Achieving QoS for Aeronautical Telecommunication Networks over Differentiated Services *

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ABSTRACT

Aeronautical Telecommunication Network (ATN) has been developed by the International Civil Aviation Organization to integrate Air-Ground and Ground-Ground data communication for aeronautical applications into a single network serving Air Traffic Control and Aeronautical Operational Communications.[1] To carry time critical information required for aeronautical applications, ATN provides different Quality of Services (QoS) to applications. ATN has been designed as a standalone network with its own protocols which requires building an expensive separate network for ATN. However, the cost of building ATN can be reduced if it can run over a public network such as the Internet. Although the current Internet does not provide QoS, Internet Engineering Task Force (IETF) is standardizing the Differentiated Services (DiffServ) network to provide differential QoS to users of next generation data networks. The *objective* of this paper is to investigate the possibility of providing QoS to ATN applications when it runs over the DiffServ network in the next generation Internet. Our results show that the QoS requirements of ATN applications can be successfully provided when they run over a DiffServ backbone in the next generation Internet.

Keywords: QoS, DiffServ, ATN, Internetworking, Next Generation Internet

1. INTRODUCTION

The International Civil Aviation Organization (ICAO) has developed the Aeronautical Telecommunication Network (ATN) as a commercial infrastructure to integrate Air-Ground and Ground-Ground data communication into a single network to serve air traffic control and aeronautical operational communications.[1] One of the objectives of ATN internetwork is to accommodate different Quality of Service (QoS) required by ATSC (Air Traffic Services Communication) and AINSC (Aeronautical Industry Service Communication) applications, and the organizational policies for interconnection and routing specified by each participating organization. In the ATN, priority has the essential role of ensuring that high priority safety related and time critical data are not delayed by low priority non-safety data, especially when the network is overloaded with low priority data.

The time critical information carried by ATN and the QoS required by ATN applications has led to the development of the ATN as an expensive standalone network. The largest public network, the Internet, only offers end-to-end *best-effort* service to the users and hence is not suitable for carrying data which has priority requirements, such as, time critical ATN traffic. However, the rapid commercialization of the Internet has given rise to demands for QoS over the Internet.

QoS is generally implemented by different classes of service contracts for different users. A service class may provide low-delay and low-jitter services for customers who are willing to pay a premium price to run high-quality applications, such as, real-time multimedia. Another service class may provide predictable services for customers who are willing to pay for reliability. Finally, the *best-effort* service provided by current Internet will remain for those customers who need only connectivity.

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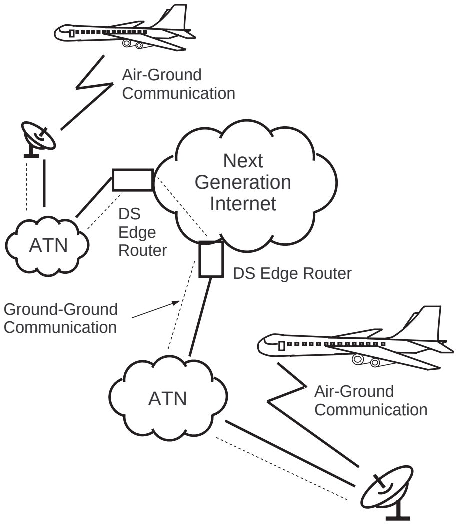

Figure 1. Interconnection between ATN and Differentiated Services.

The Internet Engineering Task Force (IETF) has proposed a few models to meet the demand for QoS. Notable among them are the Integrated Services (IntServ) model[2] and Differentiated Services (DiffServ)[3] model. The IntServ model is characterized by resource reservation; before data is transmitted, applications must set up paths and reserve resources along the path. This gives rise to scalability issues in the core routers of large networks. The DiffServ model is currently being standardized to overcome the above scalability issue, and to accommodate the various service guarantees required for time critical applications. The DiffServ model utilizes six bits in the TOS (Type of Service) field of the IP header to mark a packet for being eligible for a particular forwarding behavior. The model does not require significant changes to the existing infrastructure, and does not need too many additional protocols. DiffServ does not suffer from scalability problems, and hence is *suitable at the core of the network*.

