PERFORMANCE OF RATE-BASED CONGESTION CONTROL ALGORITHM WITH BINARY-MODE SWITCH IN ATM NETWORKS

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Abstract — A rate-based congestion control algorithm has been developed and standardized in the ATM forum for ABR service class. In the standard, the behavior of end systems is specified by several rate-control parameters such as RIF (Rate Increase Factor) and RDF (Rate Decrease Factor). Even though the performance of the rate-based congestion control heavily depends on a selection of these control parameters, the selection method of parameters is not shown in the standard. In this paper, by using analytic and simulation techniques, appropriate settings of rate-control parameters in the various circumstances are investigated.

I. INTRODUCTION

A rate-based congestion control algorithm has been standardized for ABR (Available Bit Rate) service class by the ATM forum [1, 2, 3, 4]. The target of the standard is an operation algorithm of both source and destination end systems. Although some example behaviors of intermediate switches are introduced in the standard activities [5, 6, 7], implementation issues regarding intermediate switches are left to manufactures. In this paper, we will focus on the simplest switch among them, which is referred to as an *EFCI bit setting switch* or a *binary switch*. In the binary switch, the congestion is detected by a predefined threshold in the switch buffer. If the number of cells in the buffer exceeds this threshold value, it is recognized as congestion.

In the standard document [2], several control parameters are defined for controlling cell transmission at the source end system. These include RIF (Rate Increase Factor) and RDF (Rate Decrease Factor) that control rate increase and decrease envelopes. During a connection establishment process, the source end system negotiates these control parameters with the network. In [8, 9], we have shown that effectiveness of the rate-based congestion control is heavily dependent on a choice of control parameters. If control parameters are configured properly, the rate-based congestion control can achieve high performance (i.e., no buffer overflow, high link utilization and small cell delay). However, a selection method of control parameters has not been specified in the standard, and parameters should be determined intuitively unless a proper tool is provided.

In [10, 11, 12], we have shown the analytic method to determine an appropriate setting of control parameters including RIF, RDF and ICR (Initial Cell Rate) for a single-hop network configuration. In the analysis, we have assumed that all source end systems behave identically, and that they always have cells to transmit. Under these assumptions, we have derived conditions that control parameters should satisfy to achieve two main objectives: preventing cell loss and achieving full link utilization. Based on these results, we have proposed a simple guideline for parameter tuning at the ATM Forum [13].

In [14], we have analyzed the dynamical behavior of the rate-based congestion control for a single-hop network but each group of connection is allowed to have a different propagation delay. We have also derived the maximum queue length at the switch after a new CBR connection is established in the network.

In this paper, we investigate an appropriate setting of control parameters for a multi-hop network configuration by simulation. In the simulation, we use the model with multiple connections with different numbers of hops. The main purpose is to evaluate the effect of two rate-control parameters (RIF and RDF) on the performance. In [15, 16], the authors have provided simulation results for several combinations of control parameters. In this paper, control parameters are chosen based on our analytic results. As performance measures, cell loss possibility, link utilization and fairness among connections are considered. We also validate how our analytic results of the single-hop model can be applied to generic network models.

The rest of this paper is organized as follows. In Section II, we first introduce our simulation model. We then show simulation results to discuss the robustness of the rate-based congestion control in terms of cell loss, link utilization and fairness in Section III. In Section IV, we present some concluding remarks, and summarize a detailed guideline for determining control parameters for the ABR service class with a binary-mode switch.

II. SIMULATION MODEL

Figure 1 illustrates our simulation model that is commonly referred to as the *parking lot* configuration [17, 4]. This model consists of five interconnected switches and four con-

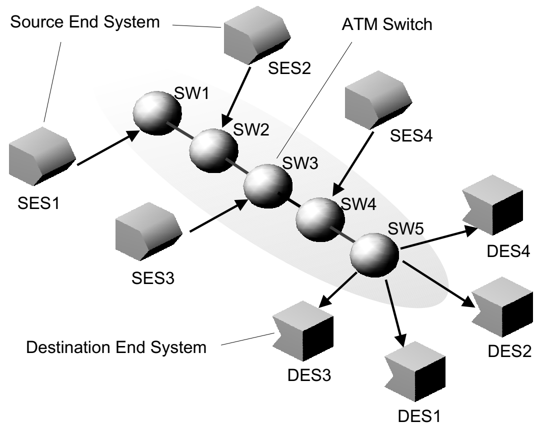

Fig. 1: Parking Lot Configuration.

