removed from the top and appended to the end of the priority sorted list of queues. Since packets with priority p, p = 1, ..., P are inserted into the queue with the current index p, i.e. nothing is inserted to the top queue anymore, and since the CAC ensures that none of the queues overflows, a deterministic, delay bounded service as required by Guaranteed Service [RFC 2212] can be realised. Consequently, RPQ is used to aggregate Guaranteed Service flows with different delay requirements over a single VC (or several VCs).

For the Controlled Load [RFC 2211] service flows that do not include delay bound information, separate FIFO queues are used. In addition, a default queue for best-effort traffic is applied. Unlike the other classes, the default best-effort class does not filter traffic. Furthermore, it is the only „class“ that does not have a VC of its own but uses CLIP in a standard fashion. As an additional feature, the queuing discipline assigns dedicated RSVP over ATM control CBR-VCs to protect RSVP signalling messages, which would otherwise be forwarded via CLIP (UBR-VCs) from being dropped when congestion occurs.

The components of the traffic control architecture described above form the basis for traffic descriptor and QoS parameter based resource reservation with reduced control overhead. Flows are aggregated to a limited number of flows without considerably affecting the QoS experienced by an individual flow within this aggregate. Thus, DIANA´s RSVP over ATM is one of various scalable approaches towards QoS in future broadband networks.

4. Differentiated Services : Simple Integrated Media Access

4.1. Architecture

Traditional resource reservation architectures that have been proposed for integrated service networks (RSVP [RFC2205], ATM [UNI] etc.) all have in common that intermediate systems (routers or switches) need to store considerable amount of reservation state information. The more recently designed Differentiated Services architecture [RFC2475] offers improved scalability by aggregating flows to a limited number of classes and by maintaining state information only for such aggregates. The basic architecture does not include resource reservation but depends on additional mechanisms for signalling (e.g. RSVP) and for resource allocation (e.g. provisioning or so-called ``bandwidth brokers'' [DSFRAME]).

One of the versions of Differentiated Services [DSFRAME, Kilkki] is Simple Integrated Media Access [SIMA]. It is an implementation of the DRT-PHB [DRT-PHB] framework. Some of its properties are similar to those of other Differentiated Services Per Hop Behaviours (PHB) such as Assured Forwarding (AF) [RFC 2597] and Expedited Forwarding (EF) [RFC 2598]. In a nutshell, it provides relative QoS for end users that have access to the SIMA domain.

A SIMA domain consists of Access Nodes at the domain boundaries [RFC 2475] and Core Nodes between them. When a packet arrives to the SIMA domain, the Access Node associates it with a known flow. It then retrieves flow specific parameters from a local database and calculates a suitable QoS value that is written to the DS field [RFC 2474] of the packet header. The QoS value consists of two components: a three bit Drop Preference (DP) value and a real-time bit.

The Access Node routes packets to a Core Node that has separate Scheduling and Buffering Units (SBU) at each output interface. Each SBU has its own buffers for real-time and non-realtime packets. If the DP of a packet is less than the allowed DP, the packet is discarded. The allowed DP value depends on the occupancy levels of the buffers. When sending packets from the buffers, real-time packets always have priority over non-real-time ones.

4.2. Parameters and mechanisms

Flows are recognised by comparing packet source and destination IP addresses to a list of references. A trivial example of a flow has a unique source but any destination address. An end user requires only two QoS parameters for a flow: choice between real-time and non-realtime, and the Nominal Bitrate (NBR). Access Nodes constantly measure the Momentary Bitrate (MBR) of each flow and use the MBR/NBR ratio to define a unique DP value for each packet of that flow. The relation between the MBR/NBR ratio and the DP value is logarithmic. The highest DP value of 7 is reserved for non-SIMA traffic such as RSVP or network management. After the Access Node has marked the packet with the proper DP it forwards it to the Core Nodes.

MBR/NBR	**Special**	**<¼**	**<½**	**<1**	**<2**	**<4**	**<8**	**=8**
DP	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**

Table 1. An example of the relation between MBR, NBR and DP values.

Buffer occupancy levels of real-time and non-realtime buffers are used to indices to an array from which the threshold DP_A value is retrieved in the SBUs of a Core Node. The DPs of the incoming packets are compared against this threshold. If the DP is higher than DP_A then the packet is forwarded to the corresponding buffer which is served as a FIFO queue.

