LETTER

Realtime Cell-Loss Ratio Evaluation Using Allan Variance

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SUMMARY This paper describes a realtime cell-loss ratio evaluation algorithm for ATM connection admission control. This algorithm gives an efficient evaluation of cell-loss ratio from traffic descriptors such as peak cell rate, sustainable cell rate, and maximum burst size for each VC. The most remarkable characteristics of this algorithm are that it terminates within a millisecond and that its time is independent of both the number of VCs and the capacity of a cell buffer.

key words: *ATM, CAC, CLR, Allan variance*

1. Introduction

Since Asynchronous Transfer Mode (ATM) networks support many types of traffic generated by a variety of applications, they must be able to guarantee Quality of Service (QoS) for these types of traffic. Cell-Loss Ratio (CLR) is one of the most important QoS parameters. So, it is required that a realtime evaluation of CLR under the environment that heterogeneous traffic types are multiplexed.

This paper describes burstiness caused by Variable Bit Rate (VBR) traffic by using a notion of the Allan variance of VP utilization. Using useful properties obtained from the Allan variance, we show a realtime CLR evaluation algorithm for VBR, based on Peak Cell Rate (PCR), Sustainable Cell Rate (SCR), Maximum Burst Size (MBS), and the capacity of a cell buffer. The most remarkable characteristics of this algorithm are that it terminates within a millisecond and that its time is independent of both the number of VCs and the capacity of a cell buffer. These characteristics are necessary for Connection Admission Control (CAC) application.

2. Terminology

Each transmission link can accommodate one or more VPs. Each VP is assumed to have a rigid boundary, or in other words, each VP is assigned a fixed bandwidth. The transmission link may be used as one VP.

In this paper, time is divided into fixed-length slots, each of which corresponds to an ATM cell's transmission time. The slot length is defined as L/C, where L is the cell length [bits] and C is the capacity of the VP [bps]. We adopt the slot length as a unit of time.

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Each VC in the VP is indexed by i. Notations of traffic parameters, used in this paper, are listed in Table 1.

3. Allan Variance of VP Utilization

Allan variance, originally introduced as a fluctuation index for frequency of an atomic clock [6], is defined as the variance of finite-time average. It is closely related to the spectrum analysis using the Fourier transformation [7].

Let us consider a observation of VP utilization during a finite time period t. If t is large, the observed value $X(t)$ is close to the real one $E[X]$. For small t, however, the observed values are fluctuated around $E[X]$, in general. This is caused by burstiness of traffic. We describe the burstiness using Allan variance such as

$$E[(X(t) - E[X])^2],$$

where this is a function of t.

There are n VBR VCs in a VP. Then we have three parameters PCR P_i, SCR S_i, and MBS B_i for each VC i $(i = 1, 2, \ldots, n)$. We assume that the traffic characteristics of the VBR VCs comply with the GCRA specified by the ATM Forum [1], [2].

For the worst case evaluation of Allan variance, source traffic of each VBR VC i is limited to satisfy the following three conditions

- Actual maximum cell rate is PCR, P_i,
- Actual average cell rate is SCR, S_i, and
- For arbitrary time t_0, the maximum length of a burst at the PCR is always included in $t > t_0$.

We call the traffic patterns ceiling patterns, and define the set of all ceiling patterns as $\mathcal{S}_i$.

For a ceiling pattern $\varsigma \in \mathcal{S}_i$, we define the average utilization of the VP caused by the ith VBR VC, and observed during successive time $[0, t)$, to be $X_i(t, \varsigma)$. Allan variance [4] of the VP utilization with respect to the ith VBR VC is defined as

Table 1 Notations.

