Applying QoS Control through Integration of IP and ATM

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ABSTRACT

The article describes the application of the integrated services concept where IP is using ATM as the transport layer for providing QoS control. Integrated services technologies based on IPv6 have been developed and implemented in a pan-European field trial where students are evaluating distance learning applications with QoS control. An overview of the architecture is given, followed by a description of the features of the basic technologies. The background for selecting the technologies is described. The focus is on the access network domain, and the objective is to reduce the resources required and be able to offer a range of premium services. The work of extending user applications for distance learning with QoS is described. The technical performance and user perception of QoS control were tested and evaluated in the trials. The main conclusions and recommendations are discussed. The integrated services concept is recommended for use in the access network. It was found that QoS control of end-user applications is of benefit for distance learning. However, the design of the user interface should hide all network-relevant parameters from the end user. There is a need for standard software to support integrated services.

INTRODUCTION

The demand for providing Internet services with well specified quality is increasing rapidly. This article describes the work that was done in the European Union (EU) funded project Broadband Trial Integration (BTI)[1] [1] to develop and demonstrate a concept for improving quality of service (QoS) when asynchronous transfer mode (ATM) is used as a transport mechanism for the Internet traffic. This is called the *integrated services* (IntServ) approach.

The focus of the work has been on implementing QoS in an ATM-based passive optical network (APON). Technologies have been selected to meet requirements for high network performance, lowering cost, and providing a well defined network service quality for the end user. These technologies are multicasting, the IPv6 Internet Protocol, the Resource Reservation Protocol (RSVP) [2], the Next Hop Resolution Protocol (NHRP), and ATM with point-to-point and point-to-multipoint switched virtual circuits (SVCs).

The technical performance of the network has been measured in order to evaluate the viability of the concept. In addition, a program of structured usability testing has been performed to evaluate the user perception of the QoS control and user interface. For this purpose user applications for distance learning were enhanced with QoS network control via RSVP and ATM signaling. Students and teachers at universities and schools in Denmark, Poland, and Portugal were evaluators, connected to a trial network.

The consortium behind the BTI project comprises network operators, equipment vendors, and universities. The role of the network operators was to organize trials and evaluate results, including both the technical and user trials with educational applications. Vendors specified, developed, and evaluated the performance of the equipment and delivered it to the trial sites. Universities were responsible for the educational applications and the interface to the network protocols.

This article gives an overview of the network architecture, and describes the technologies and the role they have in optimizing network perfor-

[1] Partners in the BTI project are Tellabs Denmark A/S, Portugal Telecom Inovaçao, Telekomunikacja Polska, University of Mining and Metallurgy Cracow, Teledanmark, Ericsson Telebit, University Carlos III de Madrid, University Politecnica de Madrid, University of Edinburgh-CCIR, UNI-C, Technical University of Denmark-COM.

