PERFORMANCE EVALUATION OF RATE-BASED CONGESTION CONTROL ALGORITHMS IN MULTIMEDIA ATM NETWORKS

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Abstract — Rate-based congestion control promises effective traffic management for the ABR service class suitable to data communications in ATM networks. There have been proposed several rate-based congestion control schemes in the ATM Forum, including Enhanced Proportional Rate Control Algorithm (EPRCA) and EPRCA++ methods. While many studies have been devoted for these schemes in the past, only ABR traffic is taken into account; the effect of VBR and CBR service classes, in which multimedia traffic are accommodated, are not considered. In this paper, we evaluate performance of rate-based congestion control schemes when not only ABR traffic but also VBR traffic is incorporated into the ATM network. Through simulation experiments, we show drawbacks of current proposals of rate-based congestion control schemes for multimedia traffic, and give several suggestions to overcome those problems.

I. INTRODUCTION

The rate-based congestion control scheme controls the cell emission rate of each connection between end systems. As practical realizations, several rate-based congestion control schemes have been proposed in the ATM Forum. In this paper, we focus on two schemes: EPRCA and EPRCA++. EPRCA (Enhanced Proportional Rate Control Algorithm) is a basis of standard traffic management mechanism adopted by the ATM Forum [1]. In the standard, only the behaviors of the source and destination end systems are described, and the implementation issues regarding the ATM switches are left to manufacturers. In [1], however, they suggest three types of switches, EFCI bit setting switch (EFCI), binary enhanced switch (BES), and explicit down switch (EDS), which have different processing capabilities against congestion. On the other hand, EPRCA++ is a newly proposed algorithm for improving the network performance but needs more complex functions at the switch as summarized in Section II. Historical overview of rate-based schemes including EPRCA and EPRCA++ could be found in [2].

While a lot of studies have been devoted to evaluation of these schemes, only ABR traffic is taken into account; the effect of VBR and CBR service classes, in which multimedia traffic are accommodated, are not considered. In this paper, we evaluate performance of rate-based congestion control schemes when not only ABR traffic but also VBR traffic is incorporated into the network. In the current paper, we assume that CBR service class is used for video traffic. Namely, when the video traffic is generated, the call setup process is performed before its actual cell transmissions (i.e., call admission control based on closed-loop control is invoked). Since we consider the CBR service class, only the peak rate is required for the traffic descriptor in this case. Furthermore, in the network, CBR service class cells are assumed to be given higher priority than ABR service class cells for assuring QoS of CBR service class. See, for example, [3] for switch architecture to provide such priority services.

The problem is, however, that video traffic essentially has a bursty nature. That is, the cell generation rate per frame is varied if the compression technique like MPEG is applied to the video sources. Note that we here distinguish a traffic class and a service class; CBR traffic generates cells in the constant bit rate while CBR service class is the class related to CAC. Therefore, the CBR service class may accept VBR traffic which generates cells in the variable bit rate. Then the available bandwidth (i.e., residual bandwidth) to the ABR service class is changed dependent on cell generation of the VBR traffic. It was never considered in the past studies in which the available bandwidth to the ABR service class is fixed. In the current paper, we treat such a case that the VBR traffic is applied to the CBR service class, which is most likely to be realized in the ATM network by its simplicity since VBR service class still has difficulties for implementation in CAC and UPC.

When we consider both ABR and CBR service classes in the network, the rate-based control algorithms for ABR service class must be affected by the characteristics of video traffic, which has never been considered. In this paper, we will use sampled data taken from MPEG streams. Then, we investigate the performance of ABR traffic class. For this purpose, EPRCA and EPRCA++, the rate-based control algorithms discussed in the ATM Forum, are used and drawbacks of those algorithms are demonstrated through simulation experiments.

The rest of this paper is organized as follows. We first introduce basic mechanisms of EPRCA++ with its control parameters in Section II. In Section IV simulation results for the effect of VBR traffic on these schemes are investigated. In Section V we provide concluding remarks and open issues.

In this section, we first summarize basic operation of EPRCA++. EPRCA has been adopted as a standard mechanism for a traffic management scheme for ABR service class in the ATM Forum, and EPRCA++ has been proposed in [4] as an improved version of EPRCA. Refer to [1, 5] for details of EPRCA.