A significant cost saving can be achieved if the ATN protocol could run over the next generation Internet protocol as shown in Figure 1. In this paper, we are interested in developing a framework to run ATN over the next generation Internet. This requires appropriate mapping of parameters at the edge routers between the two networks. The *objective* of this paper is to investigate the QoS that can be achieved when ATN runs over the DiffServ network in the next generation Internet. Based on the similarity between an IP packet and an ATN packet, our *approach* is to add a mapping function to the edge DiffServ router so that the traffic flows coming from ATN can be appropriately mapped into the corresponding *Behavior Aggregates* of DiffServ, and then marked with the appropriate DSCP (Differentiated Service Code Point) for routing in DiffServ domain. We show that, without making any significant changes to the ATN or DiffServ infrastructure and without any additional protocols or signaling, it is possible to provide QoS to ATN applications when ATN runs over a DiffServ network.

The *significance* of this work is that considerable cost savings could be possible if the next generation Internet backbone can be used to connect ATN subnetworks. The main *contributions* of this paper can be summarized as follows:

- Propose a framework to run ATN over the DiffServ network;
- Show that QoS can be achieved by end ATN applications when run over the next generation Internet.

The rest of this paper is organized as follows. In Sections 2 and 3, we briefly present the main features of ATN and DiffServ, respectively. In Section 4, we describe our approach for the interconnection of ATN and DiffServ and the simulation configuration to test the effectiveness of our approach. In Section 5, we analyze our simulation results to show that QoS can be provided to end applications in the ATN domain. Concluding remarks are finally given in Section 6.

2. AERONAUTICAL TELECOMMUNICATION NETWORK (ATN)

In the early 1980s, the International Civil Aviation Organization (ICAO) recognized the increasing limitations of the present air navigation systems and the need for improvements to take civil aviation into the 21st century. The need for changes in the current global air navigation system is due to two principal factors:

- The present and growing air traffic demand which the current system will be unable to cope;
- The need for global consistency in the provisioning of air traffic services during the progression towards a seamless air traffic management system.

The above factors gave rise to the concept of the Aeronautical Telecommunication Network (ATN).[4]

ATN is both a ground-based network providing communications between ground-based users, and an air-ground network providing communications between airborne and ground users. It was always intended that ATN should be built on existing technologies instead of inventing new approaches. The Internet approach was seen as the most suitable approach, and was therefore selected as the basis for the ATN. ATN is made up of End Systems, Intermediate Systems, ground-ground subnetworks and air-ground subnetworks as shown in Figure 1.

2.1. Priority in ATN

The ATN has been designed to provide a high reliability/availability network by ensuring that there is no single point of failure, and by permitting the availability of multiple alternative routes to the same destination with dynamic switching between alternatives. Every ATN user data is given a relative priority on the network in order to ensure that low priority data does not impede the flow of high priority data. The purpose of priority is to signal the relative importance and (or) precedence of data, such that when a decision has to be made as to which data to act first, or when contention for access to shared resources has to be resolved, the decision or outcome can be determined unambiguously and in line with user requirements both within and between applications.

Priority in ATN is signaled separately by the application in the transport layer, network layer, and in ATN subnetworks, which gives rise to *Transport Priority*, *Network Priority* and *Subnet Priority*.[5] Network priority is used to manage the access to network resources. During periods of high network utilization, higher priority NPDUs (Network Protocol Data Units) may therefore be expected to be more likely to reach their destination (i.e. be less likely to be discarded by a congested router), and to have a lower transit delay (i.e. be more likely to be selected for transmission from an outgoing queue) than lower priority packets. In this paper, we focus on *network priority* which determines the sharing of limited network resources.

2.2. ATN Packet Format

Figure 2 shows the correspondence between the fields of an IP packet header and the network layer packet header of ATN. It is seen that the fields of IP and ATN packets carry similar information, and thus can almost be mapped to each other. This provides the possibility for mapping ATN to DiffServ to achieve the required QoS when they are interconnected.

