PAPER

Performance Evaluation of High-Speed Admission Control in ATM Networks Based on Virtual Request Generation

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SUMMARY This paper presents a high-speed CAC scheme, called PERB CAC (CAC based on Prior Estimation for Residual Bandwidth). This scheme estimates the residual bandwidth in advance by generating virtual requests for connection. When an actual new request occurs, PERB CAC can instantaneously judge if the required bandwidth is larger than the estimated residual bandwidth. PERB CAC provides very rapid response time both for statistical and deterministic bandwidth allocation services, while keeping statistical multiplexing gain for the former service. Numerical results indicate that PERB CAC provides reasonably accurate and conservative values of residual bandwidth. In addition, by using PERB CAC, both services are able to be accommodated into a single VP. VP capacity control is more relaxed than is true with conventional VP-separation management. This is another merit of PERB CAC. Therefore, PERB CAC can achieve high-speed connection set-up while utilizing network resources in a cost-effective manner.
key words: *ATM, admission control, QoS, bandwidth management*

1. Introduction

In ATM networks, cell-loss ratios are kept low by using a connection admission control (CAC) procedure for variable bit rate (VBR) service. This procedure determines whether a new connection should be accepted or not, by estimating the cell-loss ratio that would occur if the connection were accepted. The bandwidth for VBR service are allocated statistically to obtain statistical multiplexing effect while satisfying the cell-loss ratio objective.

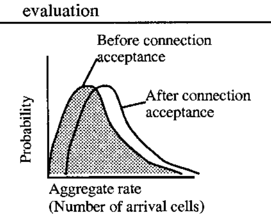
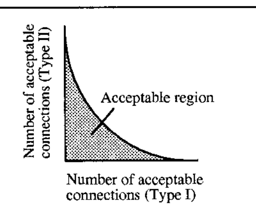
Several CAC schemes that estimate the cell-loss ratio analytically have been reported [1]–[3]. Murase et al. estimated the cell-loss ratio based on buffer-less fluid approximation by using the peak bit rate and the average bit rate declared by users [1]. Saito provided an upper bound formula of the cell-loss ratio, which introduced the cell arrival distribution into a buffer [2]. This scheme also uses the peak and average bit rate of the connection.

The computation time required for estimating the cell-loss ratio strongly impacts the connection set-up time for switched services. Therefore, it is important to reduce the CAC response time. However, the computation time in these estimations of the cell-loss ratio increases enormously as the numbers of connections and connection types increase. This is because convolution calculation in the cell-loss estimation is strongly required for each connection. As a result, connection set-up time becomes long if the cell-loss ratio is estimated after a new connection request occurs. Therefore, it is necessary to shorten the cell-loss estimation time itself in order to reduce the CAC response time. Rapid cell-loss estimation schemes were proposed in [4], [5]. It is true that the required estimation time in their scheme are shortened to some extent, but the estimation time still affects the connection set-up time.

To quickly determine whether a new connection should be accepted or not, there is another CAC approach using memory tables. In this approach, several sets of acceptable connections that do not violate the cell-loss objective are stored in memory tables in advance. Analytical cell-loss evaluation or simulation are employed to obtain these sets. When a new connection request occurs, the combination of the accommodated connections and the new connection is compared with these acceptable sets stored in memory tables. However, although the CAC response time is reduced, enormously large memory tables are required. This is because many kinds of connection types must be handled, which means that in multimedia ATM networks the number of possible combinations increases explosively. Therefore, a new CAC scheme that reduces both the CAC response time and the size of memory tables is required. The features of conventional CAC approaches are shown in Table 1.

This paper presents a high-speed connection admission control scheme, called PERB CAC (CAC based

Table 1 Features of conventional CAC approaches.

(a) CAC using analytical cell-loss evaluation	(b) CAC using memory tables
	
• Cell-loss ratio estimation is executed after a new connection request occurs. • A large CAC time is required.	• The set of accommodated and new connections is compared with the acceptable region. • Large memory tables are required.

