Integrating Differentiated Services with ATM*

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Abstract. IP in the edge and ATM in the core are commonplace in today's internetworks. The IETF has proposed a new Quality of Service (QoS) mechanism namely Differentiated Services (DiffServ) for IP networks. On the other hand, QoS is an inherent feature in ATM. It is imperative that IP and ATM QoS interoperate efficiently to provide an end-to-end service guarantee. DiffServ provides a class of service named Assured Forwarding (AF) that does not exactly correlate to any of the service categories offered by ATM. AF is targeted towards a range of applications, such as real-time (rt) that do not require a constant bit rate service provided by Expedited Forwarding, and other non-real-time (nrt) applications that expect a service better than Best Effort.
In this paper we propose the mapping of AF to the Variable Bit Rate (VBR) service category in ATM. VBR is suitable because it is available in the form of rt-VBR and nrt-VBR and could be translated appropriately based on the applications. The mapping is implemented and verified using the LBNL Network Simulator. The results of the experiments show that VBR is a better match for AF than any other service category in ATM.

1 Introduction

Recent advances in communications has facilitated computer networks to support a wide spectrum of applications such as voice, multimedia, and traditional data. The introduction of voice and multimedia demands stringent service requirements such as bounded end-to-end delay, and delay variance in addition to a guaranteed traffic delivery mechanism. Quality of Service is envisioned as an essential component in building efficient networks.

Several efforts in the area of QoS has resulted in approaches such as Integrated Services (IntServ) [1], MPLS traffic engineering [2], and Differentiated Services [3] in the IP domain and ATM Traffic Management Specification [4] in the ATM domain. IntServ offers an end-to-end service guarantee with Resource Reservation Protocol (RSVP) [5] as the signaling tool to reserve resources at every node in a path for every flow. The reservations are maintained in these nodes using a soft-state database imposing a very high demand for processing time and state maintenance storage in the backbone routers. MPLS Traffic Engineering is an ongoing effort by the Internet Engineering Task Force (IETF).

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A different QoS approach, Differentiated Services (DiffServ), has been recently proposed by the IETF. DiffServ attempts to reduce the processing time by pushing the functional elements required to implement QoS towards the edges of a network. QoS provisioning is based on aggregates of flows that further reduces the state information maintained on individual routers.

There are advantages to both IP and ATM technologies which have necessitated their co-existence in the network infrastructure. For instance, the ability of IP to adapt rapidly to changing networking conditions makes it appropriate for core routers. On the other hand, the scalability and cost/performance model of ATM switches are appropriate for backbone networks. The interoperation of the features of the two technologies to provide end-to-end QoS is crucial for the emergence of fast and reliable next-generation networks.

One of the issues in integrating IP DiffServ with ATM QoS is translating the Assured Forwarding Per Hop Behavior (AF PHB) [6] service requirements on to the ATM domain. The AF PHB is targeted towards a range of applications whose service requirements may vary from a level better than best-effort to applications that require a minimum guaranteed rate and delay characteristics. Additionally, AF introduces a concept of relativity that allows multiple AF aggregates of a class to be provisioned relative to one another.

In this paper we propose to map the AF PHB to the VBR service category of ATM. VBR is attractive because of its ability to serve both real-time and non-real-time applications. Through simulation experiments, we show that AF relativity concept can be achieved by tuning the traffic parameters of different VBR connections mapped to a single class.

2 Background

The task of integrating IP Differentiated Services and ATM QoS is not straightforward because of their inherent implementation differences. One of the major difficulties in merging the QoS architecture of the two technologies is that there is no service category in ATM that is similar to that of AF PHB. AF was developed to support those applications that required a minimum guaranteed rate or end-to-end delay but did not need a channel dedicated to them such as in the Premium Services. Additionally, AF incorporates the concept of relativity whereby customers have the ability to prioritize different flows emerging out of their domain. Although, AF has many attractive features, its deployment will be difficult if there were no efficient mechanisms to integrate it with other technologies.