P_i	Peak Cell Rate (PCR) of the ith VBR VC.
S_i	Sustainable Cell Rate (SCR) of the ith VBR VC.
B_i	Maximum Burst Size (MBS) of the ith VBR VC.

$$\sigma_i^2(t) := \sup_{\varsigma \in \mathcal{S}_i} E\left[(X_i(t,\varsigma) - S_i)^2\right]. \tag{1}$$

From [4], $\sigma_i^2(t)$ in asymptotic regions $t \ll 1$ and $t \gg 1$ can be evaluated by using only GCRA parameters of the ith VC, and for $t \gg 1$,

$$\sigma_i^2(t) = \mathcal{O}(t^{-2}). \tag{2}$$

In the case that there is only one VC in the multiplexer, no deformation of traffic pattern occurs. Therefore, the Allan variance $\sigma_i^2(t)$ with respect to ith VC is approximately denoted as

$$\sigma_i^2(t) = \begin{cases} S_i\,(1 - S_i), & (t \leqq T_i), \\ \alpha_i\, t^{-2}, & (T_i < t), \end{cases} \tag{3}$$

where

$$\alpha_i = \inf\{\, \xi \mid \sigma_i^2(t)\, t^2 \leqq \xi \} \tag{4}$$

$$\leqq \frac{1}{4} B_i^2, \tag{5}$$

$$T_i = \sqrt{\frac{\alpha_i}{S_i\,(1 - S_i)}}. \tag{6}$$

Next, we consider Allan variance of the VP utilization $\sigma^2(t)$ with respect to all aggregated VBR VCs accommodated in the VP. From [4] and [5], asymptotic behaviors of $\sigma^2(t)$ are derived as follows: In the case of asymptotic region $t \ll 1$,

$$\sigma^2(t) = C_1\,(1 - C_1),\ (t \ll 1), \tag{7}$$

where, we define

$$C_1 := \sum_{i=1}^{n} S_i. \tag{8}$$

In the case of asymptotic region $t \gg 1$,

$$\sigma^2(t) \leqq \alpha\, t^{-2},\ (t \gg 1), \tag{9}$$

where $\alpha := \sum_{i=1}^{n} \alpha_i$. Hereafter, we assume, for the worst case, that (9) is equality, and

$$\alpha = \frac{1}{4} \sum_{i=1}^{n} B_i^2. \tag{10}$$

The Allan variance $\sigma^2(t)$ is, therefore, approximately expressed as

$$\sigma^2(t) = \begin{cases} C_1\,(1 - C_1), & (t \leqq T), \\ \alpha\, t^{-2}, & (T < t), \end{cases} \tag{11}$$

where

$$T = \sqrt{\frac{\alpha}{\rho\,(1 - \rho)}}. \tag{12}$$

Here, we consider a physical meaning of the time T, briefly. For simplicity, let us consider the situation that there is enough capacity of a cell buffer and no cell-loss occurs. In general, traffic patterns of input/output at an ATM switch is different caused by deformation of traffic pattern at the multiplexer in the ATM switch. Thus if we count the numbers of incoming/outgoing cells during a finite time interval t, these observed values are different, in general.

If the input traffic patterns from these VCs are not deformed at the multiplexer in the ATM switch, and are mutually independent, Allan variance of the aggregated traffic is denoted as

$$\widetilde{\sigma}^2(t) = \begin{cases} \displaystyle\sum_{i=1}^{n} S_i\,(1 - S_i), & (t \leqq \widetilde{T}), \\ \alpha\, t^{-2}, & (\widetilde{T} < t), \end{cases} \tag{13}$$

where

$$\widetilde{T} = \sqrt{\frac{\alpha}{\displaystyle\sum_{i=1}^{n} S_i\,(1 - S_i)}}. \tag{14}$$

However, actual Allan variance of aggregated traffic is expressed as $\sigma^2(t)$ by including the effect of traffic deformation. Two time points T and $\widetilde{T}$ always satisfy

$$\widetilde{T} \leqq T, \tag{15}$$

where equality is valid if and only if there is one VC in the multiplexer. The inequality is caused by the deformation effect of traffic. Note that, from approximations (11) and (13), $\sigma^2(t)$ and $\widetilde{\sigma}^2(t)$ are identical in $T < t$. We can interpret that this means T denotes the maximum length of the busy period at the multiplexer.