EPRCA++ provides more effective (but expensive) *explicit rate setting* mechanism than EPRCA does [4]; the ER value of backward RM cells are directly computed based on the number of active connections and the traffic load at the switch. The number of active connections is kept to be known at the switch by using *per-VC accounting*, which can be implemented in several ways with additional hardware complexity. For instance, each switch can have a VC table to record the number of active connections. Each VC entry is marked or unmarked according to the status of its corresponding VC (active or inactive), and the number of marked entries represents the number of active connections. Furthermore, the switch is provided with an interval timer and it counts the number of cells received during every fixed time interval to monitor the traffic load. The ER value in the RM cell is computed as

$$\begin{aligned}
\text{Overload} &= \frac{\text{Input rate}}{\text{Target utilization}} \\
\text{Fair share} &= f_1(\text{Available rate}, \text{\# of active VC's}) \\
\text{This VC's share} &= f_2(CCR, \text{Overload}) \\
ER &= \max(\text{Fair share}, \text{This VC's share}) \\
ER\text{in Cell} &= \min(ER\text{in Cell}, ER),
\end{aligned}$$

where f_1 and f_2 are some appropriate functions, for example, typical functions are:

$$\begin{aligned}
f_1(\text{Available rate}, \text{\# of active VC's}) &= \frac{\text{Available rate}}{\text{\# of active VC's}}, \\
f_2(CCR, \text{Overload}) &= \frac{CCR}{\text{Overload}}.
\end{aligned}$$

By this way, rates of all sources are adjusted through RM cells in one round-trip time when there is one congested switch in the network. The rate of the source is kept unchanged until it receives a backward RM cell in which the explicit rate ER determined by the switch is contained.

One attractive feature of EPRCA++ is its small number of control parameters, which can be set easily by a network manager. Many control parameters required in EPRCA are eliminated in EPRCA++. Furthermore, in EPRCA+ the target utilization around which the switch is utilized, can be set freely. One may set the target utilization of the switch under 95% link utilization, and then the queue size at the switch is smaller and cell delays are shorter. Although there is an additional expense for timers and the VC table at the switch, EPRCA+ can provide better fairness and responsiveness than EPRCA [4].

III. SIMULATION MODEL

The propagation delay between the source and destination end systems τ are set at 0.01 ms and 1.00 ms as typical values for LAN and WAN environments, respectively. The link speed at the switch is set to 156 Mbit/s. and the establishment of connections is staggered by 5 ms; that is, nth connection starts its cell transmission at $(n-1) \times 5$ ms. Then all connections continue cell transmissions until the end of simulation runs. For control parameters of EPRCA and EPRCA++, we use the values suggested in [1] and [4], respectively. Each simulation is executed during 300 ms.

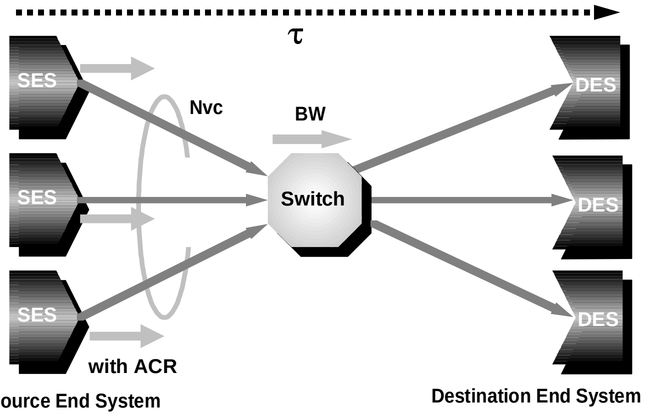


Fig. 1: Configuration of Simulation Model.

It is assumed that VBR traffic is assigned higher priority than ABR traffic; i.e., VBR traffic cells are transmitted prior to ABR cells at the switch if VBR cells exist in the buffer. Therefore, the bandwidth available to ABR traffic should be affected by the cell generation rate of VBR traffic, which is varied dependent on the time. As a typical example of VBR traffic, we adopt MPEG-1 encoded video stream of 30 frame/s, 352 × 240 pixels with average rate 4.5 Mbit/s and peak rate 14.84 Mbit/s. It means that up to ten video streams can be multiplexed since we assume that the CBR service class is used to transport video streams. In our simulation, ten identical VBR sources are multiplexed with different starting points.

