Virtual Queueing Techniques for UBR+ Service in ATM with Fair Access and Minimum Bandwidth Guarantee

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Abstract—

The ATM Forum is currently discussing the need for a new best-effort service called UBR+, which is an enhancement to the existing UBR service, to support data traffic. The objective of the UBR+ service is to provide each user with a minimum service rate guarantee and a fair access to any excess available bandwidth. In this paper, we present a new efficient scheme for supporting this service. The key advantage of our scheme is that it employs only FIFO queueing (instead of per-VC queueing) and admits simple implementation in ATM switches. Our ideas involve a simple scheduling mechanism that is based on per-VC queueing and incorporate the virtual queueing technique [10], [11] that can efficiently emulate per-VC queuing on a shared FIFO queue. Simulation results are presented to show that our schemes can deliver almost ideal performance for supporting the new service requirements of UBR+.

I. INTRODUCTION

While ATM was originally conceived as a carrier of integrated traffic, the recent momentum on the rapid standardization of the technology has come from data networking applications. Since most data applications cannot predict their own bandwidth requirements, they usually require a service that allows all competing active virtual connections (VCs) to dynamically share the available bandwidth. The unspecified bit rate (UBR) and the available bit rate (ABR) service classes in ATM have been developed specifically to support data applications.

The UBR service is designed for those data applications that want to use any available bandwidth and are not sensitive to cell loss or delay. Such connections are not rejected on the basis of bandwidth shortage and not policed for their usage behavior. During congestion, the cells may be lost but the sources are not expected to reduce their cell rates. Instead, these applications may have their own higher-level loss recovery and retransmission mechanisms, such as the window flow control employed by TCP. The advantage of using UBR service for data transport is its simplicity and minimal interaction required between users and the ATM network.

The ABR service has been developed with the goal of minimizing switch buffer requirement and cell loss in transporting data and allowing users to have fair access to the available bandwidth. To achieve such service requirements, the ABR service uses congestion control at the ATM layer. It requires network switches to constantly monitor the traffic load and feed the information back to the sources. The

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sources are expected to adjust their input to the network dynamically based on the congestion status of the network.

In fact, there has been a continuing debate in the networking community about the need for ABR service. A major argument against ABR is that while ABR assumes that the end systems comply with the ABR source behavior, most current applications are only connected to ATM via legacy networks such as Ethernet. Therefore, ABR may only push congestion to the network edges and cannot provide flow control on an end-to-end basis. Simulation results reported in recent ATM Forum contributions [12], [3] seem to support this argument.

Furthermore, it has been argued in [5] that most users today are typically either not able to specify the range of traffic parameters needed to request most ATM services, or are not equipped to comply with the (source) behavior rules required by existing ATM services. As a result, there are many existing users for whom the benefits of ATM service guarantees remain unattainable. Those users access ATM networks mostly through UBR connections, which provide no service guarantees. In view of this, [5] proposes a new service called UBR+, which will provide users with some level of service guarantees yet require minimal interaction between users and ATM networks.

The UBR+ service specifies that a user should be provided with a minimum service rate guarantee¹ and with fair access to any excess available bandwidth. In other words, the UBR+ service will guarantee a user with a minimum throughput when the network is congested, while allowing a user to send at a higher rate when additional bandwidth is available.

Our main contribution in this paper is to present a new efficient scheme for supporting the UBR+ service. The key advantage of our scheme is that it employs only FIFO queueing (instead of per-VC queueing) and admits simple implementation in ATM switches. Our scheme is based on a simple weighted round robin scheduling mechanism using per-VC queueing that can support UBR+. We then apply a variation of the virtual queueing technique [10], [11] to emulate this scheduling mechanism on a shared FIFO queue.

II. RELATED WORKS

As we discussed earlier, there has been an intensive debate in the ATM Forum on the need for an enhancement to the existing UBR service that provides each user with a minimum service rate guarantee. The essential idea in [5] is that by monitoring the rate of each connection at the ingress of an ATM network and tagging an appropriate proportion of

¹To be more precise, the minimum service rate is guaranteed under the assumption of a given maximum packet size (SDU).