4. Realtime CLR Evaluation Algorithm

The realtime CLR evaluation algorithm studied in [3] gives an accurate upper-bound for CLR when only PCR and SCR of each VC are available. This upper-bound corresponds to a situation such that each VC has very long burst with respect to the capacity of a cell buffer. The algorithm, therefore, can not take the relation between MBS and the capacity of a cell buffer into consideration. This section shows a new realtime CLR evaluation algorithm taking the relation between MBS and the capacity of a cell buffer into consideration. To this end, our approach is to extend the algorithm shown in [3] using Allan variance, but then the characteristic of realtime calculation is remained in a new algorithm.

For VBR VCs, let us define the following parameters:

$$C_2 := \sum_{i=1}^{n} S_i\,(\widetilde{P}_i - S_i), \text{ and} \tag{16}$$

$$C_3 := \sum_{i=1}^{n} S_i\,(\widetilde{P}_i - S_i)\,(\widetilde{P}_i - 2S_i), \tag{17}$$

where

$$\widetilde{P}_i := \begin{cases} P_i, & (\Gamma P_i < B_i), \\ \dfrac{B_i}{\Gamma} + S_i \dfrac{\Gamma P_i - B_i}{\Gamma P_i}, & (\Gamma P_i \geqq B_i), \end{cases} \tag{18}$$

and, Γ is a constant such that

$$\Gamma := K + 1, \tag{19}$$

when the output buffer in an ATM switch have K cell places. Physical meanings of these parameters are as follows. $\Gamma \widetilde{P}_i$ denotes the maximum number of arriving cells during Γ slots. So, $\widetilde{P}_i$ is a cell rate which is a ratio of the maximum number of arriving cells during Γ slots to Γ. Then, C_2 and C_3 mean normalized values of the second and the third cumulants of the number of arriving cells during Γ slots. In this connection, C_1 of Eq. (8) means the first cumulant of the number of arriving cells during Γ slots.

In addition, we define

$$C_L := \frac{-F_N + \sqrt{F_N^2 + G_N}}{2H_N(N+1)}, \tag{20}$$

where

$$H_N = 1 - \frac{1 + \sqrt{3 - 2/N}}{N - 1}, \tag{21}$$

$$F_N = C_2 \, H_N \, (1 - C_1), \tag{22}$$

$$G_N = 4 \, C_2^3 \, H_N \, (1 - H_N) \, (N + 1), \tag{23}$$

and $N \, (\geqq 4)$ is the number of iterations determined from the target termination time for the calculation. As shown in [3], parameter C_L guarantees that N iterations is sufficient for evaluating CLR. From C_3 and C_L, we define D as