EPRCA++ requires information about the bandwidth available to the ABR traffic. If we only consider the ABR traffic, it is identical to the VP capacity, being equal to the physical capacity of the link in most cases. When VBR traffic is also accommodated onto the link, however, we should introduce some method to measure the bandwidth available to the ABR traffic because it is dynamically changed due to the bursty nature of VBR traffic. Since such a method is not described in the original EPRCA++ method [4], we assume that the switch counts incoming VBR cells in a fixed time interval besides input traffic monitoring; That is, the available bandwidth for ABR traffic, BW', is estimated as

$$BW' = BW \times (T - N_{VBR})/T,$$

where T is the averaging interval, BW is the link speed, and N_{VBR} is the number of incoming VBR cells during T. In our simulation, T is set to 30 cell times. We note that in the case of EPRCA, such a mechanism is not necessary since the status on the bandwidth utilization is guessed from the queue length.

Simulation results for $N_{VC} = 10$ and $\tau = 0.01$ (as LAN environment) are first presented in Figs. 2 through 5. Each figure contains permitted cell rate ACR at the source end system and queue length at the switch. The target utilization of EPRCA++ is set to 0.95 as suggested in [4]. ACR of selected connections and the aggregate rate for both of ABR and VBR connections are plotted in these figures.

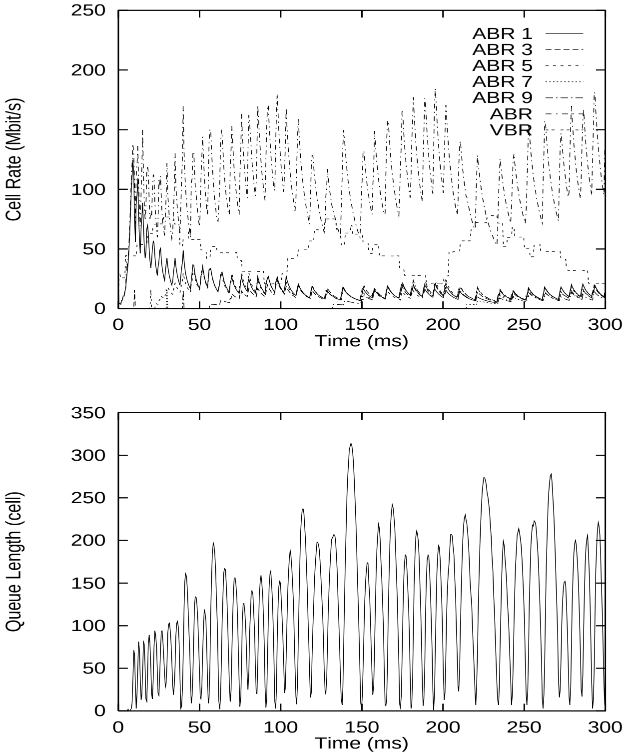


Fig. 2: EPRCA with EFCI Switch ($N_{VC} = 10$, $\tau = 0.01$).

We can observe that the frequency of the rate increase and decrease is directly influenced by the aggregate generation rate of VBR traffic as can be expected. When comparing EPRCA and EPRCA++, it may conclude that the overall performance of ABR connections are not very bad even in the existence of VBR connections, and that EPRCA++ method outperforms EPRCA methods in LAN environment.

When the propagation delay becomes large, however, VBR traffic gives a different impact on each scheme. In Figs. 6 through 9, we show cell rates and the queue length for $\tau = 1.00$ ms as WAN environment. We also illustrate the aggregate throughput of ABR and VBR traffic in Fig. 10 to see that under-utilization occurs in these cases. In these figures, the BES switch gives better utilization since (1) the EFCI switch uses FECN-like slower congestion notification and (2) the EDS switch frequently does major reduction. It is true that the performance of the EDS switch may be improved by an appropriate use of control parameters. However, it implies that too intelligent scheme causes unexpected results unless the careful parameter tuning is performed before applying such a scheme to real systems.