The NPDU header of an ATN packet contains an option part including an 8-bit field named *Priority* which indicates the relative priority of the NPDU.[1] The values 0000 0001 through 0000 1110 are to be used to indicate the priority in an increasing order. The value 0000 0000 indicates normal priority.

3. DIFFERENTIATED SERVICES

Differentiated services (Diffserv) is intended to enable the deployment of scalable service discrimination in the Internet without the need for per-flow state and signaling at every hop. The premise of Diffserv networks is that routers in the core network handle packets from different traffic streams by forwarding them using different per-hop behaviors (PHBs). The PHB to be applied is indicated by a Diffserv Codepoint (DSCP) in the IP header of the packet.[6] The advantage of such a mechanism is that several different traffic streams can be aggregated to one of a small number of behavior aggregates (BA) which are each forwarded using the same PHB at the router, thereby simplifying the processing and associated storage.[7] There is no signaling or processing since QoS (Quality of Service) is invoked on a packet-by-packet basis.[7]

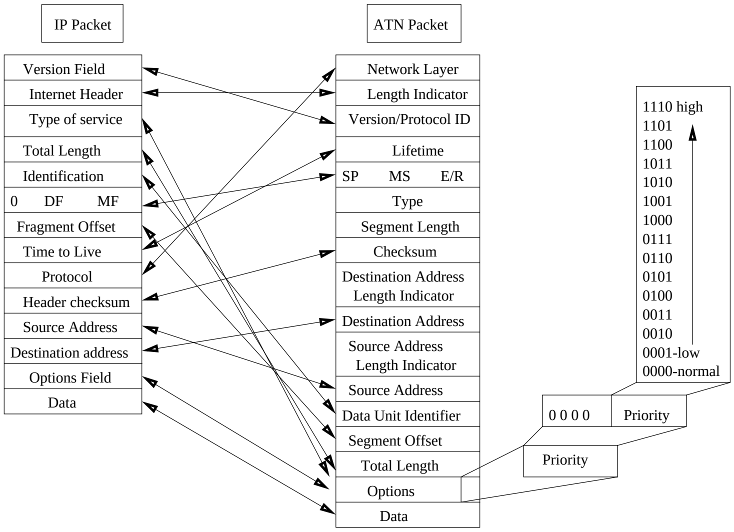

Figure 2. Similarity between an IP packet and an ATN packet.

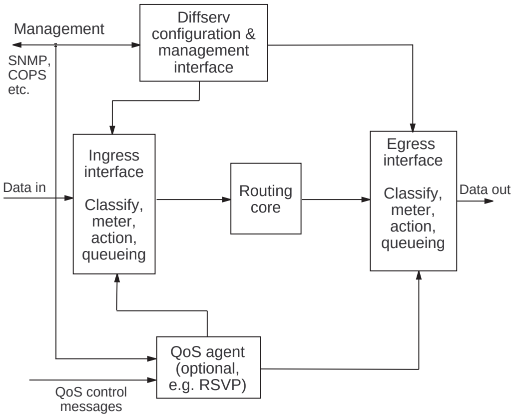

Figure 3. Major functional block diagram of a router.

The Diffserv architecture is composed of a number of functional elements, including a small set of per-hop forwarding behaviors, packet classification functions, and traffic conditioning functions which includes metering, marking, shaping and policing. The functional block diagram of a typical Diffserv router is shown in Figure 3.[7] This architecture provides *Expedited Forwarding* (EF) service and *Assured Forwarding* (AF) service in addition to *best-effort* (BE) service as described below.

