ATM 網におけるレート型輻輳制御方式の安定性解析

大崎 博之　村田 正幸　宮原 秀夫

大阪大学大学院 基礎工学研究科 情報数理系専攻
〒 560-8531 大阪府豊中市待兼山町 1-3

(Phone) +81-6-850-6588
(Fax) +81-6-850-6589
(E-mail) oosaki@ics.es.osaka-u.ac.jp

あらまし　レート型輻輳制御方式は、ABR (Available Bit Rate) サービスクラスに適用されるフィードバック型の輻輳制御方式である。レート型輻輳制御方式の動作が不安定になると、コネクション間の公平性が低下し、サービス品質 (Quality of Service) が予測できなくなるといった問題が生じる。しかし、レート型輻輳制御方式の性能が不安定になる理由はこれまで明らかにされていない。そこで本稿では、我々がこれまでに提案している解析手法を拡張することによって、レート制御方式の安定性に関する検討を行う。送信側端末の制御用セル送出方式としてカウンタ方式およびタイマ方式を用いた場合の性能評価を行い、レート型輻輳制御方式の不安定性はカウンタ方式を用いた場合にのみ発生することを明らかにし、既存のレート制御方式の本質的な問題点を指摘する。

和文キーワード　ABR サービスクラス、レート型輻輳制御方式、バイナリスイッチ、安定性解析

Stability Analysis of the Rate-Based Congestion Control Algorithm for ABR Service Class in ATM Networks

Hiroyuki Ohsaki　Masayuki Murata　Hideo Miyahara

Department of Informatics and Mathematical Science
Graduate School of Engineering Science, Osaka University
1-3 Machikaneyama, Toyonaka, Osaka 560-8531, Japan

(Phone) +81-6-850-6588
(Fax) +81-6-850-6589
(E-mail) oosaki@ics.es.osaka-u.ac.jp

Abstract　A rate-based congestion control algorithm is a feedback-based flow control mechanism for ABR (Available Bit Rate) service class. When the operation of the rate-based congestion control algorithm becomes unstable, it would cause several problems; fairness among connections is deteriorated, and QoS (Quality of Service) of ABR service class becomes unpredictable. In this paper, we analyze the dynamical behavior of the rate-based congestion control algorithm with binary-mode switches by extending our previous work. We analyze two forward RM cell generation schemes: *counter-based* and *timer-based* schemes. We also show that unstable behavior is caused only when the counter-based scheme is adopted at source end systems, which implies an inherent problem of the current rate-based congestion control algorithm.

英文 key words　ABR service class, rate-based congestion control algorithm, binary-mode switch, stability analysis

1 Introduction

A rate-based congestion control algorithm is a feedback-based flow control mechanism suitable for data transfer applications. In the rate-based congestion control algorithm, cell emission rate of each source end system (i.e., terminal) is regulated according to congestion information returned by the network. The ATM Forum has adopted it as congestion control mechanism for ABR (Available Bit Rate) service class, and has finished its standardization in 1996 [1].

A congestion notification method from a switch to source end systems has been standardized by the ATM Forum. However, detailed algorithms of binary-mode and explicit-rate switches are not standardized. Namely, their algorithms — when a binary-mode switch sets an EFCI bit or a CI bit, and how an explicit-rate switch decreases an ER field — are left to switch manufacturers. Effectiveness of the rate-based congestion control algorithm is therefore heavily dependent on a design of the switch algorithm. In [2, 3], it has been shown that a typical binary-mode switch works effectively in a LAN environment of short propagation delays. On the other hand, an explicit-rate switch has a potential to achieve high performance even in a WAN environment of significant propagation delays because of its ability to directly specify cell transmission rates of source end systems [4]。