4.3. Characteristics

Only Access Nodes search their local databases for flow parameters and perform the complex DP calculations, whereas the SBUs in the Core Nodes are used for simple discarding, buffering and scheduling. This means that the processing overhead and complexity is kept to a minimum.

The routers inside the SIMA domain need neither signalling nor flow state information, so they operate independently of each other. This, together with connectionless operation and SBU adaptation to congestion in outgoing links, makes the system very scalable and tolerant to changing conditions.

The QoS is defined by only two parameters that are easily understood by end users. An increase in the real-time or non-realtime NBR can have a simple price tag on it. If the service provider allows it, the end users may change their flow parameters themselves directly in the database without burdening customer service or suffering from service delays.

Network dimensioning depends on the NBR purchased by end users, and SBU buffer sizes should be modified to fit the ratio of real-time to non-realtime NBR. Wrong dimensioning or unexpected traffic patterns can only lead to poor QoS instead of a total rejection of service requests. Gradual degradation of QoS indicates that either the users should reduce their transmission speeds or the operator should increase capacity.

The interworking of SIMA and other Differentiated Services domains is fairly good, although the priority classes may not completely match. For protocols that require connections such as RSVP with its soft states, extra functionality is required in the Access Nodes.

4.4. Implementation

In the Access Node implementation packets are read from specified ethernet input interfaces and associated with known flows. Parameters for priority calculation and statistics are stored in two databases. The DP value for the DS field is calculated using exponential moving average function. The packet is forwarded to the appropriate output interface.

The Core Node first discards excess packets in its the SBU according to packet's DP and the buffer occupancy levels. The remaining packets are stored into real-time and non-realtime buffers. The Core Node has been implemented and tested using the Linux traffic control framework by J. Laine, S. Saaristo and J. Harju of the Tampere University of Technology [TUT-CN].

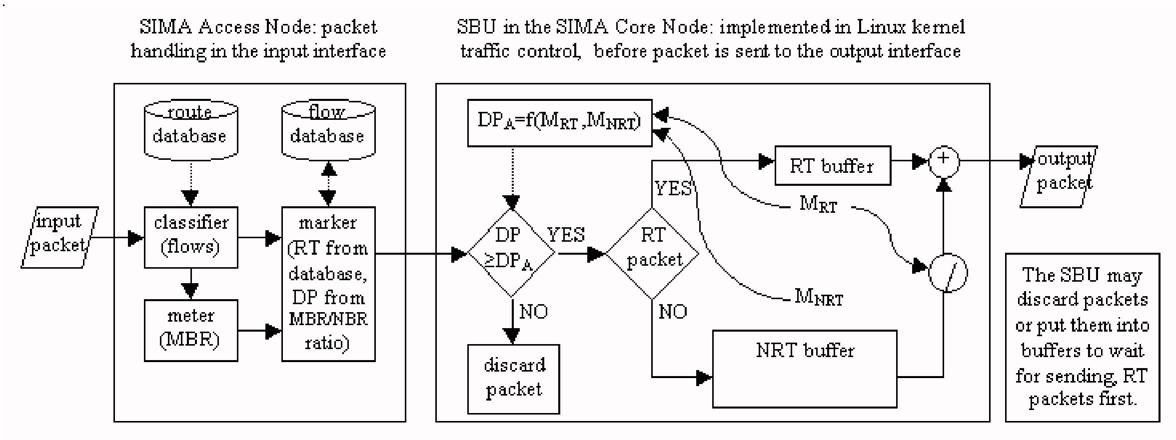

Figure 3 ***SIMA Access and Core Node in the DIANA Integration Unit.***

5. Scalable Resource Reservation Protocol

The realisation that traditional reservation mechanisms were too complex, both for rapid deployment, and for addressing user needs, led us also to look for a much more lightweight approach that still supports absolute reservations as opposed to the relative QoS with Differentiated Services. *Scalable Resource Reservation Protocol* (SRP) is the result of this work [Almes].

SRP extends upon simple aggregation by providing a means for reserving network resources in routers along the path taken by flows, using a single end-to-end protocol. It does so without explicit signalling of flow parameters, and without requiring routers to maintain per-flow state. Instead, routers monitor the aggregate flows of reserved traffic and maintain a running estimate of what amount of resources is required to serve them with the appropriate quality of service.