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on Prior Estimation for Residual Bandwidth) [6], [7]. Then, a bandwidth management scheme that employs PERB CAC is introduced. PERB CAC estimates the residual bandwidth in advance by generating a series of virtual requests for connection. When an actual new connection request occurs, PERB CAC can *instantaneously* judge if the required bandwidth is larger than the estimated residual bandwidth, so the connection set-up time can be greatly reduced. In addition, since only the residual bandwidth is required, large memory tables storing the sets of acceptable connections are not needed. Note that this method employs an appropriate cell-loss estimation scheme, for example, one of those presented in [1], [2], [4], [5] to estimate the residual bandwidth. Therefore, this approach should cooperate with the cell-loss estimation scheme to reduce the CAC response time.

In addition, PERB CAC provides another merit for VP bandwidth management. We describe conventional bandwidth management to clarify the merit of PERB CAC.

In bandwidth management based on the former conventional CAC approach as presented in Table 1, statistical bandwidth allocation service such as VBR and deterministic bandwidth allocation service such as Constant Bit Rate (CBR) and ATM Block Transfer (ABT) are accommodated in different virtual paths (VPs) as shown in Fig. 1. ABT service strictly requires very rapid bandwidth reservation [8]. This is true for ABT both with delay transmission (ABT/DT) and with immediate transmission (ABT/IT). In ABT/DT, the block is transmitted when the bandwidth reservation is completed using a resource management (RM) cell and the user receives the acknowledgment. In ABT/IT, the block is sent immediately after the preceding RM cell. In both ABT/DT and ABT/IT, the admission control for ABT blocks is executed by simply summing up peak bit rates for allocated blocks [9]. If it takes a lot of time to reserve bandwidth, high throughput for data transmission can not be achieved. On the other hand, VBR service mainly requires large statistical multiplexing gain to utilize VP efficiency at the cost of very rapid response time. Thus, since requirements for statistical and deterministic are different, different bandwidth management schemes using each separate VP are employed. However, there are some drawbacks with VP separation. Sensitive dynamic VP capacity control, such as [10], [11] is needed when a VP is separated into small VPs. This is because the traffic demand for each service may fluctuate and it is very difficult to predict the traffic demand in advance. As a result, sensitive VP capacity control will lead to an increase in network cost. In addition, since a large VP is divided into two small VPs, statistical multiplexing gain on connection and block levels is decreased.

PERB CAC solves such problems of the VP separation. PERB CAC provides very rapid response time

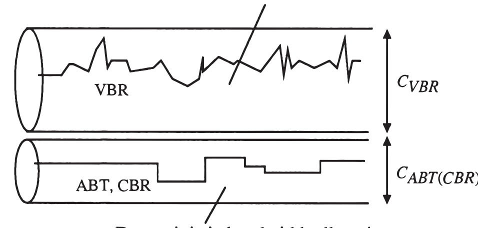

Fig. 1 Conventional bandwidth management scheme.

both for statistical and deterministic bandwidth allocation services, while keeping statistical multiplexing gain on cell level for the former service. Therefore, by using PERB CAC the both services are able to be accommodated into a single VP.

This paper is organized as follows. Section 2 presents PERB CAC. Section 3 describes its performance. Finally, section 4 summarizes the key points. In the following sections, we consider that a VP network that offers high-quality transfer capability and does not degrade QoS [12]. It guarantees a much lower cell-loss ratio than that of VP access points [13], [14]. Therefore, CAC procedures do not need to take VP QoS into account when deciding to accept or reject a new connection or a new ABT block. We note that, when we use the term, *CAC*, it includes both connection and block admission control for the convenience of description.

2. PERB CAC

2.1 Model and Notation

A CAC model, as shown in Fig. 2, is considered. We assume that the ATM switch is a non-blocking switch with an output queuing buffer at each VP, and CAC is executed on each VP. The network offers VBR, CBR, and ABT services. The output buffer is separated to support each service class. VBR service class reserves the bandwidth statistically to guarantee the cell-loss ratio objective. On the other hand, CBR and ABT service classes reserve the bandwidth deterministically. Therefore, cell losses are not assumed to occur at this VP access point for these services. Output buffers for CBR and ABT are designed to be the appropriate size to absorb arriving cells at the same cell time without cell losses. In this bandwidth management, link resources can be shared on the connection level and block level among VBR, CBR, and ABT. In these services, peak bit rate and average bit rate of the connection and block are assumed to be provided by users. Note that, in CBR and ABT services, average bit rate equals peak bit rate. In the following, we deal with only ABT as a deterministic bandwidth allocation service for simplicity.