The problem of mapping AF to an appropriate ATM Service category has caught the attention of several researchers. Rabbat et al. have proposed two mapping mechanisms to ABR [7] and GRF [8]. In both the schemes, the focus was on the effective throughput and AF relativity. Rogers et al. [9] suggested a mapping of AF to VBR in their study of a new shaping algorithm for DiffServ. The scope of their study [9] was the traffic conditioning mechanisms for Differentiated Services. The study of the performance characteristics, end-to-end delay, and jitter in particular for mapping the real-time categories of AF to ATM is yet another interesting research topic.

This paper develops a framework to map the AF PHB to the VBR service category in ATM. We manipulate the advantage in VBR to match all the types of applications targeted by AF. We further show that relativity can be achieved by tuning the traffic parameters used for different VBR services. The proposed architecture is verified using simulations using the LBNL (Lawrence Berkeley National Laboratory) Network Simulator (*ns*) [10].

3 Proposed Mapping

In designing the architecture, there are two issues to be considered: (i) the position of the mapper in an intermixed IP and ATM network, (ii) the QoS parameters that must be mapped.

The translation of DiffServ to ATM must happen at the IP boundary on a per-aggregate basis. Translation in the ATM domain may lead to complications due to the connection oriented nature of ATM. Each AF aggregate exiting a DiffServ domain would be mapped to a different VBR Virtual Circuit (VC) in an ATM domain. The real-time aggregates (for example, multimedia applications) are mapped to rt-VBR (real time VBR) and non-real-time applications are mapped to nrt-VBR (non-real time VBR) [4]. In ATM, the traffic parameters corresponding to a service category is accepted at connection establishment time through the Connection Admission Control (CAC) procedure.

In case of VBR, the parameters that constitute the service characteristics are the Peak Cell Rate (PCR), Sustainable Cell Rate (SCR), Maximum Burst Size (MBS in cells), Cell Delay Variation Tolerance (CDVT). The service parameters used in AF are Peak Information Rate (PIR), Committed Information Rate (CIR), Maximum Burst Size (MBS in packets) and Packet Delay Variation. Packet Delay Variation is an optional parameter and is mostly used when the application is real-time. The mapping from AF to VBR is done as follows:

- PIR to PCR.
- CIR to SCR.
- PDV/cells per packet to CDVT
- MBS*packetsize to MBS*cellsize

It is important to tune SCR and CDVT for the real-time applications. In case of the AF relativity feature, the relative priority is usually assigned on the basis of the amount of bandwidth shared at a particular time in transmission. Therefore, the important parameters to consider are the SCR and the MBS. Other parameter to consider is the Cell Loss Priority (CLP). The CLP is particularly useful after connection establishment. All the packets that conforms to SCR are marked as *good* (CLP=0) and the non-conforming ones are marked as *bad* (CLP=1). In case of DiffServ, there are three levels of drop precedence while CLP can be assigned only two values. To address this issue, packets arriving at a rate

$$Mapped\_SCR = SCR + \delta_{SCR},$$

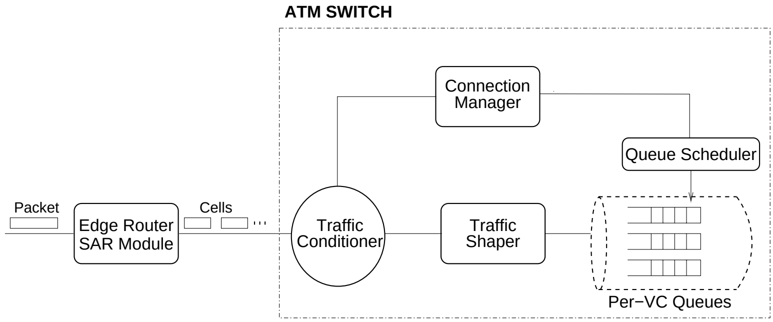


Fig. 1. Architecture of ATM implementation on *ns*.

where $\delta_{SCR} = \pm 10\%$ of SCR value are marked as good. The other option is to use the VBR3 [4] category of ATM in which, cells are tagged and service degraded instead of cells being discarded during times of congestion.