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the cells when the rate exceeds the negotiated rate, one can provide each connection with a minimum bandwidth guarantee. However, this scheme when implemented in switches with only FIFO queues cannot provide each connection with a fair share of the excess available bandwidth. It is further suggested in [5] that per-VC queueing may be necessary for supporting UBR+ service.

It is proposed in [6] that the service requirements of UBR+ can actually be achieved with a new conformance definition within the VBR service category, and therefore no new techniques need to be invented. However, as argued in [5], the advantage of the proposed UBR+ service is that it requires little or no involvement on the user part since most service parameters can be negotiated off-line, e.g., by network management, configuration means, or inferred from existing parameters in the setup phase.

This paper describes an efficient solution for supporting UBR+ service. Unlike the proposal in [5], our techniques can be implemented in switches with FIFO queues to provide users with fair access to the excess available bandwidth in addition to the minimum service rate guarantee. Moreover, our techniques eliminate the need for monitoring the rate of each connection at the ingress of an ATM network. Our results are based on the idea of virtual queueing as reported in several recent works [1], [10], [11].

The virtual queueing technique was first proposed in [1] to improve rate allocations for ABR connections in the presence of VBR traffic. This technique is applied in [10] to emulate the round robin service of per-VC queueing on a FIFO queue for improving the performance of TCP over ATM. Simulation results in [10] illustrate that when combined with the EPD techniques [9], virtual queueing can provide significant improvement of fairness among TCP connections.

The virtual queueing technique utilizes the queue length on a per-VC basis in a shared FIFO queue to achieve fair buffer allocation. While this choice of per-VC state variable is quite intuitive and yields reasonably good performance, no analysis is given in [10] to provide a theoretical understanding of the technique. In [11], we propose a new choice of per-VC state variable, which has a precise analytical relation to the number of cells transmitted for each VC. The theoretical insights allow us to design an improved scheme that achieves nearly perfect fairness of average throughput among multiple TCP connections. In this paper, we shall apply a variation of the virtual queueing technique developed in [11] that can emulate a weighted round robin service on a FIFO queue.

III. SCHEDULING BASED ON PER-VC QUEUEING

We now describe a mechanism for scheduling UBR+ connections based on per-VC queueing.

In ATM networks, data traffic supported by UBR+ is usually mixed with other higher priority CBR/VBR traffic. Consequently, it is expected that the available bandwidth B allocated to UBR+ connections will vary dynamically. Since UBR+ guarantees each connection a minimum cell rate (MCR), we shall assume that before admitting a connection, the network will use some admission control and bandwidth

Fig. 1. Two phases of the scheduling mechanism

reservation procedure to ensure that the available bandwidth B (in cells/sec) is always greater than or equal to the sum of the MCR of every VC, i.e., $B \geq \sum_{i=1}^N MCR_i$, where MCR_i (in cells/sec) is the minimum cell rate of VC_i , and N is the number of UBR+ connections.

We first pick a fixed but arbitrary time period T (in sec) such that $T \cdot MCR_i \geq 1$ for each VC_i . Our scheduling mechanism consists of two phases in each period T . In the first phase, the scheduler will serve $T \cdot MCR_i$ cells for each VC_i . In other words, the number of cells to be served during the first phase of each period T is $T \cdot \sum_{i=1}^N MCR_i$. Note that since the available bandwidth is $B \geq \sum_{i=1}^N MCR_i$, the total number of cells that can be served during the period T is $T \cdot B \geq T \cdot \sum_{i=1}^N MCR_i$. Thus, after the first phase is complete, there are $E = T \cdot (B - \sum_{i=1}^N MCR_i)$ cells to be served within each period T . These E cells correspond to those that can be served whenever there is left-over bandwidth after serving each VC at its minimum guaranteed cell rate. In the second phase of each period T , the scheduler simply serves each VC in a round robin fashion to achieve fair allocation of the left-over bandwidth.