nections with different numbers of hops. The connection VCn is established from SESn to DESn. Each VCn enters the network at SWn, and all exit from SW5. Since each connection has the different number of hops, unfairness among these connections may be caused, which is our main concern in this paper. Note that the link between SW4 and SW5 possibly becomes bottleneck in this model. The operation algorithm of source and destination end systems follows the standard draft [2]. Each source end system is assumed to always have cells to transmit, by which we evaluate robustness of the rate-based control in the worst case condition.

Bandwidth of all links is fixed at 150Mbit/s (353.7 cell/ms), and propagation delays between the source and the switch, τ_{sx}, and between the destination and the switch, τ_{xd}, are also fixed at 0.00 1ms (about 0.2 km). On the other hand, propagation delays between two interconnected switches, τ_{xx}, are 0.01 ms or 1.00 ms (about 2 km and 200 km, respectively) as values for LAN and WAN environments. For intermediate switches, we model the binary mode switch with the FIFO scheduling, and provide 300 Kbyte (5,796 cells) of the buffer. Upper and lower threshold values in the buffer, Q_H and Q_L, are fixed at the half of the buffer size. Other control parameters used in our simulation are $PCR = 150$ Mbit/s, $MCR = PCR/1000$, $ICR = PCR/20$, $TCR = 0.01$ cell/ms, $Mrm = 2$, $Trm = 100$, $C_{RM} = 32$, $CDF = 1/2$ and $TOF = 2$. Refer to [2] for the description of these control parameters.

As we have shown in [10, 11, 12], key parameters that determine the efficiency and stability of the rate-based congestion control are RIF and RDF. In these papers, we have analytically derived two boundary conditions for RIF and RDF to prevent cell loss and achieve full link utilization for a single-hop network configuration. In [13], we have proposed a guideline for parameter tuning based on our analytic results and simulation experiments. Here, we summarize this guideline.

1. Estimate the round-trip delay, τ, and the number of active connections, N_{VC}, in the worst case condition.
2. Obtain two boundary conditions for preventing cell loss and achieving full link utilization for these parameters from our analysis [10, 11, 12].
3. Set RDF to be a smaller value than 1/8, and determine RIF that satisfies the condition of preventing cell loss.

In our simulation, the number of active connections is set to be constant but the round-trip delay and the number of hops for each connection is varied. Thus, it is impossible to directly apply our analysis to the simulation model. In what follows, we investigate how our analytic methods, which is for a single-hop model and homogeneous sources, should be applied to a more generic model.

One problem is in determination of the round-trip delay, τ, that is used for obtaining two boundary conditions in our analysis. As we have shown in [14], the difference in propagation delays of connections has little effect on fairness. However, cell loss probability and link utilization are affected by the propagation delay since the larger round-trip delay implies the larger feedback delay [10, 11, 12]. By letting τ_n be the round-trip delay for the nth connection, VCn, we consider three schemes for determining τ being applied to our analysis as follows.

- Scheme 1: Adjust to the shortest connection

This scheme tunes parameters for the connection with the shortest round-trip delays. Thus, by assuming that VC1 has the shortest round-trip delay, we simply have

$$\tau = \tau_1.$$

- Scheme 2: Adjust equally to all connections

This scheme determines τ as an average of propagation delays of all connections. Thus, we have

$$\tau = \frac{1}{N_{VC}} \sum_{n=1}^{N_{VC}} \tau_n.$$

- Scheme 3: Adjust to the longest connection

This scheme is the opposite of Scheme 1; that is, parameters are tuned for the longest connection. Thus, by assuming that VCN has the longest round-trip delay, we have

$$\tau = \tau_N.$$

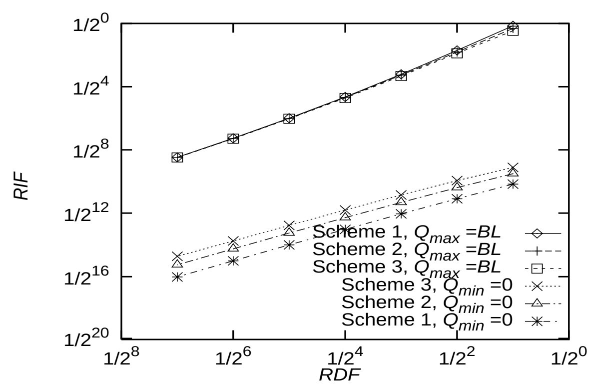

Fig. 2: Analytic Results for Appropriate Parameters for $\tau_{xx} = 0.01$.