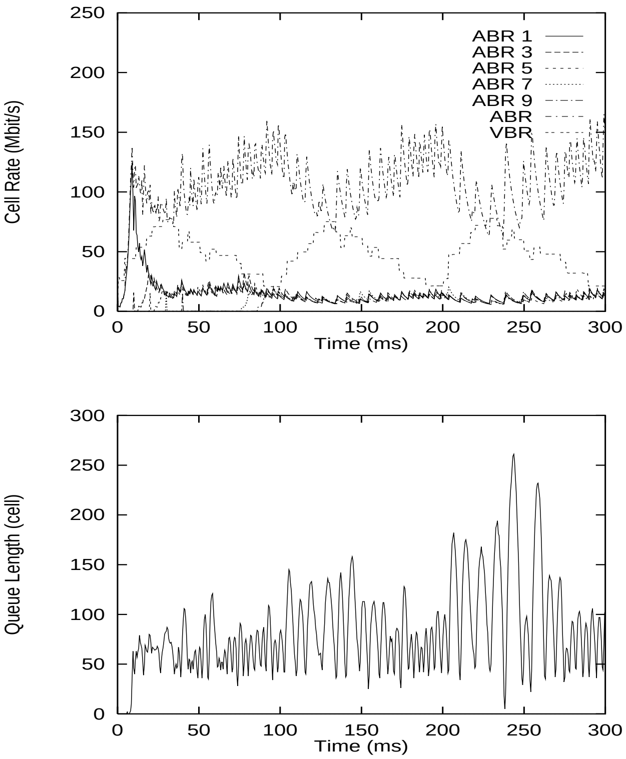


Fig. 3: EPRCA with BES Switch ($\tau = 0.01$).

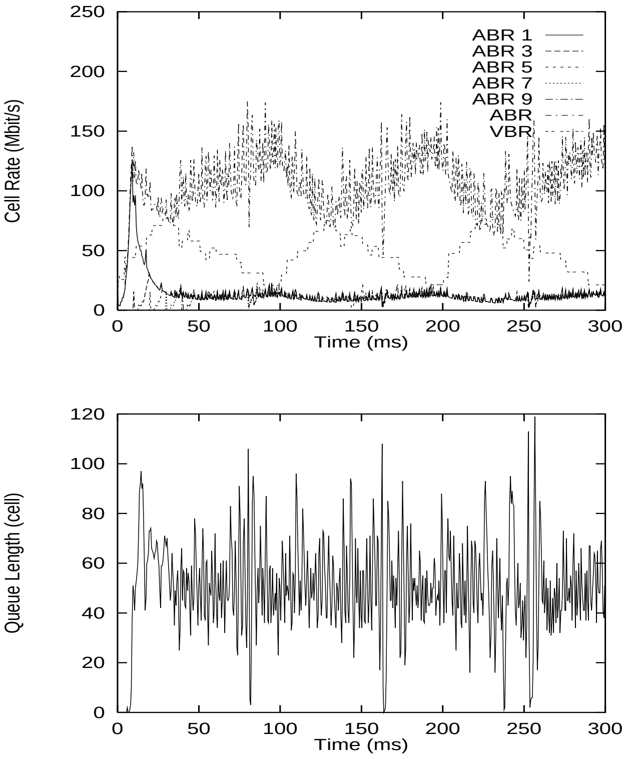


Fig. 4: EPRCA with EDS Switch ($\tau = 0.01$).

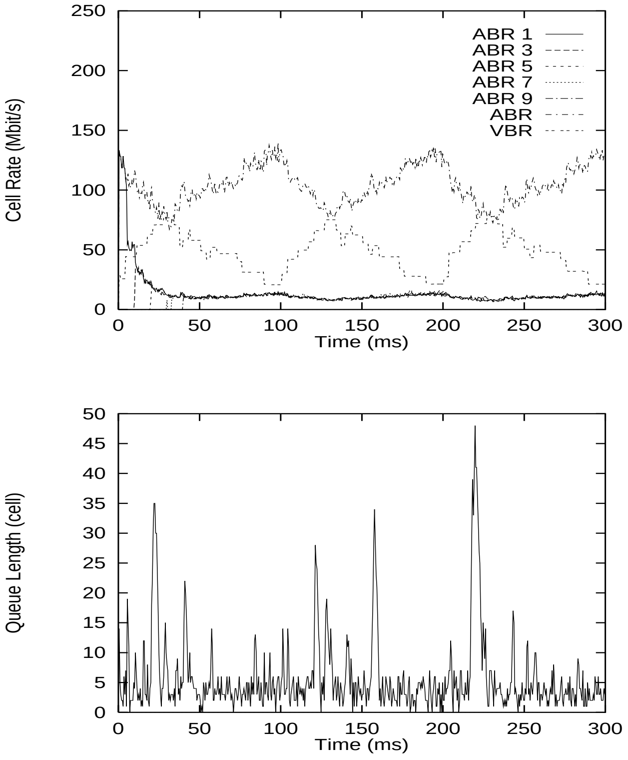


Fig. 5: EPRCA++ ($\tau = 0.01$).