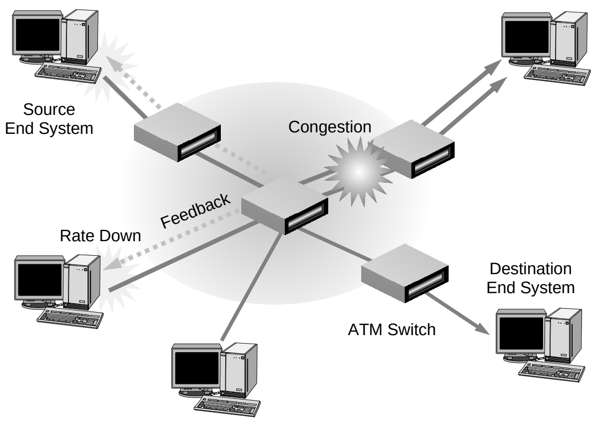


Figure 1: Rate-based congestion control algorithm.

There have been a lot of research on the rate-based congestion control algorithm. Since most of commercially available switches support only binary-mode operation (i.e., only an EFCI bit of a data cell header can be changed), many performance evaluations of the rate-based congestion control algorithm with binary-mode switches have been made in the literature. In [5], we have shown that its performance is determined by a choice of control parameters such as RIF (Rate Increase Factor) and RDF (Rate Decrease Factor). Unless these parameters are configured appropriately, performance of the rate-based congestion control algorithm is severely degraded even in a LAN environment. In [6], we have analytically derived the appropriate values of RIF and RDF, which are dependent on various system parameters: the number of active connections, propagation delays, and a buffer size of a switch.

A cell transmission rate of a source end system oscillates with regularity because a binary-mode switch uses just one-bit information and the propagation delay from the switch to the source end system is non-negligible. In [7], Pecelli *et. al* have analytically shown the existence of unstable operation in their feedback-based rate control mechanism although their analytic model is different from the rate-based congestion control algorithm standardized by the ATM Forum. Once the operation of the rate-based congestion control algorithm becomes unstable, it would cause several problems; that is, fairness among connections is deteriorated, and QoS (Quality of Service) of ABR service class becomes unpredictable. In [8], we have shown that unstable behavior of the rate-based congestion control algorithm occurs by simulation experiments, but the cause of such unstableness has not been clarified.

Henceforth, the main objective of the current paper is to analyze the rate-based congestion control algorithm with binary-mode switches, and to investigate the cause of performance degradation and unstableness. Several analytic approaches have been performed in the literature [3, 5, 9], but they assume homogeneity of connections; that is, all source end systems are assumed to behave identically and have identical propagation delays. Thus, the possible interference between connections is intractable. In [7], the authors of the paper have presented an analysis for two connections having different propagation delays. However, it is assumed that cell transmission rates of two connections follow the identical governing function. Namely, by letting $x_1(t)$ and $x_2(t)$ be cell transmission rates of two connections at a time t, $x_2(t)$ is assumed to follow $r \times x_1(t-m)$, where r is a constant and m is a difference in propagation delays of two connections. However, this assumption is not realistic. Moreover, as our numerical examples presented in Section 3 indicates, unstableness that the authors have shown in [7] is probably not caused by an intrinsic problem of the rate-based congestion control algorithm but simply caused by this unrealistic assumption. In [6], we have analyzed a dynamical behavior of the rate-based congestion control algorithm with binary-mode switches for heterogeneous connections, where connections are allowed to have different control parameters and different propagation delays. However, the analysis presented in [6] did not strictly consider an arrival rate of backward RM cells at the source end system, which is actually determined by transmission rates of corresponding forward RM cells. Consequently, unstable behavior of the rate-based congestion control algorithm cannot be observed in our analysis, and a more precise analysis is required.