To compare these schemes, we plot two boundary lines obtained in [10, 11, 12] for preventing cell loss and achieving full link utilization for $\tau_{xx} = 0.01$ ms and $\tau_{xx} = 1.00$ ms

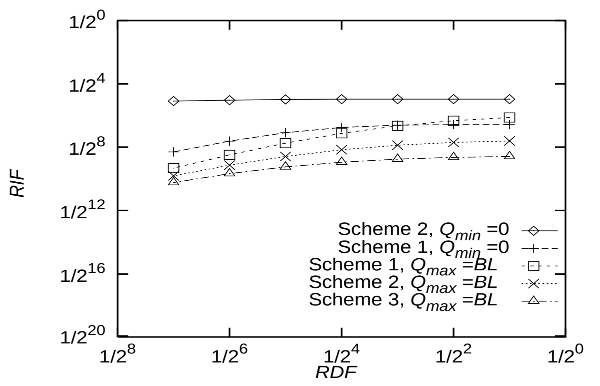

Fig. 3: Analytic Results for Appropriate Parameters for $\tau_{xx} = 1.00$.

in Figs. 2 and 3, respectively. N_{VC} is fixed at 4, and BL is 300 Kbyte to conform to the simulation parameters. The line labeled by "$Q_{max} = BL$" is the upper-bound of control parameters for preventing cell loss; that is, by selecting RIF and RDF from the lower region of this line, cell loss can be avoided. On the contrary, full link utilization can be fulfilled by selecting RIF and RDF from the upper region of the line labeled by "$Q_{min} = 0$". Hence, for preventing cell loss and achieving full link utilization, RIF and RDF should be chosen from the region between these two curves. One can find from these figures that when the round-trip delay is small, the boundary line for preventing cell loss (the "$Q_{max} = BL$" line) is nearly independent of schemes. However, the boundary line for full link utilization (the "$Q_{min} = 0$" line) is affected by schemes especially when the round-trip delay is large. Thus, for simulation of a WAN environment, we compare these three schemes although only Scheme 3 is used for simulation of a LAN environment.

III. SIMULATION RESULTS

A. Case of LAN Environment

In this subsection, we show simulation results for a small propagation delay, $\tau_{xx} = 0.01$ ms, as a LAN environment. As described in the previous subsection, Scheme 3 is used for determining τ. However, in this subsection, we use three values of RIF for a given RDF to investigate how the values of RIF and RDF should be chosen from the region between two boundary lines. We first fix RDF to be 1/4 as a fast rate-down case. Then, two values of RIF (1/4 and 1/512) are chosen from Fig. 2. That is, $RIF = 1/4$ is chosen from the "$Q_{max} = BL$" line for preventing cell loss, and $RIF = 1/512$ is from the "$Q_{min} = 0$" line for achieving full link utilization. Note that $RIF = 1/4$ is slightly smaller than the "$Q_{max} = BL$" line, and $RIF = 1/512$ is larger than the "$Q_{min} = 0$" line because RIF and RDF is represented in a form of $1/2^n$ [2]. We also use $RDF = 1/16$ and 1/64 as moderate and slow rate-down cases, respectively. We summarize values of RIF and RDF used in this subsection in Table 1.

	fast down	moderate down	slow down
$Q_{max} = BL$	1/4, 1/4	1/32, 1/16	1/256, 1/64
$Q_{min} = 0$	1/512, 1/4	1/2048, 1/16	—

Table 1: Values of RIF and RDF for LAN Environment.