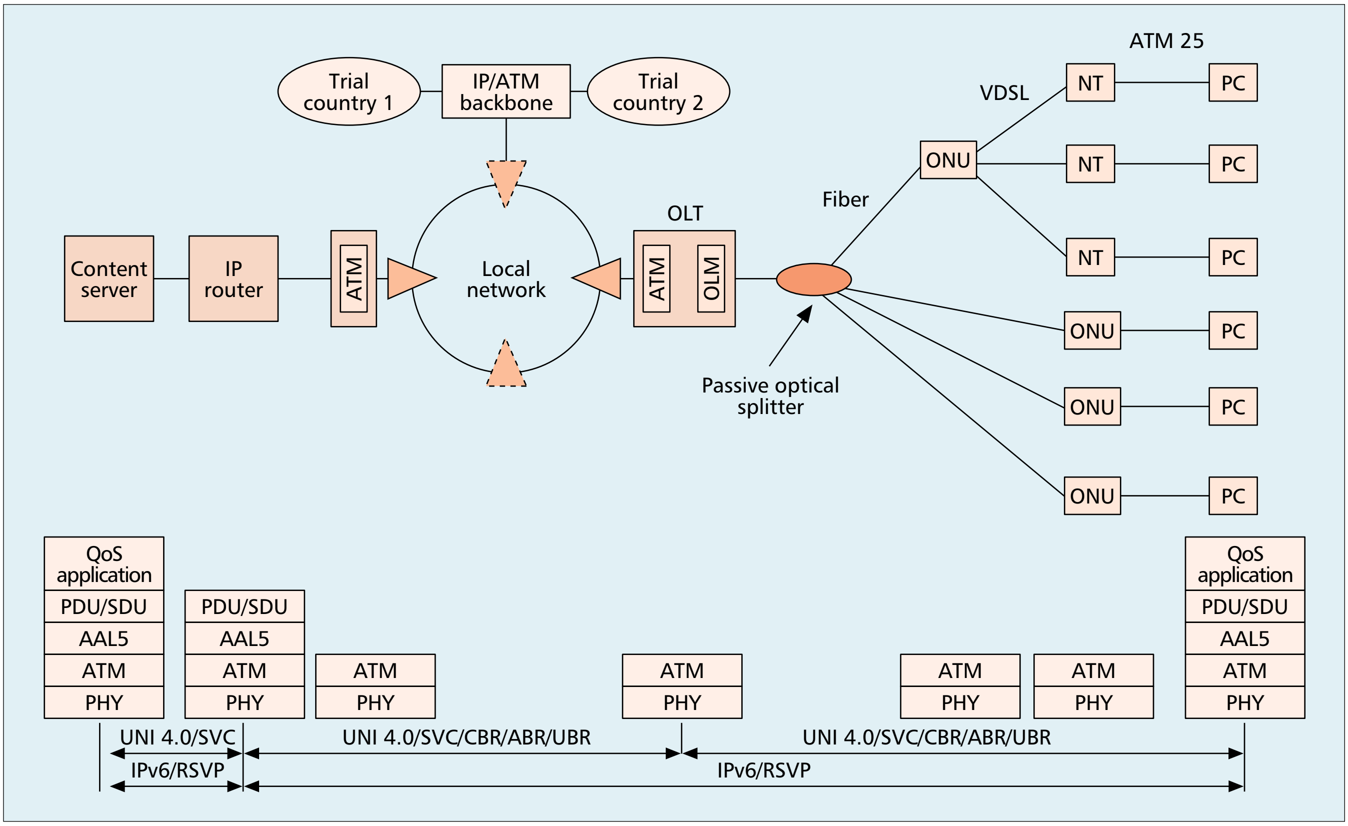


Figure 1. *The BTI network architecture.*

mance. Results from the technical and user-oriented tests are described, and finally, conclusions and recommendations for implementations on a larger scale are given.

The BTI Architecture

In BTI the work was focused on optimizing the services offered over an APON. The architecture depicted in Fig. 1 comprises an APON and a local network with an IP router with support for IPv6 and an application server for video applications. This architecture was implemented in Portugal, Denmark, and Poland [3]. The three sites were interconnected through a pan-European test network depicted as an IP/ATM backbone network.

The APON consists of the APON optical line terminal (OLT), including an ATM switch (ATM) and an optical line module (OLM) serving as interface to the single fiber optical distribution network with up to 16 optical network units (ONUs). Users are connected directly to the ONUs or use very high rate digital subscriber line (VDSL) modems in the last drop. The VDSL modem at the user premises in Fig. 1 is depicted as a network termination unit (NT). ONUs and NTs provide ATM-25-based user interfaces.