4 Simulation Setup and Experiments

The LBNL Network Simulator (*ns*) with the DiffServ and ATM enhancements was used for our experiments. The Simulator has the facility to simulate IP networks with the RSVP and DiffServ QoS mechanisms. We enhanced the Simulator to incorporate ATM functionality as well.

4.1 ATM Simulator

The ATM feature added included two main components, an *ATM End Station* and an *ATM Switch*. The ATM Switch consists of a *Connection Manager*, *Traffic Conditioner* and a *Queue Scheduler*. Figure 1 depicts the design of the ATM Simulator.

The *Connection Manager* provides the functions to create, and delete ATM Permanent Virtual Circuits (PVC), and lookup the created PVC Database. The *Traffic Conditioner* performs the Connection Admission Control (CAC), and the Traffic Policing/Usage Parameter Control (UPC) and the Traffic Shaping functions. The *Queue Scheduler* schedules the traffic on the link. Queuing is done on a per-VC basis to provide fairness to all traffic especially during congestion. Two different scheduling mechanisms namely Priority and Weighted Round Robin (WRR) were considered. On the high level, priority is given on the basis of ATM QoS classes, i.e., 0 for CBR, 1 and 2 respectively for rt-VBR and nrt-VBR, 3 for ABR, 4 for GFR and 6 for UBR. Between the various VC Queues of each category, Weighted Round Robin scheduling was used. The weights depend on the Peak Cell Rate (PCR) for CBR, Sustainable Cell Rate (SCR) for real time and non-real time VBR, Minimum Cell Rate (MCR) for ABR and GFR. For UBR the weights assigned to all VCs were same since the category is best-effort.

The *ATM End Station* provides the facility to the perform the segmentation of IP packets to cells and reassemble cells to IP packets using the ATM Adaptation Layer 5 (AAL5) protocol.

4.2 Topology and Experiments

A network topology used by most researchers for the study of QoS is shown in Figure 2 [8]. There are 12 sources (S1 ... S12) and destinations (D1 ... D12) on either side of a core network consisting of 6 Edge Routers (ER1 ... ER6) and two ATM switches (SW1 and SW2) separated by a bottleneck link as shown. All the links from the sources to the Edge Routers and Edge Routers to destinations were 6 Mbps. The links from Edge Routers to Switches and vice versa were 25 Mbps. The bottleneck link was 40 Mbps. The links were chosen such that the only bottleneck in the network was the core, i.e., the link between switches. A small propagation delay was also accounted for and it was a value of 5ms for all the links. The traffic sources used were CBR with UDP Transport Agent as real time generators and FTP with TCP Transport agents as non-real time generators. At the sources, each traffic flow is assigned to one of the four different AF classes (Platinum, Gold, Silver, and Bronze). The relatively low transmission rates were chosen in order to keep the number of packets generated and hence the simulation times at a reasonable level.

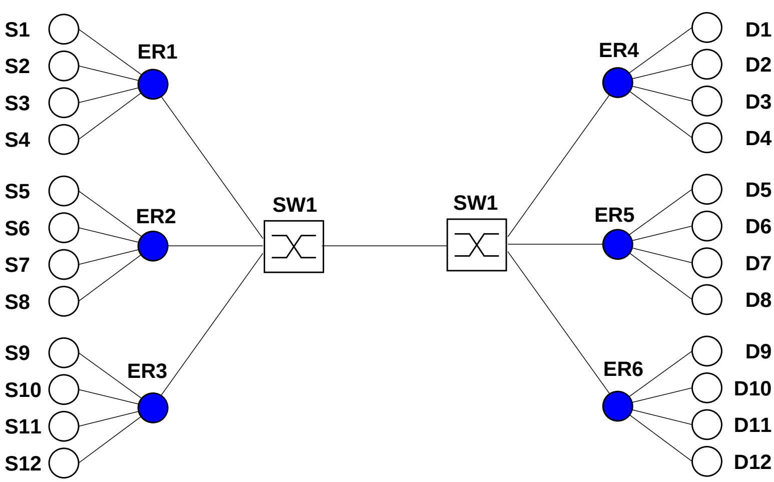


Fig. 2. Network topology for experiments.