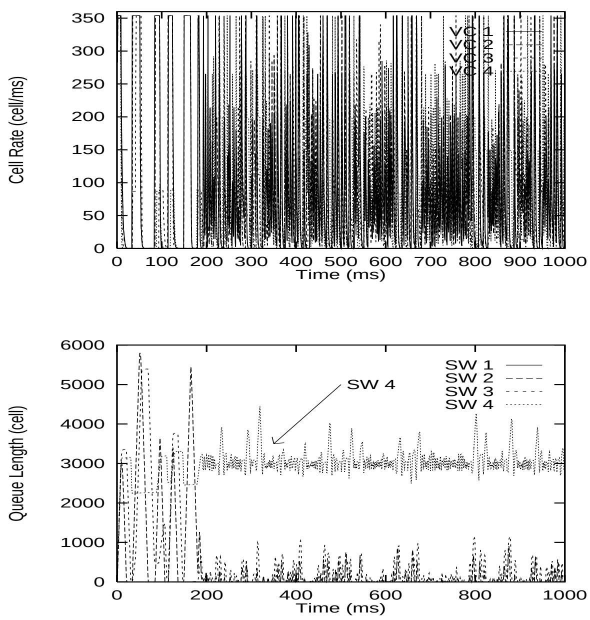

Fig. 4: LAN Case for $RIF = 1/4$ and $RDF = 1/4$.

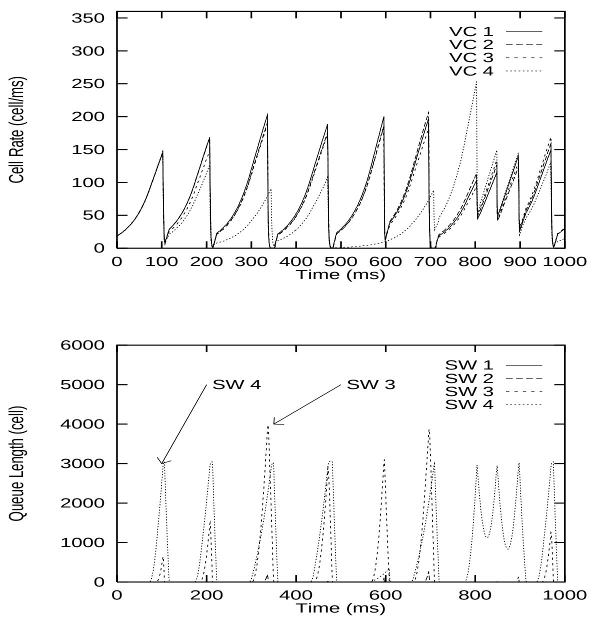

Fig. 5: LAN Case for $RIF = 1/512$ and $RDF = 1/4$.

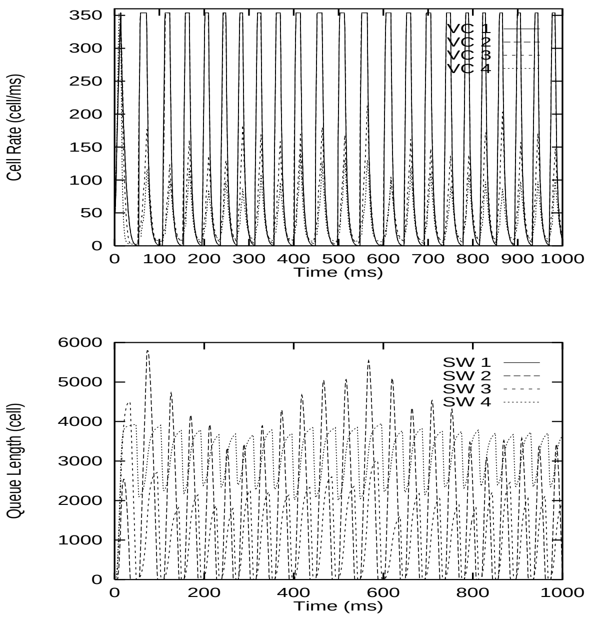

Fig. 6: LAN Case for $RIF = 1/32$ and $RDF = 1/16$.