ATM is used on top of the physical layer. The ATM UNI 4.0 signaling protocols are used by the end system to request connections to particular destinations with a specific QoS. The ATM network ensures that connections set up in response to such requests can indeed meet the requested QoS. The approach to provide QoS at the IP layer is based on the IntServ architecture and a mapping of IP QoS to ATM QoS. A QoS request from the user applications is signaled through the Resource Reservation Protocol (RSVP). The basic principle applied is, through RSVP signaling, to define unicast and multicast IP flows having specific QoS demands. These flows are mapped to ATM switched virtual connections (SVCs) with QoS parameters equivalent to the QoS requests signaled through RSVP.

The IntServ concept provides the ability for applications to choose among multiple controlled levels of delivery service. To support this capability it is required that individual network elements (subnets and IP routers) along the path followed by an application's data packets must support mechanisms to control QoS delivered to those packets. QoS classes supported are the controlled load and guaranteed services.

Controlled load service has the following properties:

- A very high percentage of transmitted packets will be successfully delivered by the network to the receiving end nodes.
- The transit delay experienced by a very high percentage of the delivered packets will not greatly exceed the minimum transmit delay experienced by any successfully delivered packet.

To ensure that these conditions are met, clients requesting controlled load service provide the intermediate network elements with an estimation of the data traffic they will generate.

The guaranteed QoS has the following properties:

- There is delay-bounded service with no queuing loss for all conforming datagrams.

Component	User application		
	Video retrieval	Virtual workspace	Audio-video conference
Delay	Not sensitive	Moderately sensitive	Sensitive
Delay variation	Sensitive	Moderately sensitive	Sensitive
Bandwidth	1–4 Mb/s	About 200 kb/s	1–2 Mb/s
Packet loss	Not sensitive	Sensitive	Not sensitive
ATM circuit	CBR	ABR	CBR
Multicast	Yes	Yes	Yes
Excess traffic	No	Best effort	No

Table 1. *Network requirements from user applications.*

- The maximum end-to-end queuing delay and bandwidth provided along a path will be stable.

Guaranteed service does not control the minimum or average delay of datagrams, merely the maximum queuing delay.

Schools and universities connected to the trials contributed to the evaluation of the network performance from a user standpoint. Applications were tailored to support a distance learning environment through:

- Sharing of educational material stored in digital databases and libraries
- Sharing of teachers and professors based on virtual presence environments
- Allowing the interaction between groups of students, groups of teachers/professors, and students and teachers/professors

The applications were chosen to take advantage of multicasting and QoS communication support over a broadband infrastructure, and applications were tailored to allow client-level setting of QoS parameters for various tasks within the applications. Three applications were implemented: audio-video conference, virtual workspace, and video retrieval from a digital library. These applications implied particular requirements of the network performance, as shown in Table 1.

Network Technologies

The technologies were selected with the aim to support the QoS requirements together with the requirements for low cost and simplicity for the end user. The IntServ approach was selected because the technology offer a fine-grained control of network resources, a particular issue in the access network domain which is the most cost-sensitive. The following paragraphs give a description of how each technology contributes to the objectives.

IPv6

Important advantages of IPv6 are the extended address space and QoS support built into the protocol. The assumptions behind the development of IPv6 is that it shall interwork with IPv4 and be of specific importance to new subnet technologies where freedom of address assignment is of major importance. The extended address space is of particular importance as the number of so-called always on users is expected to increase rapidly. Always on users would benefit from globally unique addresses due to lower processing requirements since the server has to allocate user addresses only once. In present IPv4-based implementations, addresses are assigned by a server each time users are connected.

The BTI approach is to provide QoS through the IntServ framework with RSVP as the application-level signaling protocol. IntServ is defined for both IPv4 and IPv6, but for IPv6 IntServ can take advantage of the flow label in the IPv6 header, which allows for efficient classification of IP flows. An IPv6 flow wouldn't be fragmented in the network. IPv4 does fragmentation.

The NHRP provides a mechanism to obtain the ATM network address of the destination station (i.e., a host or a router) along the path to the destination. This information can subsequently be used to avoid extra router hops in an ATM network with multiple logical IP subnetworks (LISs). NHRP is not itself a routing protocol. The concept is illustrated in Fig. 2.