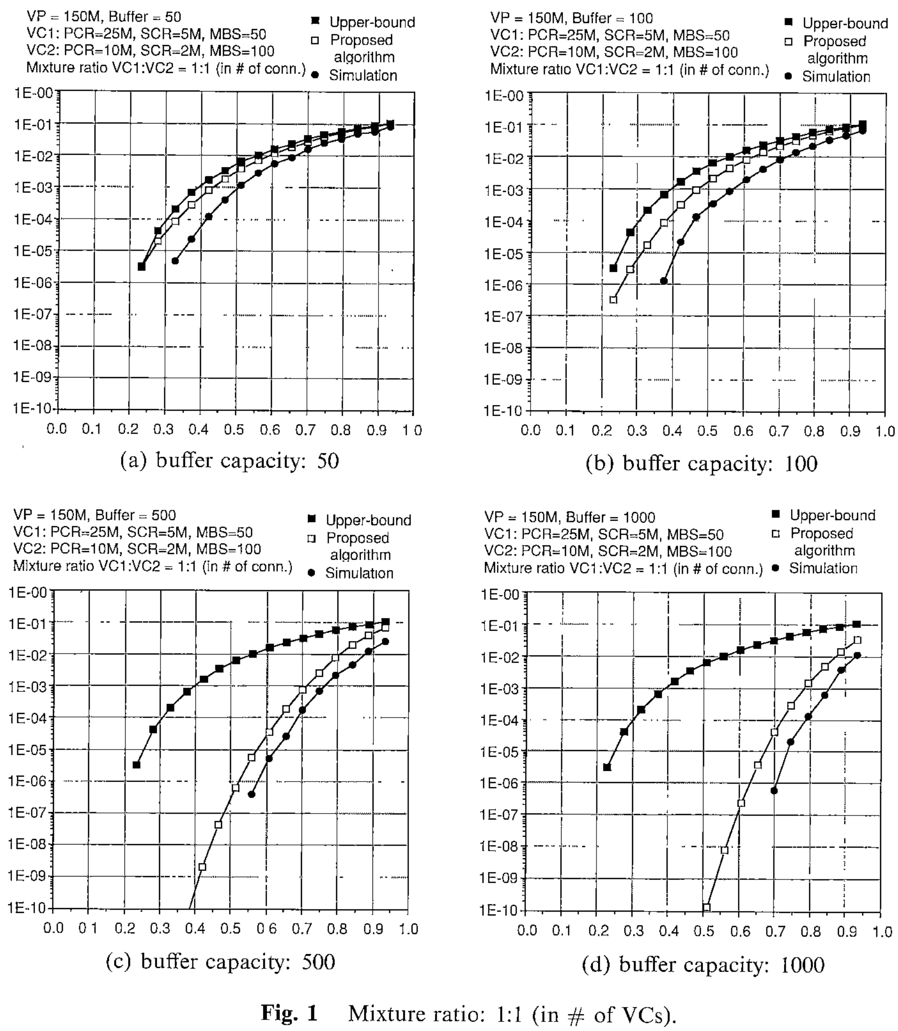
$$D := \max(C_3, C_L). \tag{24}$$

Thus, we obtain CLR evaluation B by the following formula

$$B = \frac{R}{C_1} \exp(-A/R) \times \sum_{k=0}^{N-1} (M - \Lambda + k) \frac{(A/R)^{M+k}}{(M+k)!}, \tag{25}$$

where

$$R := \frac{D}{C_2}, \; A := \frac{C_2^2}{D}, \; \delta A := C_1 - A, \tag{26}$$



(a) buffer capacity: 50

(b) buffer capacity: 100

(c) buffer capacity: 500

(d) buffer capacity: 1000

Fig. 1 Mixture ratio: 1:1 (in # of VCs).

and, using T obtained from the Allan variance,

$$\Lambda := \frac{1+\min(1,\Gamma/T)\,(1-C_1)-\delta A}{R}, \quad (27)$$

$$M := \lceil \Lambda \rceil, \quad (28)$$

where $\lceil x \rceil$ denotes the minimum integer greater than or equal to x. Here, a physical meaning of Λ is a factor for correcting VP capacity. If busy period T is very longer than the capacity of a buffer, then $\Gamma/T \cong 0$ and it is reduced to

$$R\Lambda = 1 - \delta A,$$

as the same in [3]. This is the case for long burst-length limit based only on PCR and SCR or for small buffer-capacity limit. In this case, if the number of cells arriving during a Γ-slot interval is greater than Γ, arriving cells exceeding Γ is considered to be lost. In general case, however, although the number of cells arriving a during Γ-slot interval exceeds Γ, all the exceeded cells are not lost. $\min(1,\Gamma/T)\,(1-C_1)$ in (27) describes how many cells can be carried forward to the next Γ-slot interval.

In the CLR evaluation formula (25), however, it is necessary to calculate the factorial. In order to achieve realtime evaluation, this can be done by using Stirling's law,

$$\log m! \cong (m+1/2)\log m - m + (1/2)\log 2\pi. \quad (29)$$

Accuracy of evaluation formula (25) is discussed in the section below. This algorithm terminates within constant time independent of both the number of VCs and the capacity of the cell buffer.