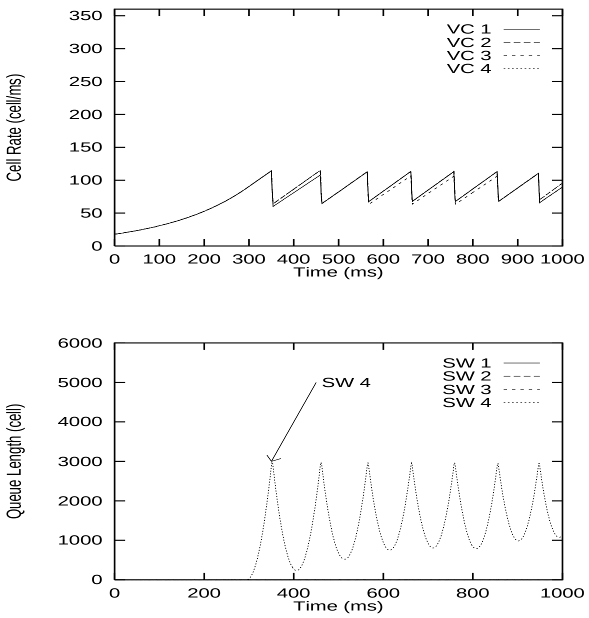

Fig. 7: LAN Case for $RIF = 1/2048$ and $RDF = 1/16$.

Figures 4 and 5 show the cell transmission rate of each connection and the queue length at the switch for $RIF = 1/4$ and 1/512, respectively. It can be found from these figures that SW4 is fully utilized when $RIF = 1/4$, and that cell loss is prevented in both cases. However, fairness among connections is not fulfilled; longer connections (VC1 and VC2) transmit more cells than shorter connections (VC3 and VC4) (for example, VC1 reaches PCR but VC4 does not in Fig. 4). it can be explained as follows. If SW4 becomes congested, each source decreases its rate by receiving backward RM cells of $CI = 1$. Because of different propagation delays, longer connections require more time to respond to congestion, and their ACR's remain high compared with shorter connections. Noting that an arrival rate of backward RM cells is proportional to its ACR, longer connections can receive much backward RM cells of $CI = 0$ after the congestion relief. Thus, longer connections can increase their ACR faster than the others, and it results in unfairness among connections.

We then change RDF to 1/16 for slower rate decrease (the third column of Table 1). Simulation results for $RIF = 1/32$ and 1/2048 are plotted in Figs. 6 and 7, respectively. We choose the values of RIF similarly to the previous case. From the figures, we can observe that $RIF = 1/2048$ achieves good fairness as well as full utilization of the bottleneck link while $RIF = 1/32$ cannot. Therefore, we conclude that too fast rate increase/decrease degrades fairness among connections and utilization of the bottleneck link.

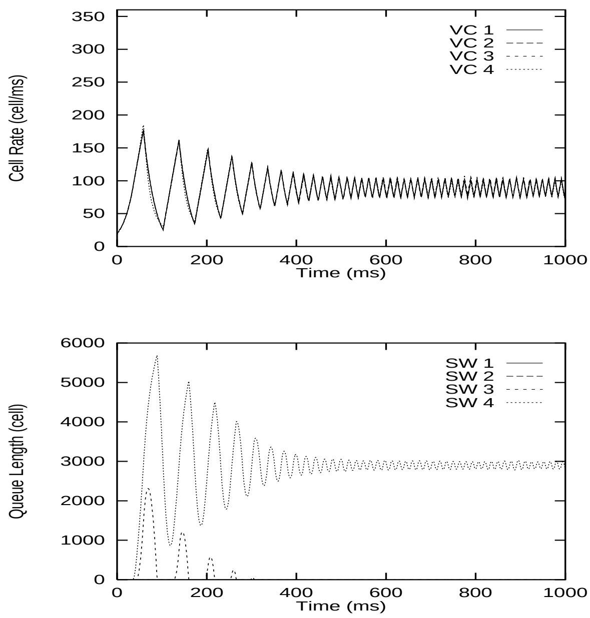

Fig. 8: LAN Case for $RIF = 1/256$ and $RDF = 1/64$.

Figure 8 shows simulation results for $RIF = 1/256$ when RDF is 1/64, which means much slower rate decrease. This figure indicates good fairness compared with the cases of $RDF = 1/4$ and 1/16. However, it should be noted that it takes longer time for each connection to be settled (around 500 ms). We conclude that a smaller value of RDF (i.e., slower rate decrease) is appropriate for achieving good fairness and stable operation, and that RIF should be chosen from the "$Q_{max} = BL$" line.

B. Case of WAN Environment

The objective in this subsection is to compare three schemes explained in Section II, and to investigate an appropriate setting of RIF and RDF in the WAN environment. We set the propagation delay between switches, τ_{xx}, to 1.00 ms (about 200 km). In what follows, we use $RDF = 1/16$ and 1/64.