In this paper, we analyze the dynamical behavior of the rate-based congestion control algorithm by extending our analysis in [6]. We take account of two schemes of a source end system: *counter-based* and *timer-based* schemes. The counter-based scheme is a mechanism adopted by the ATM Forum. The source end system periodically sends one forward RM cell per N_{RM} data cells. On the contrary, the timer-based scheme uses an interval timer at the source end system, which regularly sends a forward RM cell every T_s

(sec). We compare performances of these two schemes, and show that unstable behavior of the rate-based congestion control algorithm is caused by the counter-based scheme, which is an inherent problem of the current rate-based congestion control algorithm. This paper is motivated by our findings that unstableness of the rate-based congestion control algorithm can be avoided by regulating the interval of successive forward RM cells [8].

The rest of this paper is organized as follows. In Section 2, we analyze dynamical behavior of the rate-based congestion control algorithm with heterogeneous connections, considering both the counter-based and the timer-based approaches. In Section 3, we investigate causes of performance degradation and unstableness of the rate-based congestion control algorithm through several numerical examples. Finally, we summarize this paper in Section 4.

2 Analysis

2.1 Analytic Model

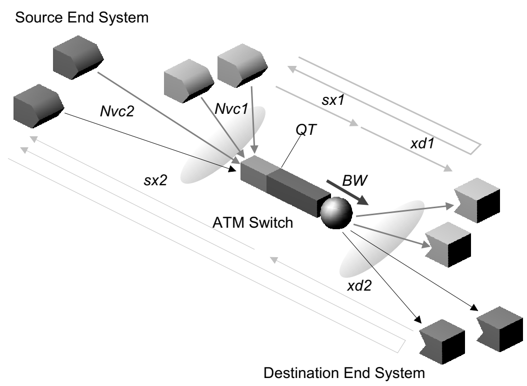


Figure 2: Analytic model for $N = 2$ and $N_{VC1} = N_{VC2} = 2$.

All connections are divided into N groups, and all connections in each group have identical propagation delays. Let N_{VCn} be the number of connections in group n. Figure 2 illustrates our analytic model for $N = 2$ and $N_{VC1} = N_{VC2} = 2$. Propagation delays between the source end system and the switch, and between the switch and the destination end system are denoted by τ_{sxn} and τ_{xdn}, respectively, for group n. For brevity, we introduce $\tau_n (= 2\tau_{sxn} + 2\tau_{xdn})$ and $\tau_{xdsn} (= \tau_{sxn} + 2\tau_{xdn})$. We assume that all connections in each group behave identically. Let us further introduce PCR_n, RIF_n, RDF_n, N_{RMn}, and T_{sn} as PCR (Peak Cell Rate), RIF (Rate Increase Factor), RDF (Rate Decrease Factor), N_{RM} (only in the counter-based scheme), and T_s (only in the timer-based scheme) of group n, respectively. Let $ACR_n(t)$ be the cell transmission rate of the source end system belonging to group n observed at time t. The number of cells in the switch buffer at time t is represented by $Q(t)$. The buffer size is denoted by BL, and a threshold value in the switch buffer, which is used to detect congestion at the switch, is denoted by Q_T. We assume that both forward and backward RM cells are given higher priority than data cells; that is, forward and backward RM cells are immediately processed at the switch even when data cells are awaited in the switch buffer.

2.2 Counter-Based Scheme

In the counter-based scheme, a source end system sends a forward RM cell per N_{RMn} data cells. So the receiving rate of backward RM cells at the source end system, $B_n(t)$, is dependent on its previous sending rate of forward RM cells. Formally, providing that high priority is given to RM cells, $B_n(t)$ is determined by

$$B_n(t) = \frac{ACR_n(t-\tau_n)}{N_{RMn}+1}. \tag{1}$$

Since $ACR_n(t)$ is increased or decreased according to the congestion information contained in the received backward RM cell, its change is determined according to relation between $Q(t-\tau_{xdsn})$ and Q_T. At receipt of each backward RM cell, $ACR_n(t)$ is increased by $(RIF_n \cdot PCR_n)$ if $Q(t-\tau_{xds})$ is less than Q_T. Otherwise, $ACR_n(t)$ is decreased by $(ACR_n(t) \cdot RDF_n)$ [1]. Hence, the differential equation of $ACR_n(t)$ can be formulated as

$$\frac{dACR_n(t)}{dt} = \begin{cases} \frac{RIF_n \cdot PCR_n}{B_n(t)}, & \text{if } Q(t-\tau_{xdsn}) < Q_T \\ \frac{-ACR_n(t) \cdot RDF_n}{B_n(t)}, & \text{otherwise} \end{cases} \tag{2}$$