We use the following notations in this paper.

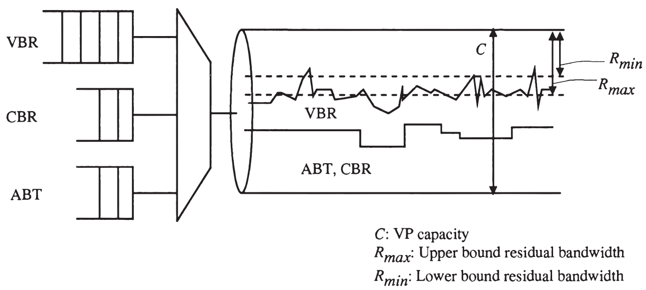

Fig. 2 PERB CAC model.

R_{max}:	Upper bound residual bandwidth
R_{min}:	Lower bound residual bandwidth
C:	VP bandwidth
CLR_{obj}:	Cell-loss ratio objective of VBR
CLR_{est}:	Cell-loss ratio estimate of VBR
P_i:	Peak bit rate of connection or block i
A_i:	Average bit rate of connection i
P_{req}:	Peak bit rate of a new requested connection or block
P_{dis}:	Peak bit rate of a released connection or block
A_{dis}:	Average bit rate of a released connection
$\boldsymbol{T}$:	Set of parameters for accommodated connections and blocks $= \{P_1, A_1, \ldots, P_i, A_i, \ldots\}$

As far as we know, no existing scheme can *explicitly* estimate the residual bandwidth that satisfies the cell-loss objective. In PERB CAC, to estimate the current residual bandwidth before the next new connection request or block, two parameters, R_{max} and R_{min} are used. They are updated by iterated calculations to obtain the residual bandwidth as accurately as possible. When a new connection or block request occurs, PERB CAC compares P_{req} with the latest R_{min} and determines whether to accept the connection or block. Here, R_{min} is the residual bandwidth that satisfies the cell-loss ratio objective CLR_{obj} even if the next new connection or block is accepted. The maximum actual residual bandwidth that can be provided while not violating CLR_{obj} always lies between R_{max} and R_{min}.

To explain the behavior of PERB CAC clearly, we classify it into three phases. Phase 1 is when there is no connection or block request, and no connection or block release. Phase 2 occurs when a new connection or block is requested. Phase 3 occurs when an accommodated connection or block is released. In the following subsections, we describe the behavior of PERB CAC for each phase. Note that we first initialize $R_{max} = C$ and $R_{min} = c$ $(0 < c < C)$.

2.2 Phase 1: No Request and No Release

To accurately estimate the residual bandwidth, the difference D between R_{max} and R_{min} should be small.

$$D = R_{max} - R_{min} \tag{1}$$

We employ a well-known binary search method to make D small [15].

$$m \leftarrow (R_{max} + R_{min})/2 \tag{2}$$

$$CLR_{est} = f(C, \boldsymbol{T}, m) \tag{3}$$

The right side of Eq. (3) is a function that estimates the cell-loss ratio after the virtual request for connection whose peak bit rate is m is accepted. For example, the cell-loss estimation formula given in [1], [2], [4], [5] can be applied. We assume that in the virtual request for connection the traffic is CBR in order to evaluate CLR_{est} conservatively. After an actual VBR connection is newly accepted, the average bit rate of the connection is reflected at $\boldsymbol{T}$. Instead of $\boldsymbol{T}$, we can also use a measured cell arrival distribution as presented in [16]. In the PERB CAC, we can employ the most suitable cell-loss estimation scheme, considering calculation time and hardware resources. For the convenience of description, in this paper we use the cell-loss evaluation scheme presented in [1].