Figure 1 illustrates the two phases of the scheduling mechanism. The time axis is divided into consecutive time periods of length T . In the figure, t_m denotes the time it takes to serve the minimum guaranteed traffic of all VCs within each period T . Since the available bandwidth B for the UBR+ connections is constantly varying, the time t_m also varies between two different periods. But we always have $t_m \leq T$ because $\sum_{i=1}^N MCR_i \leq B$. During the remaining time $(T - t_m)$ within each period T , the excess bandwidth can be shared equally among the VCs simply by serving the VCs in a round robin fashion.

There are several ways of implementing the MCR scheduling phase. Our idea is to associate each VC_j with a weight corresponding to the number of cells ($T \cdot MCR_j$) that should be served within each period T to guarantee its MCR. We next present the pseudocode for the MCR scheduling algorithm based on per-VC queueing.

MCR scheduling based on per-VC queueing

We assume a separate queue is maintained for each active VC. A register W_i with initial value 0 is maintained for each VC_j , whose MCR_i (in cells/sec) is given. A time period T (in sec) is chosen such that $T \cdot MCR_i \geq 1$ for each i . (Note $T \cdot MCR_i$ needs not be an integer.)

For $j = 1, 2, \dots, N$

$$W_j = W_j + MCR_j \times T$$

While $W_j \geq 1$ for at least some VC_i

If $W_j \geq 1$ AND the queue of VC_j is non-empty

serve one cell of VC_j

$W_j = W_j - 1$

go to the next VC

End of **MCR Scheduling** $\square$

The above MCR scheduling algorithm requires that any VC can be served at any time, and thus relies heavily on the use of per-VC queueing. In subsequent sections, we shall show how to approximate the above scheduling algorithm with the use of a shared FIFO queue. To help understand our scheme, we next discuss the ideas of early packet discard (EPD) mechanism and its role in our scheduling mechanism.

IV. EPD AND FAIR BUFFER ALLOCATION TECHNIQUES

As we discussed earlier in the introduction, UBR service does not specify any congestion control mechanism at the ATM layer. When TCP or UDP traffic is transported over UBR, cells are simply discarded when there is a buffer shortage during network congestion. Since each discarded cell is likely to belong to a different packet, a significant number of transmitted packets may have already been corrupted by cell loss and thus need to be retransmitted, resulting in a substantial waste of bandwidth and degradation of throughput.

To address this problem, more sophisticated frame discarding mechanisms such as the *early packet discard* (EPD) algorithm [9] for UBR service have been proposed. The basic idea of EPD is to discard an entire packet prior to buffer overflow, so that the bandwidth is only utilized for the transmission of noncorrupted packets.

A simple way to implement the EPD mechanism in a shared FIFO queue is to set a threshold value (EPD threshold). An incoming packet will be dropped whenever the queue length exceeds the preset threshold value. To be more specific, the first cell of an incoming packet will be discarded if the total queue length at an ATM switch exceeds the EPD threshold. Once the first cell of a packet is discarded, the remaining cells of this packet will also be discarded, even when the queue length reduces below the EPD threshold. However, a cell will not be discarded by the algorithm if the first cell of the same packet has already been accepted into the queue, so that packet integrity is preserved. Thus, with EPD, the switch delivers either all or none of the cells of an incoming packet, to ensure that no bandwidth is wasted in delivering corrupted partial packets. Hence, UBR with EPD achieves higher bandwidth utilization than plain UBR service. The EPD threshold should be chosen so that the excess buffer (difference between total buffer size and EPD threshold) is large enough to ensure a low rate of buffer overflow.

A drawback of the EPD scheme described above is that it cannot achieve fair bandwidth allocation among competing VCs [7]. For example, EPD tends to allocate less bandwidth for VCs traversing multiple congested nodes.