By solving this equation, the dynamics of ACR_n after time t can be determined by

$$ACR_n(t+\Delta) = \begin{cases} ACR_n(t) \cdot e^{\alpha_n \Delta}, & \text{if } Q(t-\tau_{xdsn}) < Q_T \\ \frac{ACR_n(t)}{ACR_n(t) \cdot \beta_n \Delta + 1}, & \text{otherwise} \end{cases} \tag{3}$$

where α_n is defined as the root of the following equation.

$$\alpha_n e^{\alpha_n \tau_n} = \frac{RIF_n \cdot PCR_n}{N_{RMn}+1} \tag{4}$$

Also β_n is defined as

$$\beta_n = \frac{RDF_n}{N_{RMn}+1}.$$

Since the cell transmission rate of group n observed at the switch at time t is given by $ACR_n(t-\tau_{sxn})$, the differential equation of the queue length, $Q(t)$, can be formulated as

$$\frac{dQ(t)}{dt} = \sum_{k=1}^{N} \left(N_{VCk} \cdot ACR_k(t-\tau_{sxk}) \frac{N_{RMk}+1}{N_{RMk}} \right) - BW,$$

which yields

$$Q(t+\Delta) = Q(t) - BW \cdot \Delta + \int_{x=t_0}^{t} \left\{ \sum_{k=1}^{N} \left(N_{VCk} \cdot ACR_k(x-\tau_{sxk}) \frac{N_{RMk}+1}{N_{RMk}} \right) \right\} dx \tag{5}$$

Noting that $0 \le Q(t) \le BL$ since the queue length is limited by the buffer capacity, $Q(t)$ in Eq. (5) is further transformed using Eqs. (3) and (5) as

$$\begin{aligned} Q(t+\Delta) &= Q(t) - BW \cdot \Delta \\ &+ \sum_{k=1}^{N} \left(N_{VC\,k} \cdot S_k(t - \tau_{sx\,k}, \Delta) \frac{N_{RM\,n}}{N_{RM\,n}+1} \right) \end{aligned} \quad (6)$$

where $S_n(t, \Delta)$ is given by

$$S_n(t,\Delta) = \begin{cases} ACR_n(t) \frac{e^{\alpha_n \Delta} - 1}{\alpha_n}, & \text{if } Q(t) < Q_T \\ {\beta_n}^{-1} \log(1 - ACR_n(t) \cdot \beta_n \Delta), & \text{otherwise} \end{cases}$$

2.3 Timer-Based Scheme

In the timer-based scheme, the source end system sends the forward RM cell every $T_{s\,n}$; that is, the forward RM cell is generated after $T_{s\,n}$ since the last forward RM cell transmission. Because RM cells are assigned higher priority than data cells, the receiving rate of backward RM cells at the source end system, $B_n(t)$, is equivalent to the reciprocal of $T_{s\,n}$, i.e.,

$$B_n(t) = \frac{1}{T_{s\,n}}. \quad (7)$$

From Eqs. (2) and (7), $ACR_n(t)$ in the timer-based scheme is given by

$$ACR_n(t+\Delta) = \begin{cases} ACR_n(t) + \alpha_n \Delta, & \text{if } Q(t - \tau_{xds\,n}) < Q_T \\ ACR_n(t) \cdot e^{\beta_n \Delta}, & \text{otherwise} \end{cases} \quad (8)$$

where α_n and β_n are defined as

$$\begin{aligned} \alpha_n &= \frac{PCR_n \cdot RIF_n}{T_{s\,n}}, \\ \beta_n &= -\frac{RDF_n}{T_{s\,n}}. \end{aligned}$$