Then, CLR_{est} and CLR_{obj} are compared.

$$CLR_{est} < CLR_{obj} \tag{4}$$

When Eq. (4) is satisfied, we set,

$$R_{min} \leftarrow m. \tag{5}$$

Otherwise, we set,

$$R_{max} \leftarrow m. \tag{6}$$

Then, using the updated R_{max} and R_{min}, we go back to Eq. (2). These procedures from Eq. (2) to Eq. (6) are iterated until a connection or block is requested, or a connection or block is released. How small D becomes depends on the number of these iterations during Phase 1.

Thus, in Phase 1, virtual requests for connection are generated and CAC for the connection is executed virtually. Then current residual bandwidth is estimated in advance before an actual new connection or block request occurs.

2.3 Phase 2: New Connection or Block Request

When a new connection or block is requested, CAC is executed by comparing R_{min} and P_{req}. If

$$P_{req} \leq R_{min}, \tag{7}$$

is satisfied, the new connection or block is accepted. Then,

$$R_{min} \leftarrow R_{min} - P_{req}. \tag{8}$$

In Phase 2, to estimate the residual bandwidth conservatively and quickly, traffic in the newly accepted connection or block is assumed to be CBR in Eq. (8). However, if traffic in the VBR connection is not actually CBR, R_{min} increases in Phase 1. This is because statistical multiplexing effects on cell level can be taken into account in Phase 1. When the block is accepted, the bandwidth is reserved as the peak bit rate deterministically.

If Eq. (7) is not satisfied, the new connection or block is rejected. After Phase 2 is executed, the system returns to Phase 1.

2.4 Phase 3: Connection or Block Release

When an accommodated connection or block is released, the actual residual bandwidth increases by ΔR. If the peak bit rate and the average bit rate of the released connection or block are P_{dis} and A_{dis}, ΔR is located in the range of $A_{dis} \leq \Delta R \leq P_{dis}$. Therefore, R_{max} and R_{min} are updated as follows.

$$R_{max} \leftarrow R_{max} + P_{dis} \tag{9}$$

$$R_{min} \leftarrow R_{min} + A_{dis} \tag{10}$$

Equations (9) and (10) are conservative approximations. The actual residual bandwidth that satisfies the cell-loss objectives is surely between R_{max} and R_{min}. After Phase 3 is executed, the system returns to Phase 1.

3. Performance Evaluation of PERB CAC

3.1 Response Time

We compared the performance of PERB CAC with that of a conventional CAC scheme. First, the response time in CAC systems is discussed. Since the response time of CAC is sensitive only to statistical bandwidth allocation service, we assume that only VBR connections are accommodated in this evaluation. Here the conventional CAC is defined as the procedure in which the cell-loss ratio after a new connection acceptance is evaluated after the new connection request occurs. Conventional CACs may include those presented in [1], [2], [4], [5]. The differences among them are mainly cell-loss evaluation time and required parameters for CAC such as traffic characteristics and buffer sizes. Throughout the following evaluations in this paper, we adopt the CAC scheme presented in [1] as the conventional CAC. As we have already described, in PERB CAC the cell loss ratio is evaluated by Eq. (3) in Phase 1 before the new connection request occurs. We assume that PERB CAC employs the same cell-loss evaluation scheme as that used in the conventional scheme.

The system response time of PERB CAC $t_{res}(P)$ and that of the conventional CAC t_{res}(C) are compared in Fig. 3. It is defined as the 99.9% response time value from a connection request until the CAC is completed.

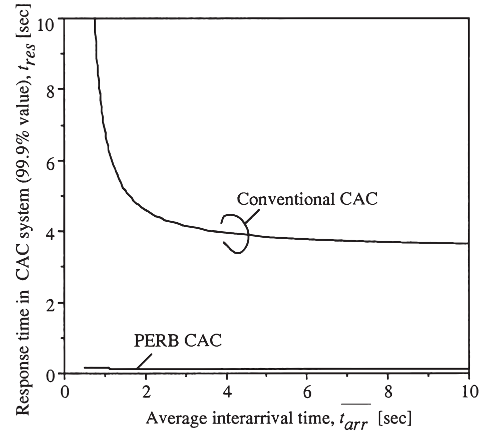

Fig. 3 Response time in CAC systems for single node.