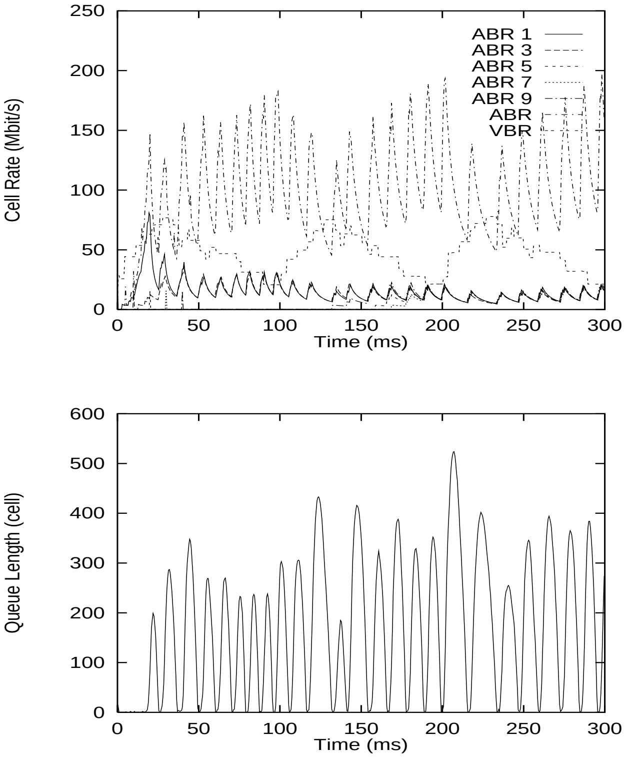


Fig. 7: EPRCA with BES Switch ($\tau = 1.00$).

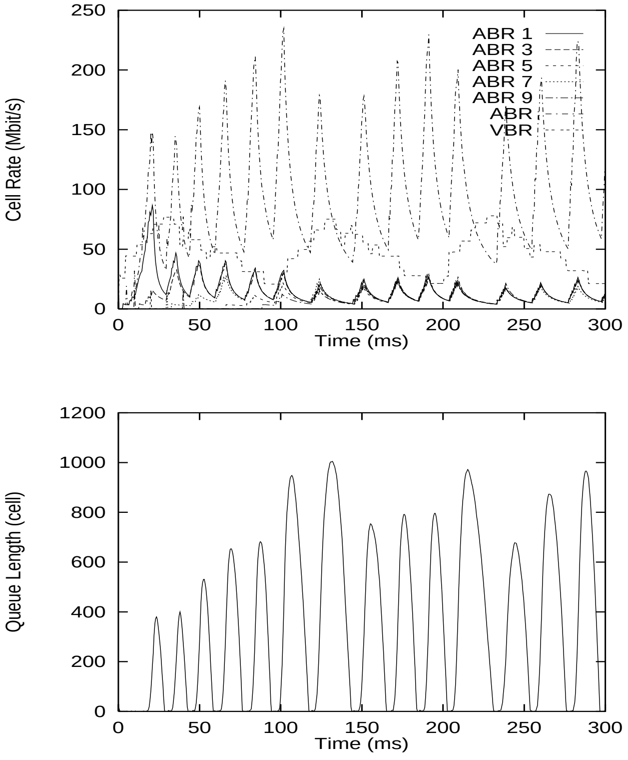


Fig. 6: EPRCA with EFCI Switch ($\tau = 1.00$).