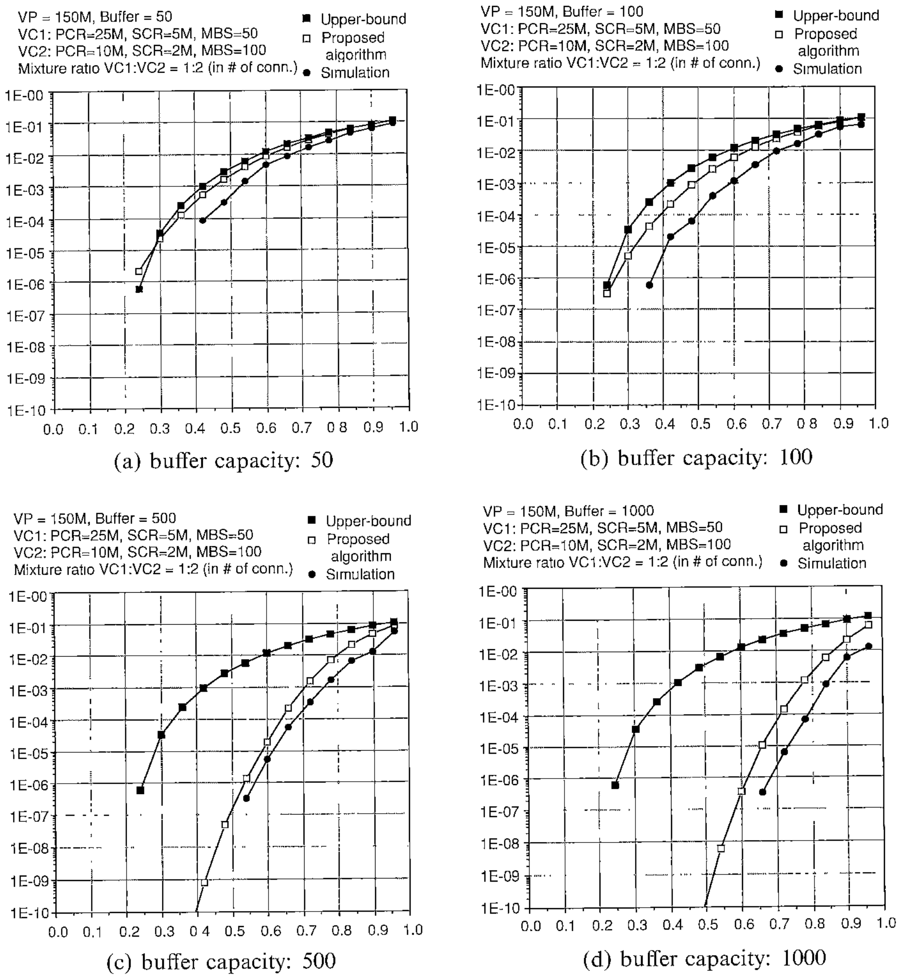
5. Numerical Examples

This section examines both the accuracy of our evaluations and the calculation time for the proposed CLR evaluation algorithm.

5.1 Accuracy of the CLR Evaluation Formula

Here we show an accuracy of evaluation formula (25) by comparing with simulation results.

Let us consider the following two evaluations:



(a) buffer capacity: 50

(b) buffer capacity: 100

(c) buffer capacity: 500

(d) buffer capacity: 1000

Fig. 2 Mixture ratio: 1:2 (in # of VCs).

- Upper-bound CLR evaluation based only on PCR and SCR.
  This is based on the nonparametric approach shown in [8] and gives an exact upper-bound for CLR when only PCR and SCR are available. Realtime CLR evaluation shown in previous study [3] is also based on this approach.

- Proposed evaluation.
  Realtime CLR evaluation formula (25) based on PCR, SCR, MBS, and the capacity of a cell buffer.