One method for improving the fairness of packet-based traffic over UBR with EPD is to use per-VC queueing [8]. The idea is that by controlling the buffer allocation for each VC, EPD can serve as a mechanism to control the through-

put of each VC. In particular, when the total queue occupancy exceeds the EPD threshold, an incoming packet will be discarded if it belongs to a VC whose queue length is greater than or equal to its fair share of the buffer (e.g., the average queue length). In other words, the first cell of a packet belonging VC_j with queue length Q_j is discarded if: 1) the current total queue length $Q \geq Th$, and 2) $Q_j \geq \overline{Th}$ where $\overline{Th}$ can be set to a predetermined value such as Th/N or a dynamic parameter such as Q/N (N is the number of active VCs that have cells in the buffer). It is easy to see that per-VC queueing improves fairness since cells are only discarded from connections that have used more resources than their fair share. This is clearly better than discarding the cells randomly as with simple EPD. Moreover, by buffering the cells of each VC on a separate queue, one can schedule cell transmission for each VC at the output in a round-robin fashion.

V. SCHEDULING BASED ON VIRTUAL QUEUEING

Virtual queueing emulates the round-robin buffer allocation provided by per-VC queueing on a shared FIFO queue. More specifically, a separate "virtual" queue is implemented for each VC by maintaining a state variable M_j for each VC_j . The variable M_j is increased by one whenever a cell of VC_j is admitted to the FIFO queue. When the cells are transmitted out of the FIFO queue, however, the variables M_j 's are decremented in a round-robin fashion, regardless of which VC the cell transmitted actually belongs to. Thus, M_j does not correspond to the actual queue occupancy of VC_j in the FIFO queue. Instead, it represents the queue occupancy of VC_j as if per-VC queueing and round-robin output scheduling are implemented. The EPD mechanism is then applied to the incoming packets as in the case with per-VC queueing, except that the virtual queue M_j is used instead of the actual queue length Q_j for each VC.

The following pseudocode describes the cell discarding policy implemented at the input port of a switch based on virtual queueing:

Discarding policy based on virtual queueing

We associate each VC_j with a virtual queue variable M_j . L is a list containing the identifiers of the active VCs. The variable Q denotes the total queue length of the FIFO queue.

When a cell in VC_i reaches a switch:

if the cell is the first cell of a packet

$\overline{Th} := Th/N$

if $Q \geq Th$ and $M_i \geq \overline{Th}$

discard this cell

else

accept this cell into the FIFO queue

$M_i := M_i + 1$;

if $M_i = -w + 1$

append i to the tail of L

else

if any cell of the packet has been discarded

discard this cell

else

if $Q \geq Q_{max}$


```

discard this cell
else
  accept this cell into the FIFO queue
   $M_i := M_i + 1$ 
  if  $M_i = -w + 1$ 
    append  $i$  to the tail of  $L$ 

```

□

In the above algorithm, a lower bound $-w$ (a negative value) needs to be imposed on M_j because packets of VC_j are accepted into the buffer as long as M_j is less than the discard threshold ($\overline{Th}$). If M_j is unbounded and becomes very negative, a large burst of incoming packets of VC_j will be accepted, which could result in buffer overflow.

Recall from Section III that our scheduling mechanism consists of 2 phases within each consecutive period T . The first phase deals with MCR scheduling and the other with round robin scheduling for sharing the excess bandwidth. We now apply the virtual queueing technique to emulate the per-VC MCR scheduling presented in Section III. The following pseudocode describes the algorithm. We use the same notations as introduced earlier.

```

For  $j = 1, 2, \dots, N$ 
   $W_j = W_j + MCR_j \cdot T$ 
When a cell of the FIFO queue is transmitted
  if  $L$  is not empty
    let  $i$  denote the first connection identifier in  $L$ 
    remove  $i$  from  $L$ 
     $M_i = M_i - 1$ 
     $W_i = W_i - 1$ 
    if  $M_i > -w$  AND  $W_i > 1$ 
      append  $i$  to the tail of  $L$ 
  If  $W_i < 1$  for all VCs
    End of MCR Scheduling

```

□

It remains to be shown how the excess bandwidth can be shared equally among the VCs. The pseudocode below describes the round-robin service emulated by virtual queueing:

```

When a cell of the FIFO queue is transmitted
  if  $L$  is not empty
    let  $i$  denote the first connection identifier in  $L$ 
    remove  $i$  from  $L$ 
     $M_i := M_i - 1$ 
    if  $M_i > -w$ 
      append  $i$  to the tail of  $L$ 

```

□

We have completed the description of our scheme for supporting UBR+ service with FIFO queueing. In the remainder of this paper, we shall present a simulation study of the performance of our scheme.