3.1. Expedited Forwarding (EF)

This service is also been described as *Premium Service.* The EF service provides a low loss, low latency, low jitter, assured bandwidth, end-to-end service for customers.[8] Loss, latency and jitter are due to the queuing experienced by traffic while transiting the network. Therefore, providing low loss, latency and jitter for some traffic aggregate means there are no queues (or very small queues) for the traffic aggregate. At every transit node, the aggregate of the EF traffic's maximum arrival rate must be less than its configured minimum departure rate so that there is almost no queuing delay for these premium packets. Packets exceeding the peak rate are shaped by the traffic conditioners to bring the traffic into conformance.

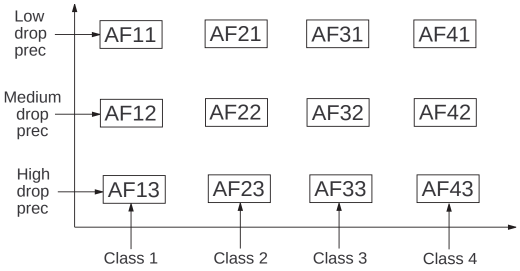

Figure 4. AF classes with drop precedence levels.

3.2. Assured Forwarding

This service provides a reliable services for customers, even in times of network congestion. Classification and policing are first done at the edge routers of the DiffServ network. The assured service traffic is considered *in*-profile if the traffic does not exceed the bit rate allocated for the service; otherwise, the excess packets are considered *out*-of-profile. The *in*-profile packets should be forwarded with high probability. However, the *out*-of-profile packets are not delivered with as high probability as the traffic that is within the profile. Since the network does not reorder packets that belong to the same microflow, all packets, irrespective of whether they are *in*-profile or *out*-of-profile, are put into an *assured queue* to avoid out-of-order delivery.

Assured Forwarding provides the delivery of packets in four independently forwarded AF classes. Each class is allocated with a configurable minimum amount of buffer space and bandwidth. Each class is in turn divided into different levels of drop precedence. In the case of network congestion, the drop precedence determines the relative importance of the packets within the AF class. Figure 4[9] shows four different AF classes with three levels of drop precedence.

3.3. Best Effort

This is the default service available in DiffServ, and is also deployed by the current Internet. It does not guarantee any bandwidth to the customers, but can only get the bandwidth available. Packets are queued when buffers are available and dropped when resources are over committed.

4. ATN OVER DIFFERENTIATED SERVICES

In this section, we describe in detail the mapping strategy adopted in this paper to connect the ATN and DiffServ domains followed by the simulation configuration we have used to test the mapping.

4.1. Mapping Function

Our goal is to run ATN over Differentiated Services to achieve QoS for ATN to integrate Air-Ground and Ground-Ground data communications into a global Internet serving Air Traffic Control (ATC) and Aeronautical Operations Communications (AOC). The main constraint is that the PHB treatment of packets along the path in the DiffServ domain must approximate the QoS offered in the ATN network. In this paper, we satisfy the above requirement by appropriately mapping the traffic coming from ATN into the corresponding *Behavior Aggregates*, and then marking the packets with the appropriate DSCP for routing in the DiffServ domain.

To achieve the above goal, we introduce a mapping function at the boundary router between the ATN and DiffServ domain as shown in Figure 5. Packets with different priorities from the ATN domain are first mapped to the corresponding PHBs in the DiffServ domain by appropriately assigning a DSCP according to the mapping function. The packets are then routed in the DiffServ domain where they receive treatments based on their DSCP codes. The packets are grouped to BAs in the DiffServ domain. Table 1 shows an example mapping function which has been used in our simulation. Packets with normal priority in ATN domain are mapped to BE PHBs in DiffServ domain. Similarly, medium priority ATN packets are mapped to AF11 PHBs; high priority ATN packets are mapped to EF PHBs.

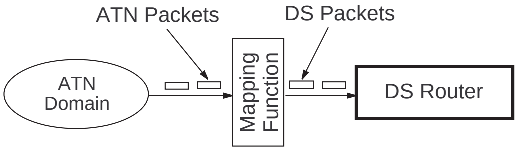

Figure 5. Mapping function for ATN over Differentiated Service.

Table 1. An example mapping function used in our simulation.