Multicast

In the BTI network architecture a multicast virtual circuit (VC) mesh approach is used. Each source establishes its own independent point-to-multipoint VC (a single multicast tree) to the set of leaf nodes (destinations) it has been told are members of the group to which it wishes to send packets.

The mapping of IP multicast addresses to ATM uses a multicast address resolution server (MARS). The MARS acts as a registry associating multicast addresses with the ATM interfaces. Endpoints query the MARS when a multicast address needs to be resolved to the set of ATM endpoints making up the multicast group. Endpoints keep the MARS informed when they need to join or leave particular groups.

In the router subsystem, the establishment of a multicast VC mesh is done by the IP forwarding module when it is first requested to transmit a multicast packet. The IP forwarding module queries the MARS to obtain a list of members of the multicast group. Then a point-to-multipoint unidirectional VC is established by adding each leaf node from the list of members. When the point-to-multipoint unidirectional VC is established, the packet requested for multicast transmission is sent.

RSVP/Integrated Services

RSVP is a resource reservation protocol designed for an IntServ Internet operating over IPv4 or IPv6. RSVP provides receiver-initiated setup of resource reservations for multicast or unicast data flows. RSVP is designed to allocate network resources appropriately for the requirements of the data being sent. An RSVP session is identified by the IP destination address (unicast or multicast address), destination port number, and protocol identifier. When the RSVP session is a multicast session, RSVP defines how reservations are merged on network links where a single flow is destined to multiple receivers. Similar to IP multicast routing, RSVP does not require a separate reservation for each receiver. Multiple reservation requests are merged along the multicast distribution tree to the source. RSVP supports two service models, guaranteed and controlled-load, already characterized in the previous section.

A cornerstone in the implementation of the IntServ model in the BTI network is the integration of RSVP and ATM signaling support [4]. In the BTI network architecture controlled load service is mapped onto the available bit rate (ABR) service with a fixed minimum cell rate, guaranteed service is mapped to the constant bit rate (CBR) service, and best effort traffic is carried via the unspecified bit rate (UBR) service. One of the main difficulties with the use of IntServ over ATM is the dynamic allocation and renegotiation of QoS characteristics for an established connection. Although RSVP allows receivers to change their reservations and senders to change their traffic descriptors dynamically, this poses problems since ATM QoS parameters for established virtual connections cannot be changed. A solution to this problem is to use predefined service mapping and to establish new ATM connections when the QoS requirement changes for a given data flow.

The integration of RSVP and ATM potentially poses scalability problems mainly due to the fact that an ATM VC has to be set up for each flow. This can represent a significant overload on switches that may have to handle thousands of flows, unless a minimum throughput value is required for QoS flow reservations.

The limitations of ATM in supporting multicast are an additional problem of RSVP over ATM. An ATM point-to-multipoint connection provides the same QoS to all receivers, which means that heterogeneous reservations have to be accommodated by either providing the best reservation to all receivers or duplicating traffic on different VCs.