5.1. Reservation mechanism

In short, the SRP reservation model works as shown in Figure 4. A source that wishes to make reservation starts by sending data packets marked as request packets to the destination. When receiving a request packet, a router determines whether hypothetically adding this packet to the flow of reserved packets would still allow it to meet the quality of service goals. If so, the request packet is accepted and forwarded towards the destination, while still keeping the status of a request packet. In the opposite case, the request packet is degraded to a lower traffic class, such as best effort, and forwarded towards the destination. A packet sent as request will reach the destination as request only if all routers along the path have accepted the packet as request.

The destination periodically sends feedback to the source indicating the amount of request and reserved packets that have been received. This feedback does not receive any special treatment in the network (except possibly for policing, see below). Upon reception of the feedback, the source can send packets marked as reserved according to a profile derived from the feedback. If necessary, the source may continue to send more request packets in an attempt to further increase the reservation.

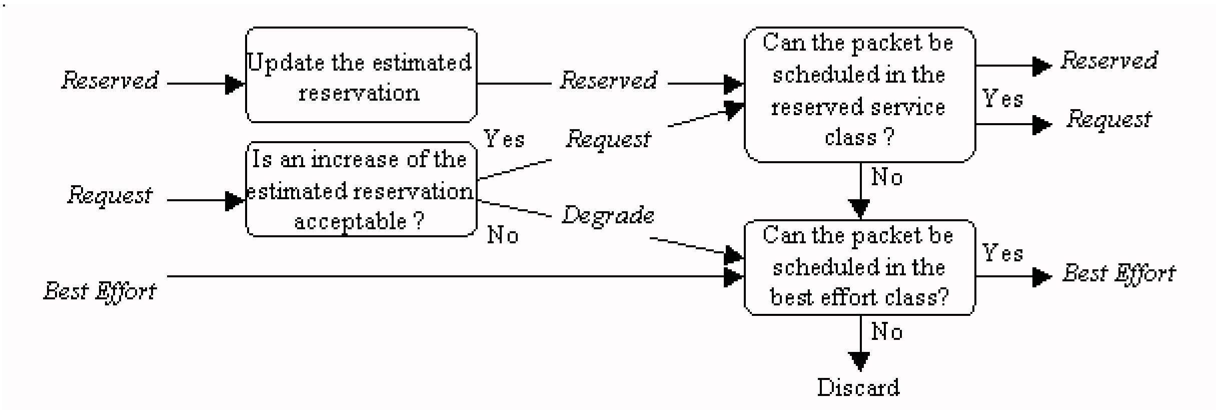

Figure 4 ***Packet processing by routers.***

Thus, in essence, a router accepting to forward a request packet as request allows the source to send more reserved packets in the future; it is thus a form of implicit reservation.

5.2. Aggregation

Routers aggregate flows on output ports, and possibly on any contention point as required by their internal architecture. They use estimator algorithms for each aggregated flow to determine their current reservation levels and to predict the impact of accepting request packets. The exact definition of what constitutes an aggregated flow is local to a router.

Likewise, senders and sources treat all flows between each pair of them as a single aggregate and use estimator algorithms for characterising them. The estimator algorithms in routers and hosts do not need to be the same. In fact, we expect hosts to implement a fairly simple algorithm, while estimator algorithms in routers may evolve independently over time.

The proposed architecture uses two protocols to manage reservations: a reservation protocol to establish and maintain them, and a feedback protocol to inform the sender about the reservation status.

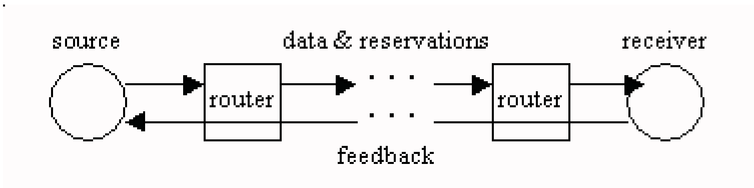

Figure 5 ***Overview of the components in SRP.***

Figure 5 illustrates the operation of the two protocols:

- Data packets with reservation information are sent from the sender to the receiver. The reservation information consists in a packet type, which can take three values, one of them being ordinary best effort. Routers process this information to control reservation increases, and to estimate the effective resource usage.

- The receiver sends feedback information back to the sender. Routers only forward this information; they do not need to process it.

6. Common element for IP level QoS - Traffic Control

The implementation of all the IP level QoS mechanisms relay on sophisticated packet processing and queue algorithms that interact with packet forwarding in a router. The implementations of these queuing and processing functions are typically platform dependent. DIANA project has applied and extended Linux Traffic Control functions to support the above-described IP level QoS mechanisms. This facilitates fair performance and complexity comparisons.