Two sets of experiments, (i) to test the performance characteristics (throughput, end-to-end delay, and jitter) of real-time sources with non-real-time sources, (ii) to test AF relativity were conducted. The experiments involved varying the source rates, the queue lengths and tuning the parameters, i.e., SCR, PCR and the MBS. Traffic entering the Edge Routers (ERs) are scheduled with differentiation performed using DiffServ. At the edge the segmentation function is applied to convert packets to cells before scheduling them on the link.

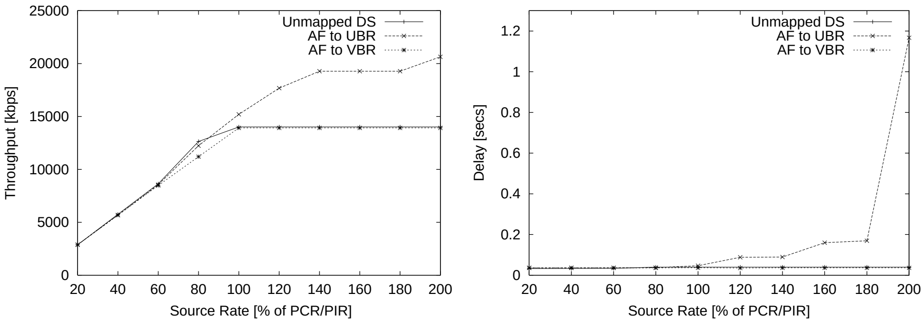
For the first set of experiments, three different experiments were conducted. In the first experiment, performance measurements of the network without any ATM, i.e., with two core DiffServ enabled IP routers were obtained. For Experiments 2 and 3, three PVCs were added one between each incoming and outgoing Edge Router. The aggregated traffic from 4 sources on each edge was transmitted on a single PVC. Each of the PVC was associated with a Traffic Descriptor that includes PCR, SCR, Maximum Burst Size (MBS) and Cell Delay Variation Tolerance (CDVT) for real-time and non-real-time VBR. The traffic parameters were assigned according to the mapping explained in Section 3. For the second experiment, we obtained results by mapping DiffServ to UBR service category. For the third experiment, we had DiffServ mapped to VBR. As explained in Section 3, we mapped traffic parameters of ER1 to rt-VBR (since this received traffic from CBR sources) and traffic parameters of ER2 and ER3 to nrt-VBR but the parameter values were different for ER2 and ER3. The first set of experiments was as follows:

Experiment 1: The source rates of CBR sources were varied keeping the Committed Information Rate (CIR) value in Experiment 1 and the equivalent mapped SCR in Experiment 3 constant. The variance of throughput, delay and jitter in Experiments 1, 2, and 3 were studied. The variance of transmission rates of sources attached to TCP agents are not necessary since the TCP sources adjust their rates according to the feedback from the network.

Experiment 2: A study of how delay and jitter in the mapping of DS to UBR vary with queue lengths in the network was conducted.

For the second set of experiments, 6 PVCs were added, one between ER1, ER4 pair, one between ER3, ER6 pair and 4 between ER2, ER5 pair. In this experiment, the traffic parameters used on ER1 and ER4 were pertaining to the EF service category of DiffServ and they were mapped to the CBR service category in ATM. The ER2, ER5 pair were configured to perform service differentiation using 4 different AF codepoints to yield AF relativity. The 4 PVCs between ER2 and ER5 correspond to 4 different codepoints used on ER2 and ER5. All the 4 PVCs were associated with nrt-VBR service category but with SCR equal to the Committed Information Rate (CIR) associated with each codepoint on the edge routers. The PVC between ER3 and ER6 was associated with UBR service category. In this study, the following experiment was performed:

Experiment 3: The source rates were kept constant, and the SCRs mapped to different CIRs for the 4 different codepoints of the PVCs mapped correspondingly from the ER2 were varied. For each of the variations, the SCRs of PVC3 was 75% of the SCR for PVC2, SCR of PVC4 was 50% of PVC2 and SCR of PVC5 was 25% of PVC2. The throughput for the 4 PVCs were verified to be relative to each other.