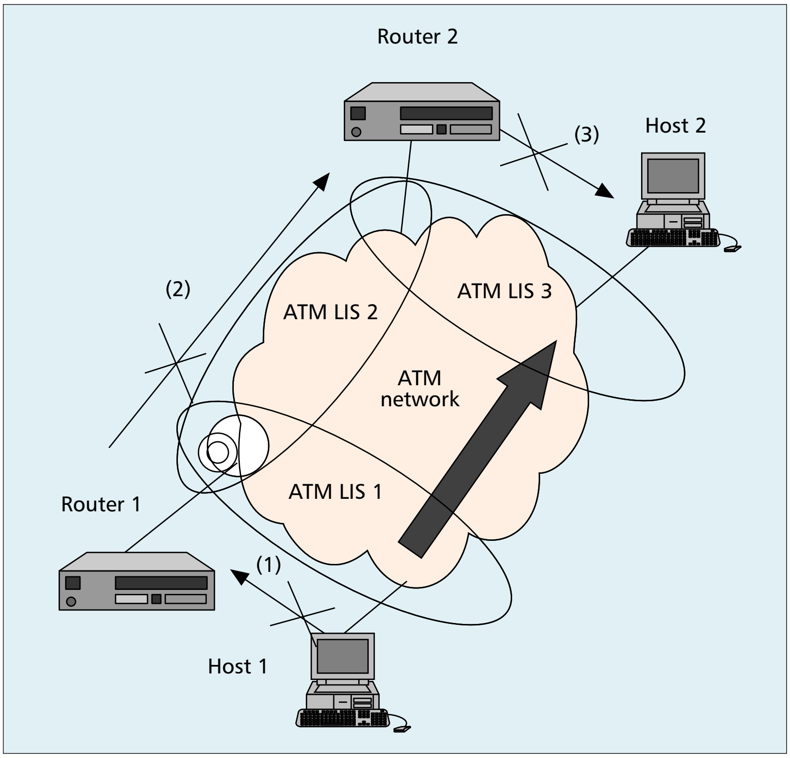


Figure 2. *Minimizing the number of hops by creating shortcuts in the ATM infrastructure.*

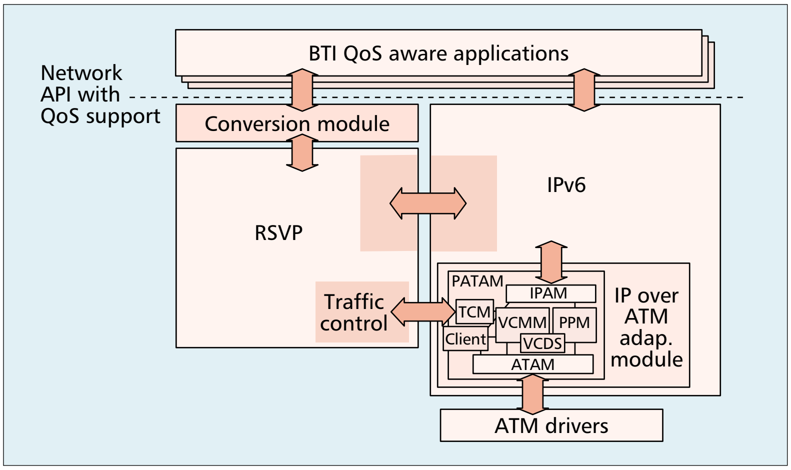
User Applications for Distance Learning

For exploring the QoS features offered by the integrated IPv6/ATM networking environment, a set of distant education applications were specified including audio-video conferencing, virtual workspace, and digital video library. The audio-video conferencing is based on videoconference (VIC) and robust audio tool (RAT) multicast tools used in the Internet Mbone [5]. The virtual workspace supports collaborative education through several integrated data conferencing applications, which allow users to create virtual meetings and interact in real time by sharing documents [6]. The digital video library consists of a video streaming engine, database, and content manager server. User interfaces for video retrieval, playback, uploading, and QoS control are embedded in a standard Web browser.

In order to interoperate with the network for the QoS requirements of the applications, an integrated protocol stack running over the target end users' stations' operating system (Windows NT) was needed. Basically, that protocol stack should support IPv6 over ATM with full dynamic multicast support using the VC mesh approach, and RSVP over IPv6/ATM following the model for IntServ. It should also offer the applications a standard application programming interface (API) to access QoS enhanced network services.

In principle, BTI planned to reuse some existing solutions available in the market or currently being researched, with the aim of concentrating the project effort on the adaptation of applications. However, as time progressed and no complete solution was available for the Windows NT platform, the project decided to develop and integrate its own protocol stack, starting from existing public protocol blocks available on the network. Figure 3 shows the general architecture of the protocol stack developed.