VI. SIMULATION MODEL AND PARAMETERS

Our simulation tool is based on the MIT Network Simulator (NetSim). NetSim is an event-driven simulator composed of various components that send messages to one another.

Fig. 2. A chain configuration.

other. We have built upon the NetSim package various ATM and TCP/UDP related components. These components include an ATM switch component, a SONET OC-x link component, an ATM host component, a greedy/bursty source component, a multiplexing and demultiplexing component, a UDP component, and a TCP component. In our simulations, we have a fine TCP timer granularity, which is 10 μ sec, instead of 300 to 500 msec as in most TCP releases. The ATM host component performs ATM Adaptation Layer for data services (AAL5) including segmentation and reassembly (SAR) of TCP packets. The ATM switch component models a UBR switch combined with early packet discarding capability. Each output port has a single FIFO queue, i.e., an output buffer.

Figure 2 illustrates the simulation model of a network with 20 persistent data connections in a chain configuration. For simplicity, instead of illustrating the details of the components, we group user, TCP/UDP, and ATM host components into a single node in this figure. Note that VC A1-A5 traverse three congested links but each of the other VCs (B1-B5, C1-C5, D1-D5) traverses only one congested link. Moreover, each link is traversed by 10 VCs and is assumed to have the same capacity (150Mbps).

In our simulations, we consider a link delay of 500 nsec (about the distance of 100 m) to model a LAN environment. We expect TCP performance to be similar as long as the link distance lies within LAN range, e.g., up to 1000 m. This is because even with a 1000 m link distance, the link delay is only 5 μ sec, which is negligible compared with the TCP packet processing delay of 300 μ sec in our simulation.

VII. SIMULATION RESULTS

We now present simulation results with the chain configuration. Note that connections A1-A5 traverse multiple links while each of the other connections (B1-B5, C1-C5, D1-D5) traverses only a single link.

Simulation results in Figure 3 show that our scheme provides almost perfect fairness and throughput when UDP sources are used. Each VC's MCR is guaranteed and the excess bandwidth is distributed fairly. These simulation results show that with greedy UDP sources, each user can get its fair rate very quickly. Although the simulation is done over a 2 second period, we note that the throughput of each connection is quite uniform over any period of time. In particular, the results regarding the throughput and the fairness will remain essentially the same if we only perform the simulation over the first 50 msec period.

Fig. 3. UDP traffic in the Chain Configuration.

Fig. 4. TCP traffic in the Chain Configuration.

The preceding simulation results using UDP traffic clearly illustrate the fairness properties of our scheme at the cell level. Since many data applications today employ TCP as their transport layer protocol, we have also performed simulations with TCP traffic using the chain configuration. Because of the window flow control mechanism used in TCP, the packet-level throughput and fairness performance of our scheme will be different from UDP traffic. For example, UDP sources can constantly transmit traffic at the peak cell rate (PCR) whereas TCP sources have to go through a slow-start phase when packets are lost. But our simulation results employing TCP sources in the chain configuration still show very good fairness and throughput, as shown in Figure 4.

VIII. CONCLUDING REMARKS

We have presented a new efficient scheme for supporting the service requirements of UBR+. Unlike other scheme [5] proposed in the ATM Forum, our technique does not require the use of per-VC queueing for fair access to the excess bandwidth. It incorporates the EPD mechanism and a fair buffer allocation technique called virtual queueing to guarantee a user with a minimum bandwidth. Moreover, our scheme admits simple implementation in ATM switches. We have also presented simulation results to show that our scheme can deliver almost ideal performance in terms of the UBR+ service requirements.

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