ATN Priority Code	*Priority*	*PHB*	*DSCP*
0000 0000	Normal	BE	000000
0000 0111	Medium	AF11	001010
0000 1110	High	EF	101110

4.2. Simulation Configuration

To test the effectiveness of our proposed mapping strategy between ATN and DiffServ and to determine the QoS that can be provided to ATN applications, we carried out simulation using the *ns* (Version 2.1b6) simulation tool from Berkeley.[10] The network configuration used in our simulation is shown in Figure 6.

Ten ATN sources were used in our simulation, the number of sources generating *high*, *medium* and *normal* priority packets were two, three and five respectively. Ten ATN sinks served as destinations for the ATN sources.

All the links in Figure 6 are labeled with a (*bandwidth, propagation delay*) pair. For the purpose of ATN over Diffserv, the mapping function shown in Table 1 has been integrated into the edge DiffServ router. CBR (Constant Bit Rate) traffic was used for all ATN sources in our simulation so that the relationship between the bandwidth utilization and bandwidth allocation can be more easily evaluated.

Inside the DiffServ router, EF queue was configured as a simple *Priority Queue* with *Tail Drop*. AF queue was configured as RIO queue and BE queue as a RED[11] queue. The queue weights of EF, AF and BE queues were set to 0.4, 0.4 and 0.2 respectively. Since the bandwidth of the bottleneck link between two DiffServ routers is 5 Mb, the above scheduling weights imply bandwidth allocations of 2 Mb, 2 Mb and 1 Mb for the EF, AF and BE links respectively during periods of congestion at the edge router.

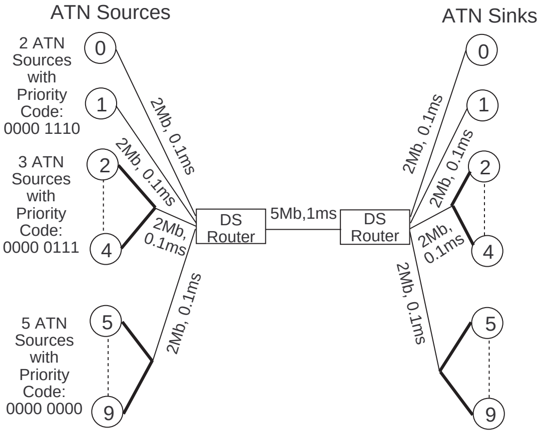

Figure 6. Network configuration.

5. SIMULATION RESULTS

In this section, results obtained from our simulation experiments are presented. The criteria used to evaluate our proposed strategy are described followed by the description of our experiments and numerical results.

5.1. Performance Criteria

To show the effectiveness of our mapping strategy in providing QoS to end ATN applications, we have used *goodput* of applications, *queue size* of DiffServ router and *drop ratio* of the scheduler as the performance criteria. In the next section, we present the results of measurements of the above quantities from our simulation experiments.

5.2. Simulation Cases

We use the following four simulation cases to determine the QoS obtained by ATN sources.