Then, for each of three schemes, we choose RIF from the "$Q_{max} = BL$" line in Fig. 3. The values of RIF and RDF are summarized in Table 2.

	medium down	slow down
Scheme 1	1/256, 1/16	1/512, 1/64
Scheme 2	1/512, 1/16	1/1024, 1/64
Scheme 3	1/512, 1/16	1/1024, 1/64

Table 2: Values of RIF and RDF for WAN Environment.

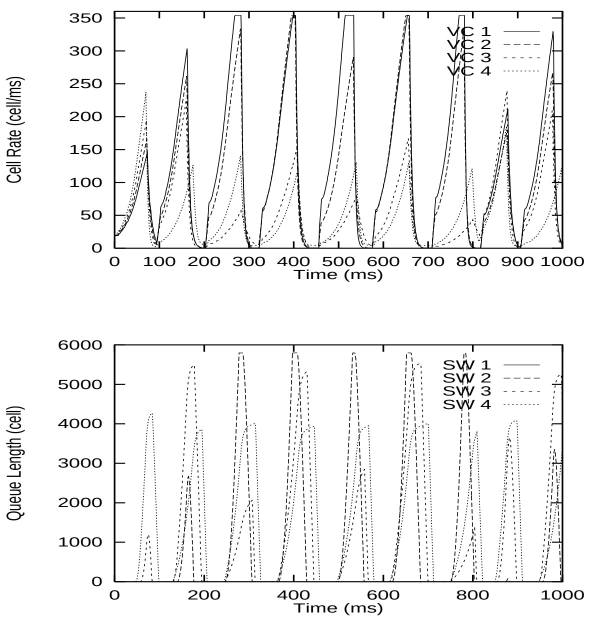

Fig. 9: WAN Case for $RIF = 1/256$ and $RDF = 1/16$ (Scheme 1).

We next change RDF from 1/4 to 1/16, which means slower rate decrease, and plot simulation results for each scheme in Figs. 9 and 10. As can be found from these figures, there is little improvement over the cases of $RDF = 1/4$. Although cell loss can be avoided by setting $RIF = 1/512$ (Schemes 2 and 3), fairness among connections is not still accomplished.

Finally, we change the rate decrease to be much slower ($RDF = 1/64$). Results are shown in Figs. 11 (Scheme 1) and 12 (Schemes 2 and 3). It can be easily found that a fairness problem is dramatically improved compared with previous two cases with $RDF = 1/4$ and 1/16. Namely, when the rate decrease is slow as $RDF = 1/64$, every scheme shows good performance in terms of good fairness, no cell loss and full link utilization. Finally, we conclude that rate-control parameters should be chosen from the "$Q_{max} = BL$" line with τ given by Scheme 2 and a smaller value of RDF (slow rate decrease) in multi-hop network configurations.

IV. Conclusion

In this paper, we have investigated an appropriate setting of control parameters for the rate-based congestion control

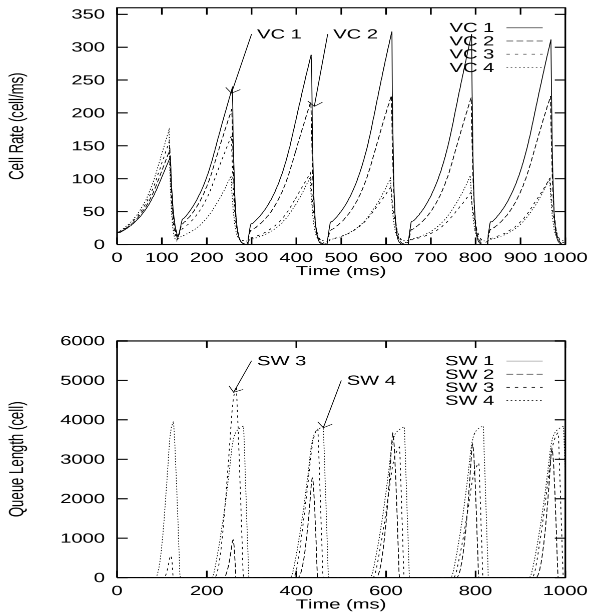

Fig. 10: WAN Case for $RIF = 1/512$ and $RDF = 1/16$ (Schemes 2 and 3).

with binary-mode switch. For this purpose, we have mainly focused on two rate-control parameters, RIF and RDF, which decides the envelope of rate increase/decrease.