Apart from implementing all the complex functions needed to run IPv6 over ATM (including MARS client and neighbor discovery functionality), the protocol stack maps the QoS requirements specified by the applications to the ATM network resources. The stack is responsible for dynamically establishing all the necessary point-to-point and multipoint ATM circuits (SVCs), with either the router or other participants, either UBR, ABR, or CBR traffic. It should also classify and schedule the transmission of IPv6 packets through the circuits created. A simple scenario of an audio conference between three participants sending and receiving audio to a multicast address illustrates the complexity involved. In this scenario each client maintains 10 different ATM circuits to send and receive all application traffic classes: control traffic with the MARS server, unicast and multicast best effort traffic, and multicast traffic with guaranteed QoS. In addition, if the conference also includes video and is sent to a different multicast address, six more circuits are created.



■ **Figure 3.** *End-user's stations protocol stack architecture.*

All the applications selected in BTI were, at the beginning, IPv4-based and included no QoS support. They were adapted to work over IPv6 and modified to include an interface for QoS control. This interface allows users to select the desired quality level, and then translate the users' choice into RSVP service primitives and parameters.

In the case of the virtual workspace, the user can choose between several levels of service, from no QoS (best effort) to high quality. These service levels are internally translated by the applications into several increasing RSVP controlled load reservations, which represent different grades of responsiveness. In the case of the videoconference application, the user can choose between several audio and video quality levels, in terms of the different audio and video codecs. The application automatically chooses the adequate reservation parameters for each user's choice.

The digital video library application was noticeably different, due to the fact that the original application source code was not available. The translation to IPv6 and all the QoS support functions were included in two proxy modules running on the application server and client terminal, as shown in Fig. 4.

The two proxy modules conduct a dialog between themselves, making the RSVP reservation for the video flow and forwarding video data from the server to the client, either unicast or multicast, depending on the user's choice. The exchange of RSVP signaling messages (Path, Resv, etc.) results in network resources along the video flow being reserved for the session, in either routers or the network (ATM circuits).

After processing a user's query for a particular recording, the server retrieves the default reservation parameters (basically a traffic specification or T_Spec) from a database, and passes them to the server proxy, which begins to send RSVP_Path messages to clients including the T-Spec retrieved.

By default, the client terminal accepts the proposed reservation parameters and responds with an RSVP reservation message including the T_Spec received. This approach ensures that the video is reproduced according to the parameters specified by the system administrator, who sets the T_Spec values for each video recording when they are uploaded to the server mass storage. Default T_Spec values are selected during the MPEG encoding process and are set to allow smooth playback without the network reducing the original video quality.

This approach is complemented by providing the user with a choice of different encoding settings [7]. For example, the server could store three different copies of each video with the following encoding parameters:

- *High quality* with a bit rate of 1.5 Mb/s at a resolution of 320 x 288 pixels, MPEG-SIF
- *Medium quality* with a bit rate of 800 kb/s at a resolution of 320 x 288 pixels, with loss in dynamic scenes
- *Low quality* with a bit rate of 600 kb/s at a resolution of 160 x 144 pixels, MPEG-QSIF, with loss in spatial resolution

These different encoding values would be mapped into three different T_Specs stored in the database, that would be used depending on the user's choice.

TRIALS

Trials were performed in Poland, Portugal, and Denmark, where students were connected to APON networks already in operation and running ATM services to users in each country. Connections between trials were provided by a pan-European test network. The main technical features of the BTI network concept were tested and in general it was noted that, apart from small service interruptions during network installation, the introduction of the new network elements did not have a significant impact on services already running on the network. The following gives main results and conclusions from the evaluation of technologies and the user evaluation of the QoS applied to distance learning applications.