- **Case 1: No congestion:** The traffic generated by the each high, medium and normal priority sources were set to 1 Mb, 0.666 Mb and 0.2 Mb respectively. According to the network configuration described in Section 4.2, two high priority sources, three medium priority sources and five normal priority sources are generating 2Mb, 2Mb and 1Mb traffic respectively. The amount of traffic of different priority are equal to the corresponding scheduled link bandwidth assigned by scheduler described in Section 4.2. Under this scenario, *there should not be any significant congestion* at the edge DiffServ router.
- **Case 2: Normal priority traffic gets into congestion:** The source rate of each high, medium and normal priority sources was set to 1 Mb, 0.666 Mb and 0.6 Mb respectively. According to the network configuration described in Section 4.2, the total amount of traffic generated by five normal priority sources is 3Mb. The amount of high and medium priority traffic are still equal to the corresponding output link bandwidth assigned by scheduler described in Section 4.2. However, the amount of normal priority traffic is greater than its corresponding scheduled link bandwidth. Under this scenario, the *normal priority traffic gets into congestion* at the edge Diffserv router.
- **Case 3: Medium priority traffic gets into congestion:** The traffic generated by the each high, medium and normal priority sources were set to 1Mb, 1.333 Mb and 0.2 Mb respectively. According to the network configuration described in Section 4.2, three medium priority sources are generating 4Mb traffic now. Similar to Case 2, the amount of high and normal priority traffic are still equal to the corresponding output link bandwidth assigned by scheduler described in Section 4.2. However, the amount of traffic of medium priority is greater than its corresponding scheduled link bandwidth. Under this scenario, the *medium priority traffic gets into congestion* at the edge Diffserv router.
- **Case 4: Both medium and normal priority traffics get into congestion:** The traffic generated by the each high, medium and normal priority sources were set to 1Mb, 1.333 Mb and 0.6 Mb respectively. In this case, two high priority sources, three medium priority sources and five normal priority sources are generating traffic of 2Mb, 4Mb and 3Mb respectively. The amount of high priority traffic is still equal to the corresponding scheduled link bandwidth assigned by scheduler described in Section 4.2. However, both medium priority traffic and normal priority traffic are greater than their corresponding scheduled link bandwidth. Under this scenario, *both medium and normal priority traffics get into congestion* at the edge Diffserv router.

5.3. Numerical Results

Table 2 shows the goodput of each ATN source for four different cases described in Section 5.2. Table 3 shows the drop ratio measured at the scheduler for four cases of the three different types of ATN sources. Figures 7, 8, 9 and 10 show the queue size for each of the four case (from *Case 1* to *Case 4*), from which the queuing delay and jitter can be evaluated.

Case 1 is an ideal case. Each type of source (high, medium and normal priority sources) generates traffic at the rate equal to the bandwidth assigned by the scheduler. Therefore, there is no significant network congestion at the edge Diffserv router. As seen in Table 2, the goodput of each source is almost the same as its traffic generating rate. From Table 3, the drop ratio of each type of sources is zero. Figure 7 shows the queuing performance of each queue. Because this is an ideal case, the size of each queue is very small. The high priority (mapping to EF PHBs, according

Table 2. Goodput of each ATN source (Unit: Kb/S).

Sources		*Case 1*	*Case 2*	*Case 3*	*Case 4*
High priority Sources	Source 0	999.9990	999.9990	999.9990	999.9990
	Source 1	999.9990	999.9990	999.9990	999.9990
Medium priority Sources	Source 2	666.6660	666.6660	668.2409	668.4719
	Source 3	666.6660	666.6660	667.3379	667.5270
	Source 4	666.6660	666.6660	664.4189	663.9990
Normal priority Sources	Source 5	200.0039	199.6469	200.0039	199.4790
	Source 6	200.0039	201.8520	200.0039	201.9780
	Source 7	200.0039	202.4190	200.0039	201.6840
	Source 8	199.9830	199.8779	199.9830	200.4660
	Source 9	200.0039	196.2030	200.0039	196.3920

Table 3. Drop ratio of ATN traffic.

Type of traffic	*Case 1*	*Case 2*	*Case 3*	*Case 4*
High priority Traffic	0.000000	0.000000	0.000000	0.000000
Medium priority Traffic	0.000000	0.000000	0.499817	0.499834
Normal priority Traffic	0.000000	0.665638	0.000000	0.665616

to our proposed mapping function) queue has the smallest average queue size; The normal priority (mapping to BE) queue has the largest jitter.