A differential equation of $Q(t)$ is obtained from Eq. (6) by replacing $ACR_n(t - \tau_{sx\,n})(N_{RM\,n} + 1)/N_{RM\,n}$ with $ACR_n(t - \tau_{sx\,n}) + {T_{s\,n}}^{-1}$. Therefore, the dynamics of $Q(t)$ is obtained as

$$\begin{aligned} Q(t+\Delta) &= Q(t) - BW \cdot \Delta \\ &+ \sum_{k=1}^{N} \left\{ N_{VC\,k} \cdot \left(S_k(t - \tau_{sx\,k}, \Delta) + \frac{1}{T_{s\,k}} \right) \right\} \end{aligned}$$

$$S_n(t,\Delta) = \begin{cases} ACR_n(t) \cdot \Delta + \frac{\alpha_n \Delta^2}{2}, & \text{if } Q(t) < Q_T \\ ACR_n(t) \cdot \frac{e^{\beta_n \Delta} - 1}{\beta_n}, & \text{otherwise} \end{cases}$$

3 Numerical Examples

3.1 Parameter Settings

In the following numerical examples, we consider the case of two connections (i.e., $N = 2$ and $N_{VC1} = N_{VC2} = 1$). The propagation delay, $\tau_{sx\,2}$, is changed from 0.1 ms (about 20 km) to 2.0 ms (about 400 km) while $\tau_{sx\,1}$ is fixed at 0.1 ms. Propagation delays of all other links are fixed at 0.1 ms. The buffer size of the switch, BL, is set to either 30 Kbytes (579 cells) or 300 Kbytes (5,796 cells). The threshold value of the switch buffer, Q_T, is fixed at the half of the buffer capacity (i.e., $BL/2$). The bandwidth of each transmission link, BW, is set to 150 Mbps (353.7 cell/ms). Settings of other control parameters are summarized in Table 1. Note that we use same values for two connections (e.g., $PCR_1 = PCR_2$).

Table 1: Control parameters of source end systems.

PCR (Peak Cell Rate)	BW
ICR (Initial Cell Rate)	PCR/10
RIF (Rate Increase Factor)	1/64 or 1/32
RDF (Rate Decrease Factor)	1/16 or 1/8
Nrm (the counter-based scheme only)	32
Ts (the timer-based scheme only)	0.2

3.2 Trajectory of (ACR1, ACR2)

In this paper, we focus on dynamics of cell transmission rates and the queue length (i.e., the number of cells queued in the switch buffer). In addition, we evaluate fluctuation of fairness between two connections (i.e., changes of a difference in cell transmission rates of two source end systems). For this purpose, we plot a trajectory of (ACR1, ACR2) where ACRi (i = 1, 2) denotes the cell transmission rate of the source end system i [10] (see Fig. 3). By tracing (ACR1, ACR2) on this graph, fairness between two connections can be observed clearly. When (ACR1, ACR2) is on the line of ACR1 = ACR2 (*fairness line*), fairness between two source end systems is completely achieved. Namely, if the cell transmission rates of two end systems are changed from (ACR1, ACR2) to (ACR1 + γ, ACR2 + γ), the trajectory moves in parallel with the fairness line, and it means that the identical fairness is preserved. If (ACR1, ACR2) is on the line of ACR1 + ACR2 = BW (*efficiency line*), the transmission link is fully utilized.