(a) Throughput vs. source rate. (b) Delay vs. source rate.

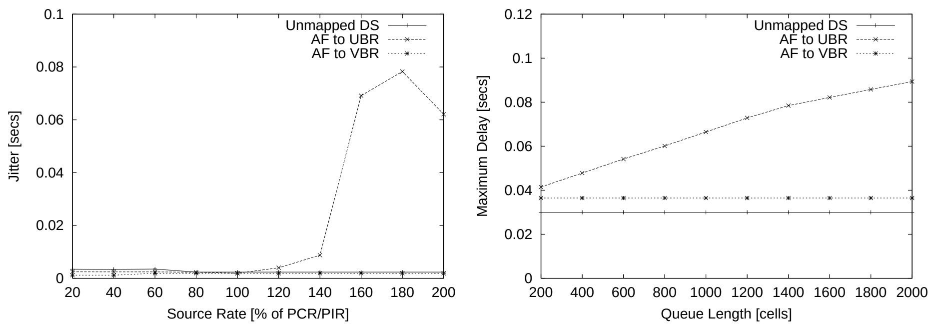
Fig. 3. Results of Experiment 1.

5 Simulation Results

For the first set of experiments explained in Section 4, the importance is laid on the behavior of real-time applications in AF mapped to the rt-VBR category. Therefore, the following results pertain to the total achieved rate, average delay, and average jitter obtained from the sources S1 through S4 which are aggregated to a single code point on router ER1.

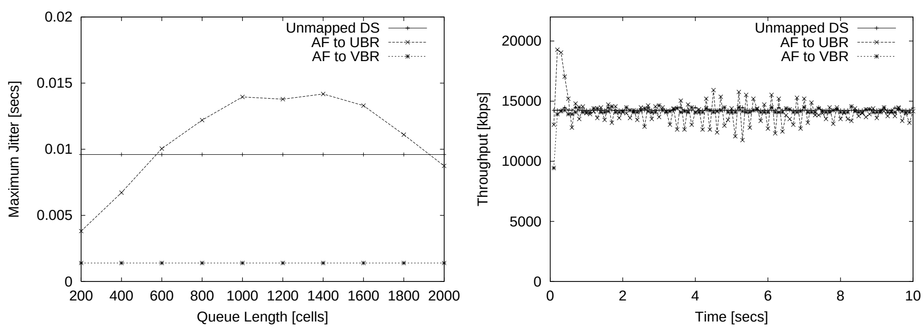
Figures 3(a), 3(b), and 4(a) display the results of Experiment 1. In each of the graphs, the behavior of the network without ATM and with ATM were studied. The expected performance of the network here is that guaranteed service be provided if the source behaves as requested. Since, the source lays a stringent requirement on service, non-adherence to service must be treated strictly by policing out excess traffic. The graphs clearly display that UBR neither maintains the consistency in delay and jitter nor does it police traffic entering beyond the requested rate. The network consists of TCP and CBR sources. Allowing excess traffic for the CBR sources causes recession in bandwidth. TCP sources depend on the feedback obtained from the network and therefore excess CBR allowed rate causes a reduction in TCP achieved rate. The achieved rate of TCP sources varied between 3 and 15 Mbps when the bandwidth available after all the CBR sources could be accommodated was 20 Mbps in the case when the total source rate of CBR sources was 20 Mbps. The behavior of UBR category is undesirable as this leads to starvation of low priority sources in the network. In case of DS and VBR, we saw that the achieved TCP rates were approximately 25 Mbps because the traffic was policed at 15.8 Mbps (PIR/PCR). We only see about 14.4 Mbps sustained rate because the CIR/SCR agreed was 14.4 Mbps.

Figures 4(b) and 5(a) present the results of Experiment 2. The UBR/ABR and the GFR scheduling mechanism used in the ATM switches is designed to utilize the bandwidth in the network to the fullest possible extent. The queue sizes in the switches are dynamically allocated until the maximum threshold of the system is reached. The sizes are allocated with respect to the incoming



(a) Jitter vs. source rate. (b) Maximum delay vs. queue length.