In this evaluation of the CAC system response time, we assume that the interarrival time of successive new connection requests t_{arr} occurs according to exponential distribution where the average interarrival time is $\overline{t_{arr}}$. t_{res} consists of the waiting time t_w until CAC starts and the required CAC completion time t_c, which is the CAC service time. $t_c(P)$ of PERB CAC can be a very small constant time ($\ll t_{arr}$). This is because PERB CAC has only to judge Eq. (7). On the other hand, $t_c(C)$ mainly depends on the required cell-loss evaluation time, and is assumed to be exponentially distributed as the average $\overline{t_c(C)}$. In Fig. 3, we set $t_c(P) = 0.03$ [sec] and $\overline{t_c(C)} = 0.5$ [sec].

In the conventional CAC scheme, as the interarrival time of new connection requests becomes small, there is an increasing possibility that while CAC for a new connection request is being executed the next new connection request will arrive. Therefore, $t_{res}(C)$ increases as $\overline{t_{arr}}$ decreases. On the other hand, since PERB CAC estimates the residual bandwidth and $t_c(P)$ is much smaller than $\overline{t_{arr}}$, $t_{res}(P)$ maintains a small value which depends very little on $\overline{t_{arr}}$. Thus, PERB CAC greatly reduces the response time in CAC system.

When the number of transit nodes increases, the reduction effect of the response time of PERB CAC becomes large. Figure 4 shows the 99.9% response time value of CAC systems in multiple transit nodes. We set $\overline{t_{arr}} = 1.0$ [sec], and the other conditions are the same as that of one node case as shown in Fig. 3. The response time in multiple transit nodes are evaluated by convolution of each response-time distribution at one node. PERB CAC provides very quick response time for VBR connections even if the network size becomes large.

3.2 Dynamic Characteristics

Dynamic characteristics of R_{max}, R_{min}, and the actual residual bandwidth R_{actual} was obtained by call-

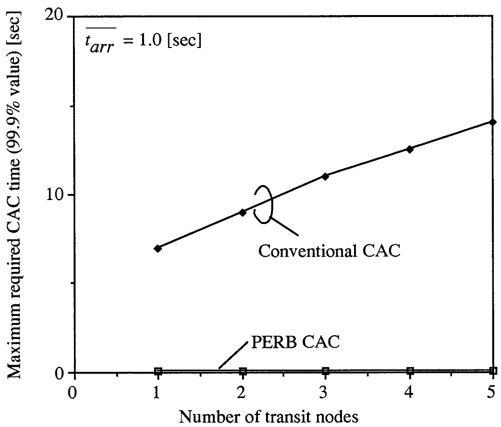

Fig. 4 Response time in CAC systems for multiple nodes.

level simulation as shown in Fig. 5. R_{actual} is defined as the maximum bandwidth at which a connection can be accepted while satisfying the cell-loss objective, $CLR_{obj} = 10^{-9}$ for VBR connections. R_{actual} was obtained by binary-search sufficiently iterated calculation as described in Sect. 2.2. In this simulation, VBR connections and ABT blocks are accommodated into a single VP. We set $C = 150$ [Mbps], $P_i(VBR) = 6.0$ [Mbps], $A_i(VBR) = 0.6$ [Mbps], and $P_i(ABT) = 20$ [Mbps]. To make the dynamic characteristics of PERB CAC clear, we dealt with one connection type and one block type. We assume that the interarrival time of new connection and block requests t_{arr} and the connection and block holding time t_{hold} are distributed exponentially. These average values are $\overline{t_{arr}(VBR)} = 3.0$ [sec], $\overline{t_{arr}(ABT)} = 20$ [sec], $\overline{t_{hold}(VBR)} = 180$ [sec], $\overline{t_{hold}(ABT)} = 20$ [sec]. In cell-loss evaluation for VBR connections for both PERB CAC and the conventional CAC, we used the buffer-less fluid cell-loss estimation scheme [1]. The required cell-loss evaluation time is also assumed to be exponentially distributed as the average $\overline{t_{est}} = 0.5$ [sec].