In **case 2**, we increased the traffic generating rate of normal priority sources, keeping the rates of the other two types of traffic unchanged. The traffic generating rate of each normal priority source is set to 0.6Mb. In this case, the normal priority traffic gets congested. As shown by Table 3, the drop ratio of normal priority traffic is greatly

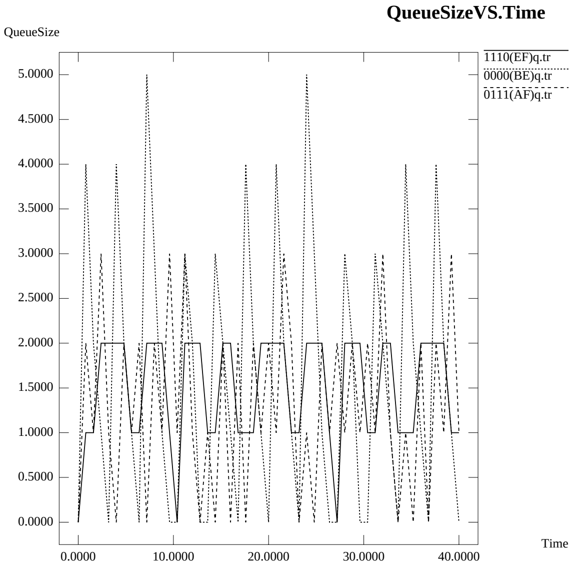

Figure 7. Queue size plots for *Case 1*.

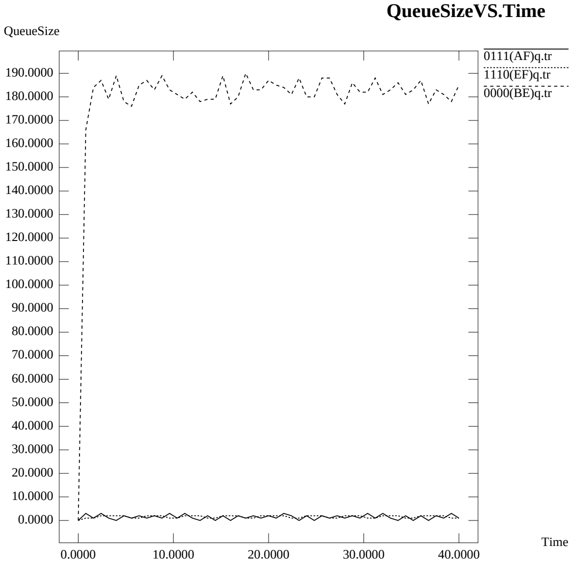

Figure 8. Queue size plots for *Case 2*.

increased. However, drop ratio for the other two sources still remain zero. As seen in Table 2, the goodput of normal priority traffic for each source is only about 0.2Mb, instead of the traffic generation rate of 0.6Mb. The reason is that the total available output bandwidth of normal priority traffic has been assigned to 1Mb by scheduler. From Figure 8, we find that the average queue size of the normal priority queue is far greater than the other two types of sources. In addition, the jitter of normal priority traffic is also greater than the other two types of sources. The high priority traffic has the smallest average queue size and the smallest jitter.

Case 3 is very similar to case 2. The only difference is that the medium priority traffic, rather than normal priority traffic, gets into congestion. Though, in reality, it is less possible for medium priority traffic than normal priority traffic to get into congestion, we still use this case to test the performance of AF11 queue in DiffServ router and the effectiveness of our proposed scheme. As expected, we find the drop ratio of medium priority traffic is increased with the other two types of traffic remaining zero, and the goodput is also limited by the output link bandwidth assigned by the scheduler (which is 2Mb). From Figure 9, we find that both the jitter and the average queue size of medium priority traffic are far greater than the other two traffic types. Though this observation is rare in reality, it is still reasonable in this simulation case that the average queue size of the medium priority traffic is greater than the normal priority traffic. Because, for the purpose we have described, we artificially make the medium priority traffic congested, however, the normal priority traffic is not congested. The high priority traffic has the smallest average queue size and the smallest jitter.

In **Case 4**, we increased the traffic generating rates of both medium and normal priority sources. Both of them get into network congestion in this case. We find from Table 3 that the drop ratio of high priority traffic remains zero, and drop ratios of both medium priority traffic and normal priority traffic are greatly increased. Furthermore, the drop ratio of normal priority traffic is greater than that of medium priority traffic. As shown by Table 2, the goodput of both the medium and normal priority traffic are limited by their link bandwidths allocated by scheduler. From Figure 10, we see that the normal priority traffic has both the biggest jitter and biggest average queue size. We can also find that the high priority traffic has both the smallest jitter and smallest average queue size.