Results from Technical Evaluations

- IPv6 proved to be a stable and reliable network protocol, and no important technical drawbacks were identified in comparison with IPv4. In particular, the feature of stateless auto-configuration of IPv6 is considered highly valuable. On the other hand, the number and variety of network applications and tools based on IPv6 are still quite limited. It was felt that for all of the operating systems tested (Windows NT, Linux, and Solaris), IPv6 support is still included as an experimental feature. A major issue has been the development of a suitable host implementation for Windows NT, including support for IPv6, ATM UNI 4.0 signaling, and RSVP.
- The coexistence and interworking of IPv4 and IPv6 is a crucial requirement for IPv6 deployment. It was possible to establish ATM connections between Poland and Denmark. The network between Denmark and Portugal was partly (Portugal to Sweden) based on ATM and partly (Sweden to Denmark) on a best effort IPv4 service. The lack of full ATM end-to-end connectivity between the trials was overcome by tunnelling IPv6 over IPv4. This is a simple but effective method to interconnect IPv6 islands over IPv4-based networks.

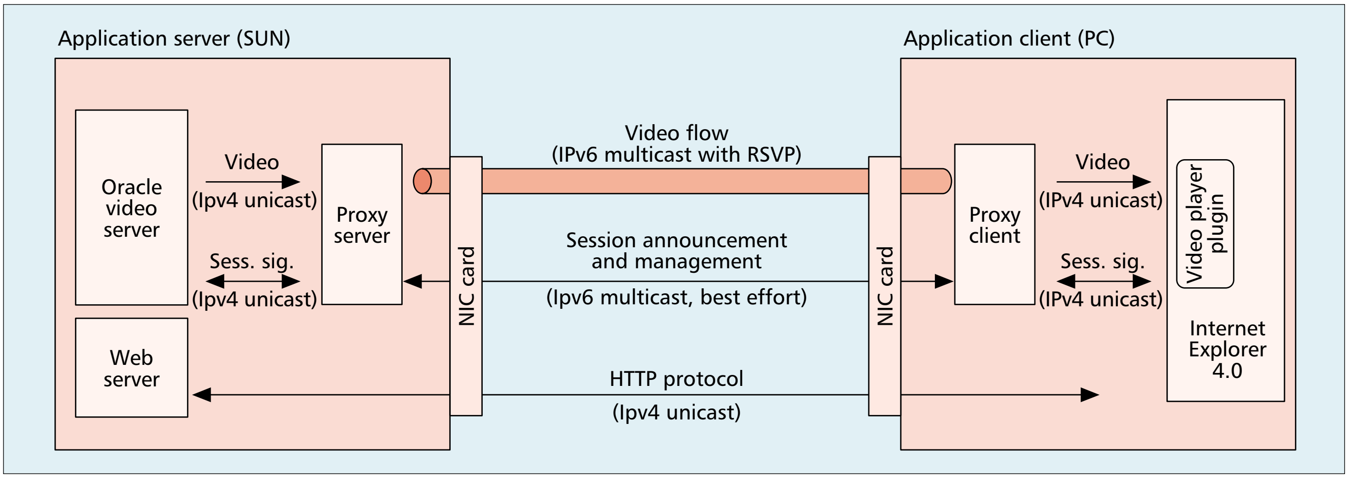


Figure 4. *QoS support in the digital video library.*

- The BTI project has provided evidence that internetworking of IPv6 over ATM is a possible networking solution. It has been demonstrated that end-to-end QoS from an application to a content server or between applications running on different hosts can be established on the foundation of IPv6 internetworking over ATM. It was also successfully demonstrated that mapping of IPv6 multicast to ATM is possible, and that multicast can benefit from the branched APON access network infrastructure, which reduces resource requirements.
- One of the attractive advantages of the NHRP is that short cut functionality can be realized without involvement of the client side. The obvious driving force for implementation of NHRP is the ability to reduce the number of routing hops along the way from a source host to a destination host. It was demonstrated that full-scale implementation of NHRP is not necessary to be able to create shortcuts in an ATM infrastructure. On the downside, SVC signaling is likely not to be implemented between various operators' domains; hence, it may take some time for NHRP to emerge in practice. However, the use of NHRP to support VPN solutions for hosts located on different ATM LISs in the same operator domains can be an attractive solution.
- The BTI project has proved the usability of the IntServ approach for control of QoS in the access network domain. Concerns about the scalability of IntServ in a larger network have been raised. However, the number of router sessions required in the access network are limited. Implementation of IntServ in the access network domain optimizes the use of bandwidth and has the attractive advantage of allowing implementation of specific policies and accounting strategies for different customer groups. This could be combined with the use of the simpler and less resource consuming differentiated services model in the core network, which allows network devices to prioritize packets based on markings in the IP packet header.

Results from Usability Evaluations — User tests were conducted with students using the distance learning applications and experimenting with QoS control with the objective of evaluating the usability of the applications and the control of the network features. The evaluations were carried out in different countries, which means in a multilingual context.

A set of well-proven evaluation techniques [8] was chosen to construct a methodical basis for the evaluations. These techniques consisted of:

- Expert evaluation
- Think-aloud sessions
- Focus group discussion