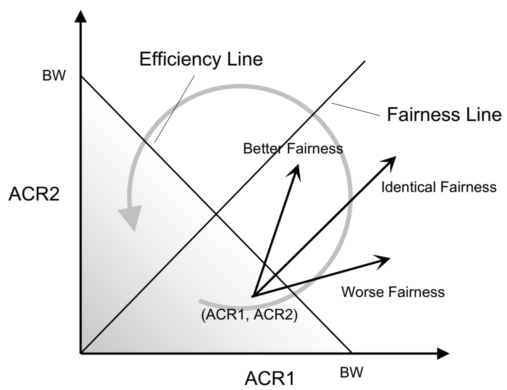
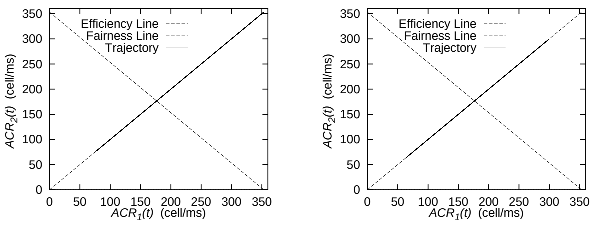


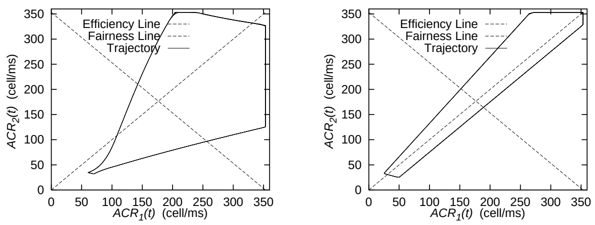
Figure 3: Trajectory of (ACR1, ACR2).

The ideal operation of the rate-based congestion control



(a) Couner-based scheme (b) Timer-based scheme

Figure 4: $BL = 300$ Kbytes, $\tau_{sx2} = 0.1$ ms, $RIF = 1/64$, and $RDF = 1/16$.



(a) Couner-based scheme (b) Timer-based scheme

Figure 5: $BL = 300$ Kbytes, $\tau_{sx2} = 1.0$ ms, $RIF = 1/64$, and $RDF = 1/16$.

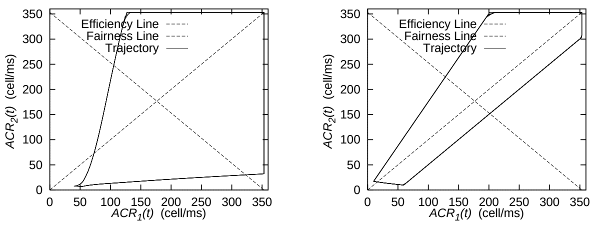
algorithm is, therefore, to stabilize (ACR1, ACR2) at the intersection point of the fairness line and the efficiency line, i.e., (ACR1, ACR2) = (BW/2, BW/2). Since the binary-mode switch uses only one-bit information and the propagation delay is not negligible, oscillation of cell transmission rates is unavoidable. Hence, the ideal operation of the rate-based congestion control algorithm with binary-mode switches is that values of (ACR1, ACR2) oscillate around the point of (BW/2, BW/2) on the fairness line. In what follows, we will investigate the dynamics of the rate-based congestion control algorithm with binary-mode switches using this trajectory graph.

3.3 Comparisons: Counter-Based vs. Timer-Based

In Fig. 4, we first show the numerical result in the case of identical propagation delays of two connections (τ_{sx1} = τ_{sx2} = 0.1 ms). In this figure, the buffer size of each switch, BL, is set to 300 Kbytes, and control parameters of each source end system, RIF_n and RDF_n, are set to be appropriate values (1/64 and 1/16) based on our analytic results in [6]. Note that our analytic results are for the counter-based scheme so that those control parameters may not be appropriate for the timer-based scheme. In this figure, we illustrate the trajectory of (ACR1, ACR2) of (a) the counter-based scheme and (b) the timer-based scheme. We depict numerical results from 500 ms to 600 ms to eliminate the effect of the initial state. Note that the trajectory of (ACR1, ACR2) moves in a counterclockwise direction in all numerical examples. It can be found from this figure that the trajectory of (ACR1, ACR2) lies on the fairness line in both counter-based and timer-based schemes. It means that operation of the rate-based congestion control algorithm is almost optimal. However, it should be noted that the amplitude of $ACR_n(t)$ in the counter-based scheme is larger than that of the timer-based scheme. In this case, the timer-based scheme achieves slightly better performance than the counter-based scheme.