The traffic control code in the Linux kernel consists of the following major conceptual components:

- queuing disciplines
- classes (within a queuing discipline)
- filters
- policing

Each network device has a queuing discipline associated with it, which controls how packets enqueued on that device are treated. A very simple queuing discipline may just consist of a single queue, where all packets are stored in the order in which they have been enqueued, and which is emptied as fast as the respective device can sent. More elaborate queuing disciplines may use filters to distinguish among different classes of packets and process each class in a specific way, e.g. by giving one class priority over other classes. Classes and queuing disciplines can be related with each other with filters leading into a recursive construction of packet processing.

The building blocks of IntServ and Diffserv traffic handling mechanisms map into the Linux TC conceptual components in following way: IntServ and DiffServ Classifiers map to a set of filters and corresponding classes, IntServ policing and DiffServ metering is mapped to corresponding queuing disciplines. Packet scheduler (IntServ) and Shaper/dropper (DiffServ) are combinations of filter, class and discipline components.

7. Conclusion

The current performance limits of the Internet make the integration of IP with ATM a hotly debated networking issue, with various competing approaches and products. Legitimate technical and market issues are, however, often intertwined with biased views and hype, with vendors competing in the standards arena as well as the market. As we have seen, all proposals have their strengths and weaknesses. In this section we identify the ideal networking environments for each of the studied QoS approaches.

RSVP over ATM supports a case where there is a need for a guaranteed QoS over IP islands as well as over ATM clouds. Applications that need flow based QoS should have RSVP capability. Each end user terminal can belong to several subnets with different QoS policies. This is because of the possibility of setting more than one logical interface on ATM boards. Applications that benefit from RSVP over ATM solutions include high-end IP telephony, video and dataconferencing applications. A common view is that RSVP could play are role in the intranet and Differentiated Services are better for wide scale backbones.

The main advantage of *Differentiated Services/SIMA* (over ATM or any other link layer) is the simplicity in both provisioning and contracting. The most promising scenario for DiffServ is Virtual Private Network overlaying existing Internet connectivity. In this case VPN flows with QoS assurance will be tunnelled among DiffServ routers in several domains: the customer will see this infrastructure as a set of leased lines. However, the pricing of this service is not clear. Typically, Differentiated Services/SIMA over ATM should be used in a large corporate network where several interconnected infrastructures are linked with PVC/SVC connections and are under the same administrative control. DiffServ/SIMA is suitable for any scenario where strict QoS is not absolutely necessary. DiffServ Networks can interwork even with regular best effort networks because they require no reservations or strict QoS.

The *Scalable Resource Reservation Protocol* provides a light-weight reservation mechanism that combines the ideas behind RSVP and DiffServ. Its main focus is on good scalability to very large numbers of individual flows. End systems (i.e. senders and destinations) actively participate in maintaining reservations, but routers can still control their conformance. Routers aggregate flows and monitor the aggregate to estimate the local resources needed to support present and new reservations. There is neither explicit signalling of flow parameters, nor maintenance of per-flow state by routers. SRP is best suited for wide scale reserved non-real-time flows with extra restrictions at the ingress routers, such as bulk residential ISP customer accounts with bandwidth quotas.

8. Bibliography

[AF 96-0258] A. Demirtjis et al., RSVP and ATM Signalling. ATM Forum Contribution 96-0258, January 1996.

[Almes] W. Almesberger, T. Ferrari and J.-Y. Le Boudec, *SRP: A Scalable Reservation Protocol for the Internet*. Technical Report, EPFL, Lausanne, Switzerland, March 1998

[BeVi 97] S. Berson and S. Vincent, *Aggregation of Internet Integrated Services State*. Work in Progress, IETF Integrated Services Working Group, <draft-berson-classy-approach-01.ps >, November 1997.

[DSFRAME] Y. Bernet, J. Binder, S. Blake, M. Carlson, E. Davies, B. Ohlman, D. Verma, Z. Wang and W. Weiss, *A Framework for Differentiated Services*. Work in Progress, IETF, <draft-ietf-diffserv-framework-00.txt>, May 1998.

[DRT-PHB] M. Loukola, K. Kilkki, J. Ruutu, *Dynamic RT/NRT PHB Group*. Work in Progress, IETF Differentiated Services Working Group, <draft-loukola-dynamic-00.txt>, November 1998

[GBH 97] R. Guerin, S. Blake and S. Herzog, *Aggregating RSVP-based QoS Requests.* Work in Progress, IETF Integrated Services Working Group, <draft-guerin-aggreg-rsvp-00.txt>, November 1997.