With this approach it was possible to work close to the users in spite of language and cultural differences. A set of guidelines was produced as a framework for the evaluation with the objectives of evaluating whether:

- The functionality offered in the applications to control the network technologies corresponds to the end user's need in the given context
- The navigation in the applications was constructed and presented to the end user in a way that makes it possible for the end user to control the technologies
- The performance differences obtained by tuning the QoS behavior affected the end users in the context of education
- Concrete functions or navigation could be designed or implemented in another way to optimize the usability of the application
- The new technologies really provide better performance and educational possibilities for the end user in a given context

It was evident from the testing performed that it will be possible to use interactive applications requiring a broadband network infrastructure with QoS control in a way that inspires and appeals to students. The testing also indicated that users can acquire an understanding of the relation between the relative usage of network resources and the quality experienced while working with the applications (e.g., in the form of quick screen updates and/or video quality). The distance learning applications were designed with interfaces that enabled users to choose between different QoS settings and then understand the consequences in terms of

The advantage of the "Integrated Services" technology is that it optimizes network bandwidth and allows implementing different policies and accounting strategies for different customers, allowing for precise market segmentation of the IP service.

application quality. The use of QoS in the network will often be a prerequisite of using applications in an environment like the distance learning environment demonstrated in BTI. However, it was clear that the user interface for QoS control with manual settings for the QoS parameters should be simpler, preferably totally hidden from the user, and handled entirely in the network stacks and OS implementation. The applications themselves can signal the QoS requirements, but they should be relieved of any details of actual network implementation.

CONCLUSIONS

This article describes the objectives of the BTI project, the key technologies developed, and the testing and evaluations performed. The trials proved that the integrated services concept can work, and users can benefit from QoS control of applications. The advantages IPv6 offers were pointed out, and the interworking of IPv6 and IPv4 was demonstrated. The advantage of the IntServ technology is that it optimizes network bandwidth and allows implementing different policies and accounting strategies for different customers, allowing for precise market segmentation of IP service. It was also shown how resources can be reduced when the Next Hop Resolution Protocol is applied. Some questions have been raised about the required complexity of having IP running on top of ATM and the scalability of the solution. It was shown that the scalability problem would not occur in the access network, but problems are likely to occur in the backbone network. Therefore, a solution with IntServ implemented in the access network and differentiated service implemented in the backbone network has been recommended. The usability tests showed that more attention must be given to design of the user interface. In particular, it was pointed out that users should be unaware of the underlying network layers and only need to work with the application. The BTI project has contributed to the work on providing QoS to IP-based services. Much work remains, however, before general worldwide solutions are available. In particular, scalability of both integrated services and differentiated services needs to be tested in large networks.

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