Fig. 4. Results of Experiments 1 and 2.



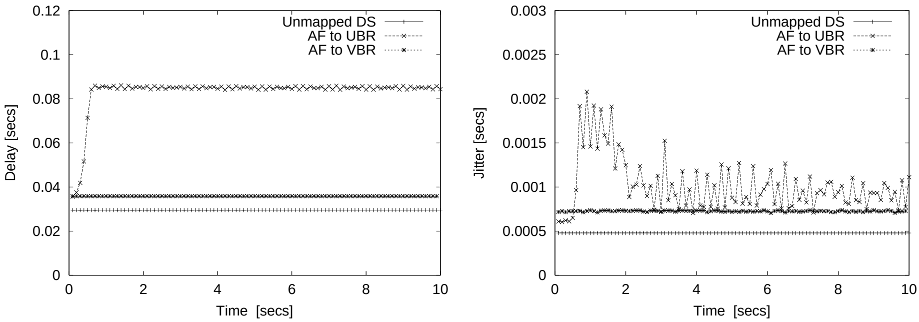
(a) Maximum jitter vs. queue length. (b) Throughput vs. time.

Fig. 5. Results of Experiment 2.

traffic. The delay and jitter experienced by these service categories is mainly due to the scheduling. In these categories, since traffic is not strictly policed beyond the guaranteed rates, traffic is not dropped until the maximum size is hit. In case of VBR and AF (higher codepoints only), the buffer sizes do not affect the delay and jitter due to strict policing. The figures display this behavior. This experiment also shows that congestion in the network and thereby multiple retransmissions of data, that further aggravates the condition of the network, can be avoided when a proper check is put to malicious resource utilization.

Figures 5(b), 6(a), and 6(b) present the additional results of Experiment 2. A source rate of 5 Mbps per source is picked for the study. The real-time applications expect that the performance remain constant with time. The graphs indicate the consistency.

In the second set of experiments explained in Section 4, the relativity is basically the measure of relative throughput to be maintained through the AF PHB group. In this experiment, the AF PHB group constitute sources S5 through S8.



(a) Delay vs. time. (b) Jitter vs. time.

Fig. 6. Results of Experiment 2.

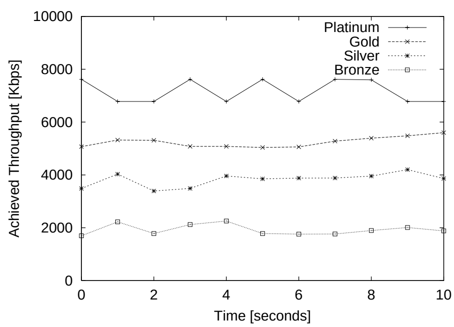


Fig. 7. Experiment 3: AF relativity with VBR mapping.

Figure 7 presents the results of Experiment 3. Comparing the results to that of the experiments by Rabbat et al. [8,7], we see that the relativity obtained is similar. We verified the relativity feature with different sets of CIR to SCR values. Table 5 displays the results. The first column in the table contains the CIR/SCR used for the Platinum source. The CIR/SCR values of the gold, silver and bronze were each 25% less than the value of the next higher level as explained in Section 4.

6 Conclusion

In this paper, the importance of QoS with an emphasis on efficient interoperation of QoS in IP and ATM networks was discussed. A framework for the translation of AF PHB to the VBR service category was put forth. The experimental setup and the results show that VBR is a suitable category for all types of applications targeted by the AF PHB. It was further shown that AF relativity can be achieved by tuning the VBR traffic parameters.

CIR/SCR of Platinum (Mbps)	Achieved Throughput			
	Platinum	Gold	Silver	Bronze
5.088	5.0	3.8	2.54	1.2
4.24	4.16	3.18	2.12	1.06
3.392	3.4	2.52	1.56	0.81
2.544	2.5	1.9	1.26	0.6

Table 1. Achieved rates of the mapped AF Olympic classes

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