[Kilkki] Kilkki K., *Differentiated Services for the Internet*. Macmillan Technical Publishing, 1999.

[Q.2963.1] ITU-T, *Peak cell rate modification by the connection owner.* ITU-T Recommendation Q.2963.1, July 1996.

[RFC 2380] L. Berger, *RSVP over ATM Implementation Requirements.* IETF Request for Comments, Integrated Services Working Group, RFC 2380, August 1998.

[RFC 2381] M. W. Garrett and M. Borden, *Interoperation of Controlled-Load Service and Guaranteed Service with ATM.* Work in Progress, IETF Request for Comments, Integrated Services Working Group, RFC 2381, August 1998.

[RFC 2382] E. Crawley, *A Framework for Integrated Services and RSVP over ATM.* IETF Request for Comments, <draft-ietf-issll-atm-framework-01.txt>, August 1998.

[RFC 2597] J. Heinänen, F. Baker, W. Weiss, J. Wroclawski, *Assured Forwarding PHB Group.* IETF Request for Comments, RFC 2597, June 1999.

[RFC 2598] V. Jacobson, K. Nichols, K. Poduri, *An Expedited Forwarding PHB Group.* IETF Request for Comments, RFC 2598, June 1999.

[RFC 2475] S. Blake et al., *An Architecture for Differentiated Services*. IETF Request for Comments, RFC 2475, December 1998.

[RFC 2474] K. Nichols, S. Blake, F. Baker, D. Black, *Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers*. IETF Request for Comments, RFC 2474, December 1998..

[RFC 2205] R. Braden (Ed.), L. Zhang, S. Berson, S. Herzog and S. Jamin, *Resource ReSerVation Protocol (RSVP) - Version 1 Functional Specification.* IETF Request for Comments, RFC 2205, September 1997.

[RFC 2209] R. Braden and L. Zhang, *Resource ReSerVation Protocol (RSVP) - Version 1 Message Processing Rules.* IETF Request for Comments, RFC 2209, September 1997.

[RFC 2210] J. Wroclawski, *The Use of RSVP with Integrated Services.* IETF Request for Comments, RFC 2210, September 1997.

[RFC 2211] J. Wroclawski, *Specification of the Controlled-Load Network Element Service.* IETF Request for Comments, RFC 2211, September 1997.

[RFC 2212] S. Shenker, C. Partridge and R. Guerin, *Specification of Guaranteed Quality of Service.* IETF Request for Comments, RFC 2212, September 1997.

[RFC 2215] S. Shenker and J. Wroclawski, *General Characterization Parameters for Integrated Service Network Elements.* IETF Request for Comments, RFC 2215, September 1997.

[RPQ 96] J. Liebeherr, D. E. Wrege and D. Ferrari, „Exact Admission Control for Networks with a Bounded Delay Service“, in *IEEE/ACM Transactions on Networking*, Vol. 4, No. 6, pp. 885-901, December 1996.

[RPQ 99] J. Liebeherr and D. E. Wrege, „Priority Queue Schedulers with Approximate Sorting in Output-Buffered Switches“, in *IEEE Journal on Selected Areas in Communications*, Vol. 17, No. 6, pp. 1127-1144, June 1999.

[SIMA] Project web site, Nokia Research Center. URL: http://www-nrc.nokia.com/sima/, valid October 1999.

[TUT-CN] J. Laine, S. Saaristo, J. Harju, *Core Node Implementation for Differentiated Services*. Faster Workshop '99, May 1999

[UNI] ATM Forum, *ATM User-Network Interface (UNI) Signalling Specification - Version 4.0*. ATM Forum, AF-SIG 0061.000, July 1996.

9. Abbreviations

AF: Assured Forwarding

CAC: Call Admission Control

CBR: Constant Bit Rate

CLIP: Classical IP over ATM

DP: Drop Preference

DS: Differentiated Services

EF: Expedited Forwarding

FIFO: First In First Out

LLDAL: Link Layer Dependent Adaptation Layer

MBR: Momentary Bitrate

NBR: Nominal Bitrate

NRT: Non-realtime

PHB: Per Hop Behaviour

RPQ: Rotating Priority Queue

RSVP: Resource Reservation Protocol

RT: Realtime

SBU: Signalling and Buffering Unit

SIMA: Simple Integrated Media Access

SRP: Scalable Resource Reservation Protocol

UBR: Unspecified Bit Rate