As you can see in Fig. 5, the actual residual bandwidth always lies between R_{max} and R_{min}. This means that PERB CAC works conservatively. When ABT blocks are accepted and released, all three values, R_{max}, R_{min} and R_{actual}, are just decreased by $P_{req}(ABT)$ and just increased by $P_{dis}(ABT)$. This is because the bandwidth for ABT is allocated deterministically. On the other hand, when VBR connections are accepted and released, shifted values of R_{max} and R_{min} are different from that of R_{actual}. This is because the estimated residual bandwidth is shifted conservatively in Phase 2 and Phase 3. Note that R_{min} is close to R_{actual} as long as Phase 1 continues. As a result, statistical bandwidth allocation for VBR connections is achieved.

When $\overline{t_{est}}$ is small, R_{min} is more rapidly close to R_{actual}. Figure 6 shows the dynamic characteristics of the estimated residual bandwidth at $\overline{t_{est}} = 0.2$ [sec].

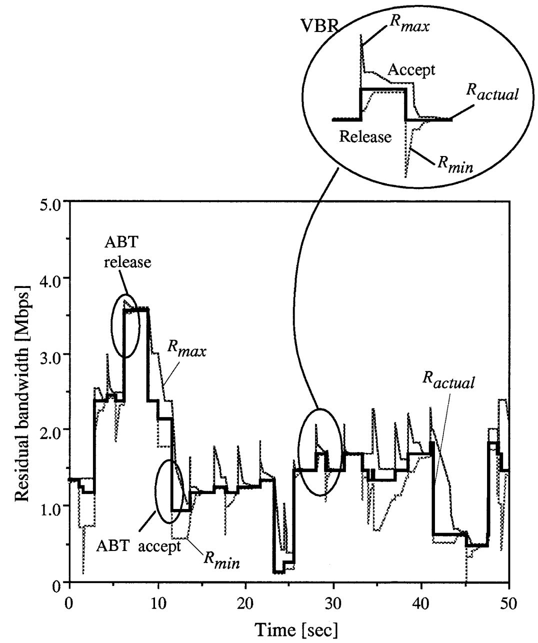

Fig. 5 Dynamic characteristics of estimated residual bandwidth ($\overline{t_{est}} = 0.5$ [sec]).

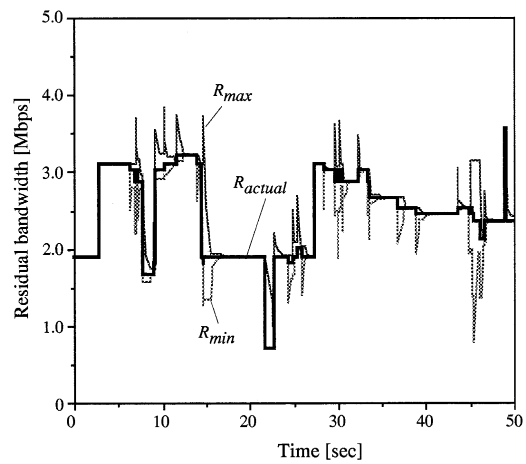

Fig. 6 Dynamic characteristics of estimated residual bandwidth ($\overline{t_{est}} = 0.2$ [sec]).

The difference between R_{actual} and R_{min} at $\overline{t_{est}} = 0.2$ [sec] in Fig. 6 is smaller than that at at $\overline{t_{est}} = 0.5$ [sec] in Fig. 5. More binary-search iteration in Phase 1 makes the difference small. On the other hand, when $\overline{t_{est}}$ becomes large, R_{min} is slowly close to R_{actual} as shown in Fig. 7.

3.3 Accuracy

The accuracy of the estimated residual bandwidth in PERB CAC depends on the relationship between the interarrival time of the connection requests t_{arr} and

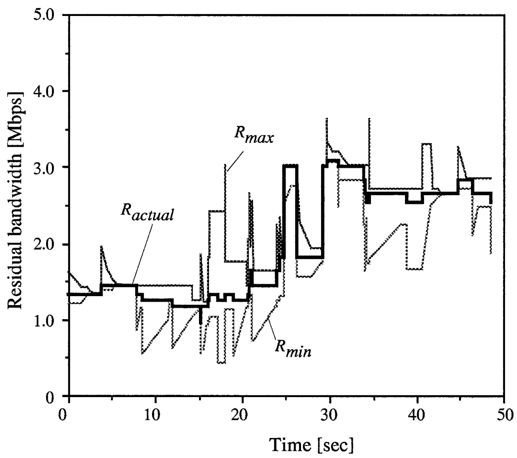

Fig. 7 Dynamic characteristics of estimated residual bandwidth ($\overline{t_{est}} = 1.0$ [sec]).