By using simulation experiments, we have examined the appropriate setting of RIF and RDF for a multi-hop network configuration. As a simulation model, we have used the parking lot configuration having five interconnected switches and four connections with different numbers of hops. We have compared three schemes for applying our analysis to generic network configurations. It has been shown that RDF should be set to a small value around 1/64 (i.e., slow rate decrease), and that RIF should be set to a large value as long as cell loss can be prevented — the maximum value of RIF is given by our analysis using Scheme 2 for parameter determination.

At the end of this paper, we summarize the guideline for determining control parameters of the rate-based congestion control algorithm.

1. Estimate the number of active connections, N_{VC}, and their round-trip delays, τ_n.
2. Choose RDF around 1/64.
3. Calculate the average round-trip delay, τ, as

$$\tau = \sum_{n=1}^{N_{VC}} \frac{\tau_n}{N_{VC}}.$$

4. For N_{VC}, τ, RDF and other given parameters, solve the equation $Q_{max} = BL$ in [10, 12] for RIF to obtain the maximum of RIF that can prevent cell loss.
5. Choose RIF smaller but closest to this solution.
6. C_{RM} can be set to a small value (for example, 2) for preventing buffer overflow caused by background traffic [14].

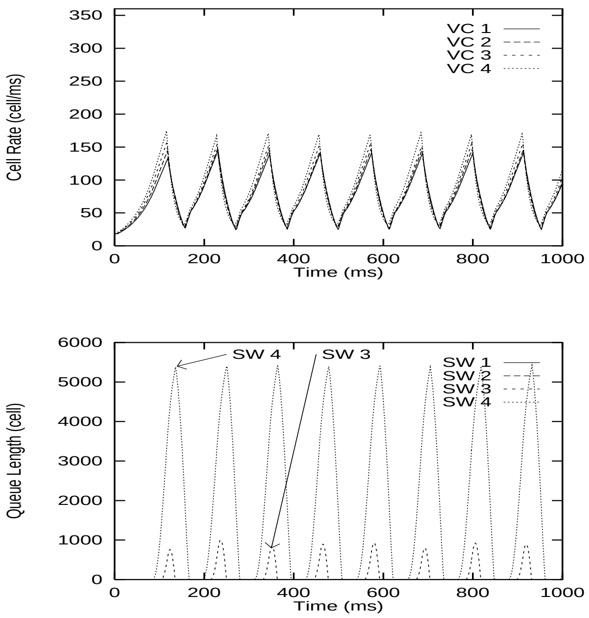

Fig. 11: WAN Case for $RIF = 1/512$ and $RDF = 1/64$ (Schemes 1 and 2).

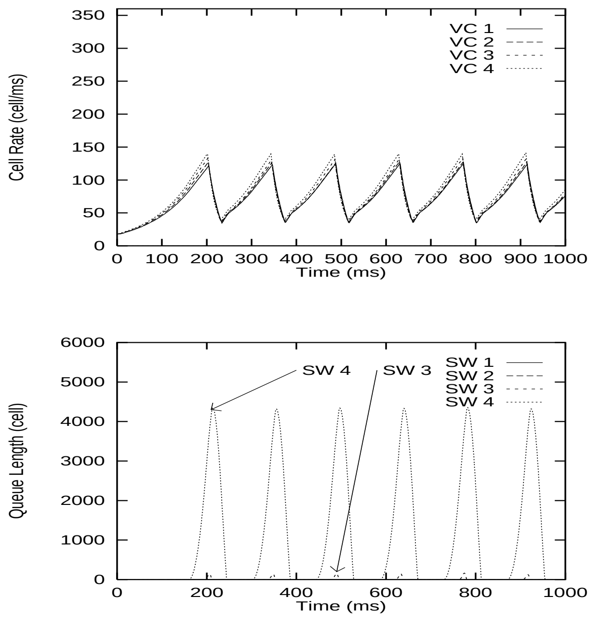

Fig. 12: WAN Case for $RIF = 1/1024$ and $RDF = 1/64$ (Scheme 3).

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