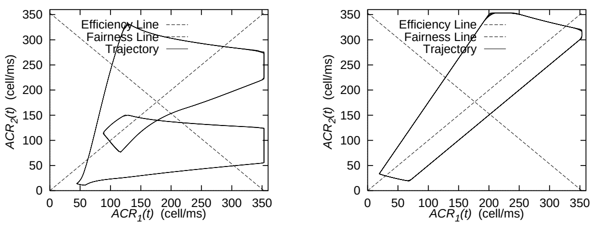
When the difference in propagation delays of two connections becomes large, superiority of the timer-based scheme to the counter-based scheme becomes more apparent as shown in Fig. 5. In this figure, the source–switch propagation delay of the group 2, τ_{sx2}, is changed from 0.1 ms to 1.0 ms while unchanging all other parameters. The round-trip delays of two connections, τ_1 and τ_2, are 0.4 ms and 2.2 ms, respectively. As can be found from Fig. 5(a), the trajectory of (ACR1, ACR2) is leaving from the fairness line, which means bad fairness between two connections. In consideration of the counterclockwise movement of the trajectory, this figure indicates that fairness is degraded as ACR1 and ACR2 are increased; that is, (ACR1, ACR2) departs from the fairness line when it moves in the upper-right direction. This problem is caused by the fact that the arrival rate of the backward RM cells is determined by the previous sending rate of forward RM cells. Namely, the connection with the short propagation delay can increase its cell transmission rate rapidly compared with the one with the long propagation delay. It can be explained from our analytic results. The evolution of the cell transmission rate in the counter-based scheme is decided by Eq. (3). This equation indicates that the larger α_n the faster $ACR_n(t)$ is increased. In addition, α_n monotonically decreases as τ_n increases so that a connection with shorter propagation delay can increase $ACR_n(t)$ faster. It should be noted that the slope of the trajectory (i.e., $dACR_2(t)/dACR_1(t)$) is determined by $ACR_2(t-\tau_2)/ACR_1(t-\tau_1)$ (see Eq. (2)). Hence, the difference between propagation delays directly results in fairness degradation. On the other hand, the timer-based scheme shows much better fairness than that of the counter-based scheme. It is because a cell transmission rate is increased linearly and also decreased exponentially as can be seen in Eq. (8), which are sufficient conditions to achieve good fairness [10].

We next show numerical results for the case of inappropriate control parameters in Fig. 6. By *inappropriate control parameters*, we mean that full link-utilization never be expected by using those parameters in the counter-based scheme [6]. In obtaining this figure, we use control parameters of $RIF_n = 1/32$ (fast increase) and $RDF_n = 1/8$ (fast decrease) for evaluating the effect of inappropriate control parameters. Other parameters used in the previous case (Fig. 5) are unchanged. Figure 6 shows that fairness between connections is significantly degraded in the counter-based scheme by changing RIF_n and RDF_n. This can also be explained from Eq. (3). Namely, the large value of RIF_n causes serious fairness degradation when both ACR_1 and ACR_2 are increased because α_n increases by a large value



(a) Couner-based scheme (b) Timer-based scheme

Figure 6: $BL = 300$ Kbytes, $\tau_{sx2} = 1.0$ ms, $RIF = 1/32$, and $RDF = 1/8$.



(a) Couner-based scheme (b) Timer-based scheme

Figure 7: $BL = 30$ Kbytes, $\tau_{sx2} = 1.0$ ms, $RIF = 1/32$, and $RDF = 1/8$.