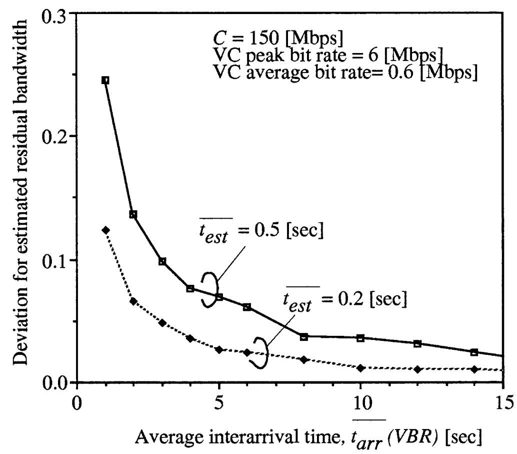

Fig. 8 Accuracy of estimated residual bandwidth.

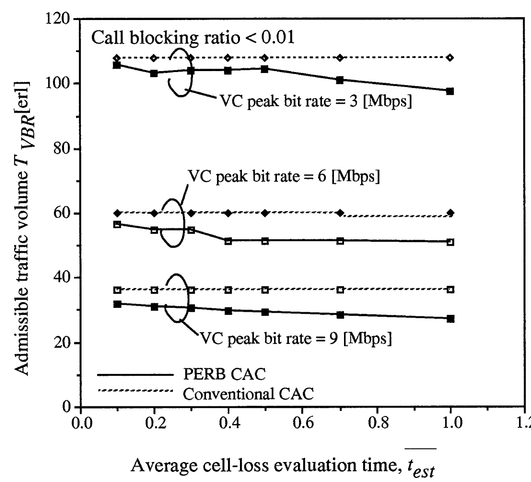

Fig. 9 Admissible traffic volume for VBR service.

the required cell-loss evaluation time t_{est} as described in Sect. 3.2. Figure 8 shows that the deviation of the estimated residual bandwidth D_R decreases as t_{arr} increases and t_{est} decreases. The deviation occurs when VBR connections are accepted and released. Here, only VBR connections are considered in the evaluation for the deviation. D_R is defined as,

$$D_R = \frac{\sum_{j=1}^{N}\{(R_{min}(j) - R_{actual}(j))/R_{actual}(j)\}}{N} \tag{11}$$

where j is an index of the jth new connection request at Phase 2 and N is the number of the samples of new connection requests. We used N large enough to converge D_R. When $\overline{t_{arr}} = 3.0$ [sec] and $\overline{t_{est}} = 0.5$ [sec], D_R is less than 10%. In the same situation, the CAC response time t_{res} of the conventional CAC scheme amounts to 4.0 [sec] while that of PERB CAC is only about 0.1 [sec], as shown in Fig. 3. Therefore, PERB CAC provides a good approximation of residual bandwidth while it lowers the connection set-up time.

3.4 Admissible Traffic Volume

3.4.1 VBR Service

Admissible traffic volume for VBR connections is shown in Fig. 9. Admissible traffic volume for VBR connections T_{VBR} [erl] is defined as the maximum traffic volume that satisfies the condition that the call blocking ratio is less than 0.01. T_{VBR} is obtained by $\overline{t_{hold}}(VBR)$ / $\overline{t_{arr}}(VBR)$. We set $\overline{t_{hold}}(VBR) = 180$ [sec], $A_i(VBR) = 0.6$ [Mbps] and $P_i(VBR) = 3$, 6 and 9 [Mbps]. We use the CAC scheme presented in [1] as the conventional CAC as described before. We emphasize that, in evaluating the cell-loss for VBR connections for both PERB CAC and the conventional CAC, the same buffer-less fluid cell-loss estimation scheme is used [1].