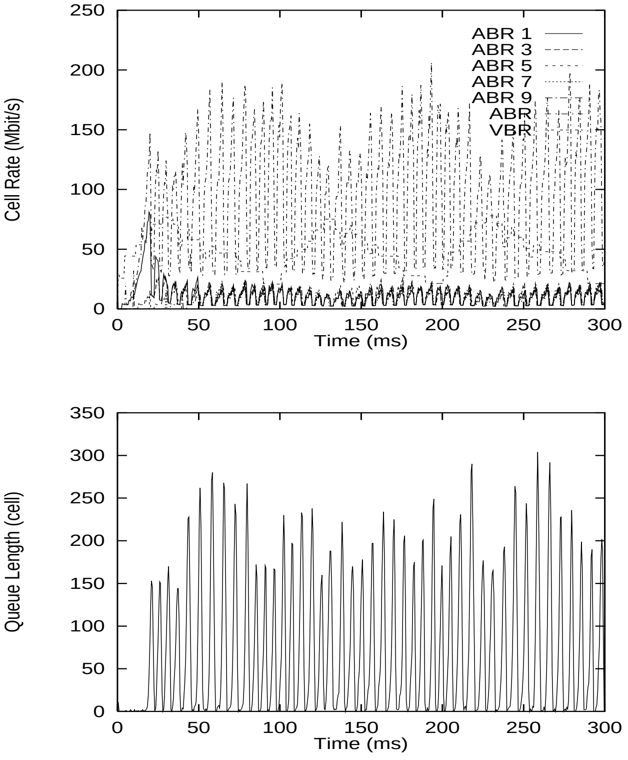


Fig. 8: EPRCA with EDS Switch ($\tau = 1.00$).

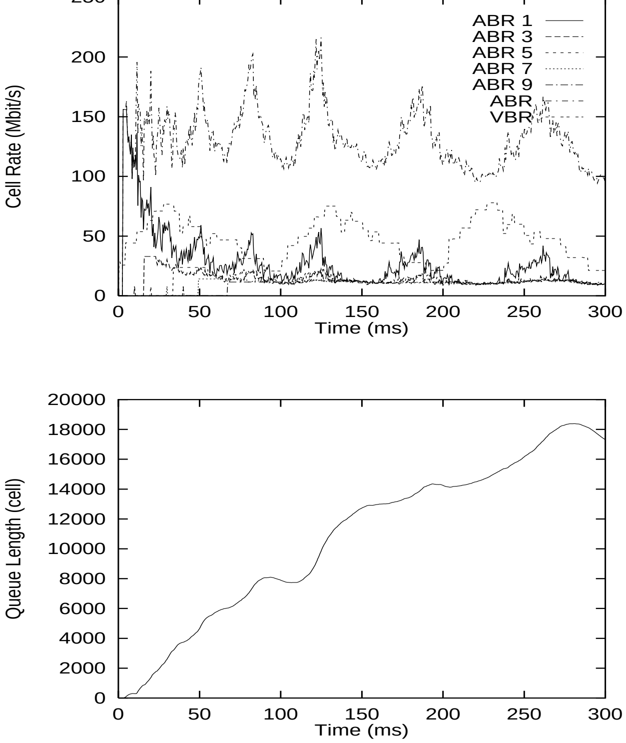
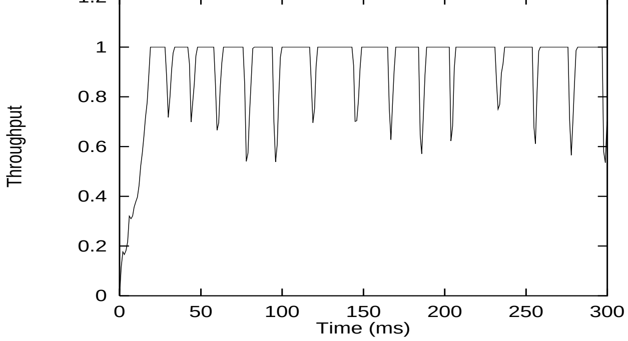


Fig. 9: EPRCA++ ($\tau = 1.00$, target utilization $= 0.95$).