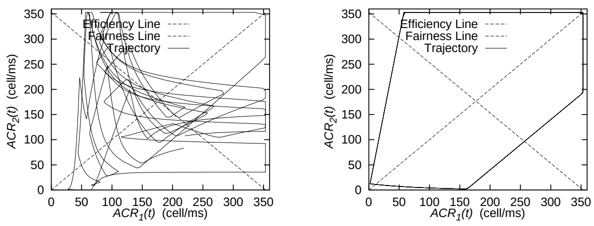
of RIF_n.

When the buffer size is decreased, fairness among connections is further degraded as shown in Fig. 7. In this figure, the buffer size is changed from 300 Kbytes to 30 Kbytes. The timer-based scheme (Fig. 7(b)) shows a nearly identical trajectory of (ACR1, ACR2) to that of the previous case (Fig. 6). On the contrary, in the counter-based scheme, the trajectory of (ACR1, ACR2) shows a more complex form than those of previous cases, which is a symptom of unstableness. Note that the behavior of $ACR_n(t)$ and $Q(t)$ is cyclic but its period is 2. It would be worth noting that we have observed that the period of the trajectory in the counter-based scheme becomes 4 for $\tau_2 = 1.3$ ms, and 8 for $\tau_2 = 1.7$ ms.

By increasing τ_2 up to 3.0 ms, the counter-based scheme exhibits a chaotic behavior as shown in Fig. 8. In this figure, the trajectory of (ACR1, ACR2) in the counter-based scheme moves almost randomly showing an unstable operation of the rate-based congestion control algorithm. Therefore, we conclude that the current rate-based congestion control algorithm might have an intrinsic problem, which would causes unstableness.

4 Conclusion

In this paper, we have analyzed the dynamical behavior of the rate-based congestion control algorithm by extending our previous work. We have analyzed two schemes by which a source end system generates a forward RM cell: the counter-based and timer-based schemes. We have compared performances of these two schemes, and have shown that unstable behavior of the rate-based congestion control algorithm is caused only when the counter-based scheme is adopted at source end systems, indicating an inherent problem of the current rate-based congestion control algorithm.



(a) Couner-based scheme (b) Timer-based scheme

Figure 8: $BL = 30$ Kbytes, $\tau_{sx2} = 3.0$ ms, $RIF = 1/32$, and $RDF = 1/8$.

References

[1] S. S. Sathaye, "ATM forum traffic management specification version 4.0," *ATM Forum Contribution 0056.000*, April 1996.

[2] C. Fang and A. Lin, "A simulation study of ABR robustness with binary-mode swiches: part II," *ATM Forum Contribution 95-1328R1*, October 1995.

[3] 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," in *Proceedings of IEEE GLOBECOM '95*, pp. 296–303, November 1995.

[4] A. Arulambalam and X. Chen, "Allocating fair rates for available bit rate service in ATM networks," *IEEE Communications Magazine*, vol. 34, pp. 92–100, November 1996.

[5] H. Ohsaki, M. Murata, H. Miyahara, C. Ikeda, and H. Suzuki, "Parameter tuning for binary mode switch — analysis," *ATM Forum Contribution 95-1483*, 1995.

[6] H. Ohsaki, M. Murata, and H. Miyahara, "Robustness of rate-based congestion control algorithm for ABR service class in ATM networks," to appear in *International Journal of Communication Systems*, 1998.

[7] G. Pecelli and B. G. Kim, "Dynamic behavior of feedback congestion control schemes," in *Proceedings of IEEE INFOCOM '95*, pp. 253–260, April 1995.

[8] H. Ohsaki, M. Murata, and H. Miyahara, "Studies on stability of rate-based congestion control algorithm for ABR service class in ATM networks," *Technical Report of IEICE*, vol. 97, pp. 63–70, January 1998.

[9] G. Ramamurthy and Q. Ren, "Analysis of the adaptive rate control for ABR service in ATM networks," *unknown*, pp. 1083–1088, 1995.

[10] D.-M. Chiu and R. Jain, "Analysis of the increase and decrease algorithm for congestion avoidance in computer networks," *Computer Networks and ISDN Systems 17*, pp. 1–14, 1989.