From the above results, we can arrive at the following *observations*:

- The high priority traffic always has the smallest jitter, the smallest average queue size and the smallest drop ratio without being affected by the performance of other traffic. In other words, the high priority traffic receives the highest priority, which satisfies the priority requirements of ATN.

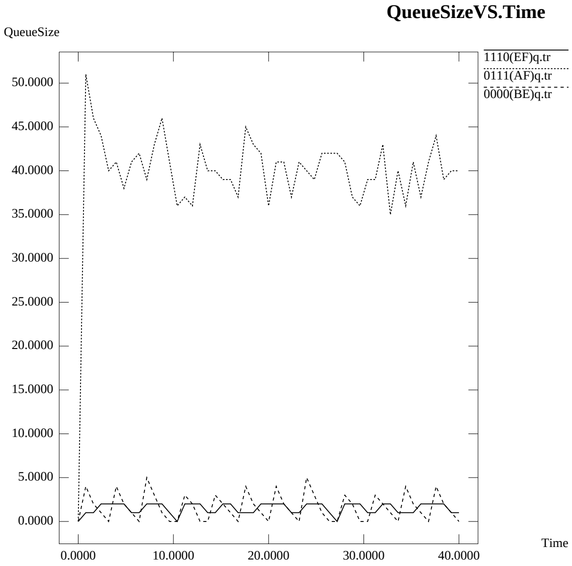

Figure 9. Queue size plots for *Case 3*.

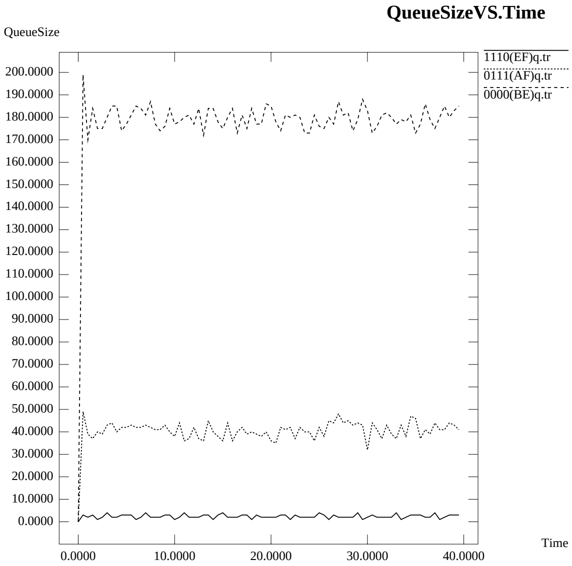

Figure 10. Queue size plots for *Case 4*.

- The medium priority traffic has smaller drop ratio, jitter and queue size than the normal priority traffic, even in the presence of network congestion. This also satisfies the priority requirements of ATN.

We therefore, *conclude that the priority requirements of ATN can be successfully achieved when ATN traffic is mapped to the DiffServ domain in next generation Internet.*

6. CONCLUSION

In this paper, we have proposed DiffServ as the network backbone to interconnect ATN subnetworks. We have designed a mapping function to map traffic flows coming from ATN with different priorities (indicated by the *priority* field in ATN packet header) to the corresponding PHBs in the DiffServ domain.

The proposed scheme has been studied in detail using simulation. It has been found that the QoS requirements of ATN can be achieved when ATN runs over DiffServ. We have illustrated our scheme by mapping ATN traffic of three different priorities to the three service classes of DiffServ. The ability of our scheme to provide QoS to end ATN applications has been demonstrated by measuring the drop ratio, goodput and queue size. We found that the high priority ATN traffic has the smallest jitter, the smallest average queue size and the smallest drop ratio, and is unaffected by the performance of other traffic. Moreover, the medium priority ATN traffic has a smaller drop ratio, jitter and queue size than the normal traffic, even in the presence of network congestion.

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