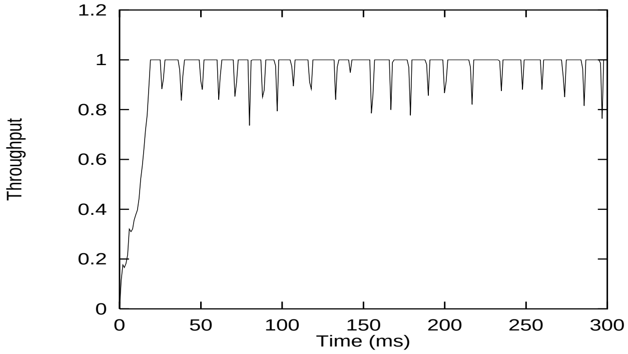
This tendency becomes more apparent when we see the results of EPRCA++. As can be observed in Fig. 9, the queue length explosion is unacceptable in the case of EPRCA++ when the target utilization is 0.95. The reason why EPRCA++ shows worst performance can be explained as follows. EPRCA++ determines the explicit rate of source end systems (ER) by observing the usable bandwidth for the ABR traffic so that it tries to fully utilize the link at the target utilization load. However, since it becomes too old when the RM cell containing the ER value arrives at the source end system in the case of large propagation delays. Therefore, when the cell arriving rate of VBR traffic at the switch grows (around at time 20 ms), the switch becomes overloaded more and more. Recalling that EPRCA++ uses FECN-like congestion notification, the larger τ introduces more overloaded switch. This problem can be avoided by setting target utilization properly (0.85, for example).

To make the effect of the target utilization clear, we show the maximum queue length of EPRCA++ with (and without) VBR traffic for different values of the target utilization ($\tau = 1.00$, $N_{VC} = 10$) in Fig. 11. From this figure, it can be found that the queue length increases rapidly unless the target utilization is set to a proper value, and that a slightly larger value of the target utilization causes a serious effect on the network performance.

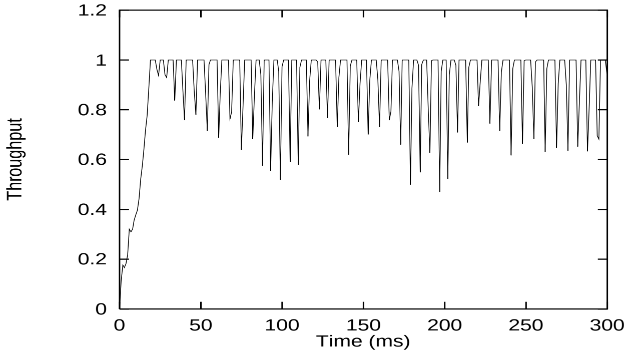
In summary, we show the effect of the propagation delay τ on the maximum queue length in Fig. 12 for $N_{VC} = 10$, and effects of the number of connections N_{VC} on the maximum queue length in Figs. 13 and 14 for $\tau = 0.01$ and $\tau = 1.00$, respectively.



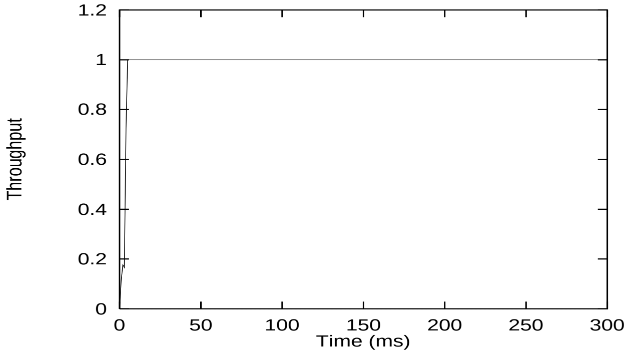
(a) EFCI Switch



(b) BES Switch



(c) EDS Switch



(d) EPRCA++

Fig. 10: Aggregate Throughput ($\tau = 1.00$).

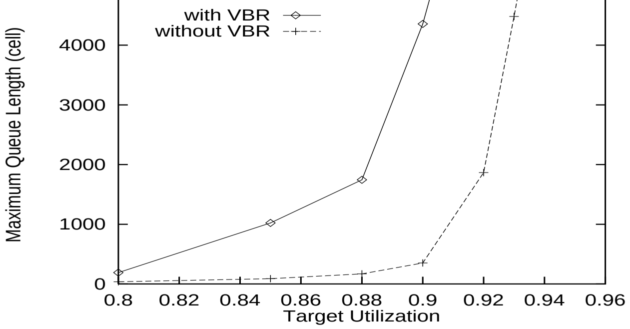


Fig. 11: Effect of the Target Utilization ($\tau = 1.00$).