The admissible traffic volume of PERB CAC is smaller than that of the conventional CAC. This difference occurs because of two reasons. First, there are deviations of the estimated residual bandwidth as described in Sect. 3.3. Second, PERB CAC judges acceptance for VBR connections by using only its peak bit rate in Phase 2. The difference between PERB CAC and the conventional CAC also depends on burstiness of VBR connections. When the burstiness becomes strong, the difference increases.

3.4.2 VBR and ABT Services

Figure 10 compares the admissible traffic volume region obtained using the proposed bandwidth management scheme based on PERB CAC and with the conventional scheme. In the proposed scheme, VBR and ABT

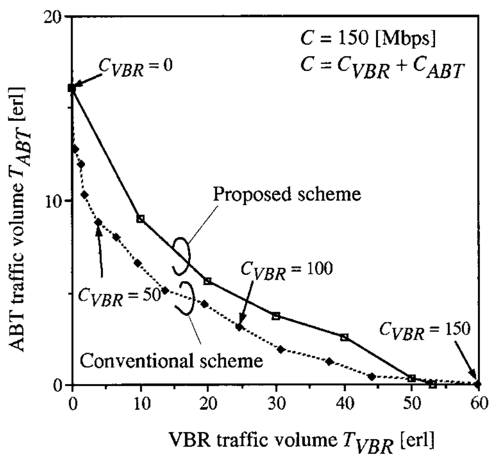

Fig. 10 Admissible traffic volume region for VBR and ABT services.

services are accommodated in a single VP as shown in Fig. 2, while in the conventional scheme, these services are accommodated in separated VPs whose capacities are C_{VBR} and C_{ABT} as shown in Fig. 1. Here, $C = C_{VBR} + C_{ABT}$. The admissible traffic volume for VBR service T_{VBR} [erl] and ABT service T_{ABT} [erl] is defined as the maximum of each traffic volume that satisfies the condition that both call blocking ratios are less than 0.01. We set $\overline{t_{hold}}(VBR) = 180$ [sec], $\overline{t_{hold}}(ABT) = 30$ [sec], $A_i(VBR) = 0.6$ [Mbps].

The admissible traffic volume region obtained by the proposed scheme is larger than that obtained by the conventional scheme for the most part. This is because the proposed scheme can achieve statistical multiplexing gain on the connection level and the block level. Since, at $C_{VBR} = 0$ [Mbps], only ABT blocks are accommodated, T_{ABT} obtained by the proposed scheme is the same as that obtained by the conventional scheme. At $C_{VBR} = C$, only VBR connections are accommodated. In this case, T_{VBR} obtained by the proposed scheme is smaller than that obtained by the conventional scheme as described in Fig. 9.

We note that the results of the conventional scheme shown in Fig. 10 can be obtained only when each traffic demand is known in advance and VPs are appropriately separated. The conventional scheme may need sensitive VP capacity control according to traffic demand fluctuation. This will lead to an increase in network operation cost. On the other hand, in the proposed scheme, VP capacity control is relaxed even when traffic demand fluctuates.

4. Conclusions

This paper has presented a high-speed CAC scheme, called PERB CAC. This scheme estimates the residual bandwidth in advance by generating virtual requests for connection. When an actual new VBR connection or ABT block request occurs, PERB CAC can instantaneously judge if the required bandwidth is larger than the estimated residual bandwidth. PERB CAC provides very rapid response time both for statistical and deterministic bandwidth allocation services, while keeping statistical multiplexing gain for the former service.

Numerical results indicate that PERB CAC provides reasonably accurate and conservative values of residual bandwidth. Furthermore, since only the residual bandwidth is required, large memory tables are not needed. Moreover, by using PERB CAC, both statistical and deterministic bandwidth allocation services are able to be accommodated into a single VP. Therefore, VP capacity control is more relaxed than is true with conventional VP-separation management. This is another merit of PERB CAC. Therefore, PERB CAC can realize high-speed connection set-up while utilizing network resources in a cost-effective manner.

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