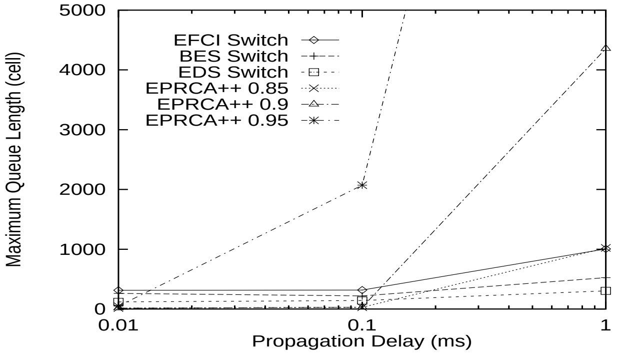


Fig. 12: τ vs. the Maximum Queue Length ($N_{VC} = 10$).

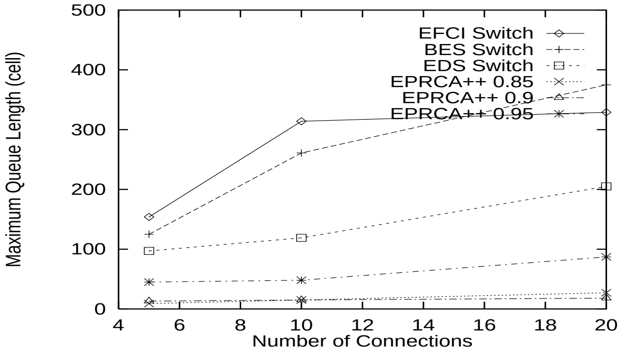


Fig. 13: N_{VC} vs. the Maximum Queue Length ($\tau = 0.01$).

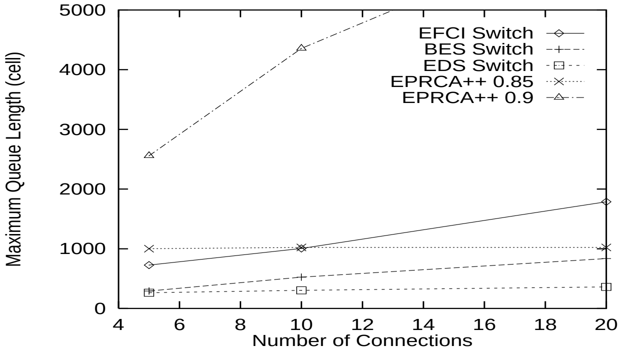


Fig. 14: N_{VC} vs. the Maximum Queue Length ($\tau = 1.00$).

of EPRCA is of good performance regardless of the network scale, and that EPRCA++ gives almost optimal performance in the LAN environment. Furthermore, it seems to be difficult to apply EPRCA++ to the WAN environment unless control parameters are set carefully.

V. CONCLUSION

Rate-based congestion control schemes have been developed in the ATM Forum as means of simple and effective traffic management scheme for ABR traffic. However, there has been little consideration on VBR and CBR service classes, which are applied for real time traffic. In this paper, we have evaluated performance of two representative rate-based control schemes — EPRCA, which is a standard scheme, and EPRCA++, a recently proposed scheme — by a simulation technique. As a typical application of VBR traffic, multiplexed MPEG streams were added on the switch to exhibit how VBR traffic influence the performance of theses schemes. We have shown the effect of VBR traffic on allowable transmission rates for ABR connections, the maximum queue length, and the throughput at the switch. It should be emphasized that control parameters of complicated schemes requires to be set carefully in order to achieve effective and stable operation.

REFERENCES

[1] L. Roberts, “Enhanced PRCA (proportional rate-control algorithm),” *ATM Forum Contribution 94-0735R1*, August 1994.

[2] H. Ohsaki, M. Murata, H. Suzuki, C. Ikeda, and H. Miyahara, “Rate-based congestion control for ATM networks,” *ACM SIGCOMM Computer Communication Review*, vol. 25, April 1995.

[3] R. Fan, H. Suzuki, K. Yamada, and N. Matsuura, “Expandable ATOM switch architecture (XATOM) for ATM LANs,” in *IEEE International Conference on Communications*, vol. 1 of 3, pp. 402–409, May 1994.

[4] R. Jain, S. Kalyanaraman, and R. Viswanathan, “Transient performance of EPRCA and EPRCA++,” *ATM Forum Contribution 94-1173*, November–December 1994.

[5] H. Ohsaki, M. Murata, H. Suzuki, C. Ikeda, and H. Miyahara, “Analysis of rate-based congestion control methods in ATM networks — part 1: Steady state analysis —,” *to be presented at GLOBECOM ’95*, 1995.