In addition, traffic model of each VC, used in simulation, is an ON-OFF process modulated by Markov process, such that cell rate during ON-period is PCR, cell rate during OFF-period is 0, the average length of ON-period is MBS, and the average length of OFF-period is determined by the average cell rate to be SCR.

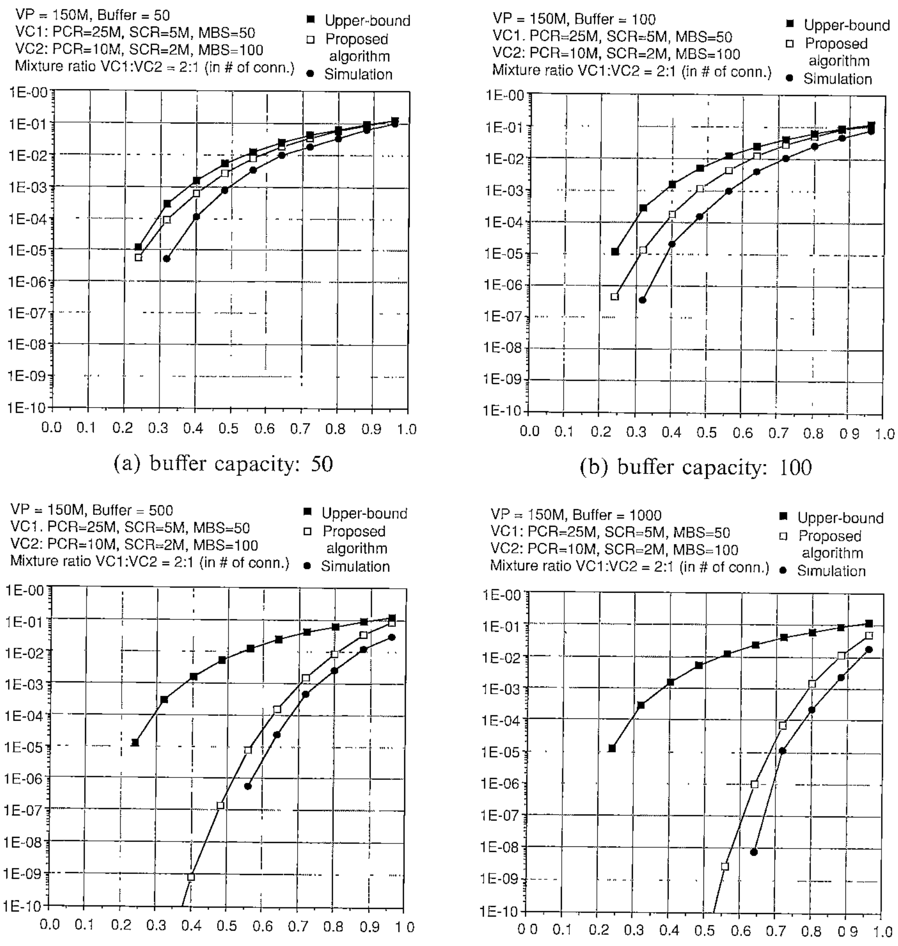
We compare the CLR evaluations and simulation results under the following conditions: There are two types of VCs, VC1 and VC2, such as

- VC1: PCR = 25 Mbps, SCR = 5 Mbps, MBS = 50 cells,
- VC2: PCR = 10 Mbps, SCR = 2 Mbps, MBS = 100 cells,

in a 150-Mbps VP. Mixture ratios of the number of VC1 VCs to that of VC2 VCs are 1:1, 1:2, 2:1. The capacities of buffer are 50, 100, 500, and 1000 cell places.

Figures 1 (a)–(d) show CLR evaluations under the condition that mixture ratio of VCs is 1:1. The horizontal axis denotes VP utilization, and the vertical axis denotes evaluated and simulated CLRs. These buffer capacity have 50, 100, 500, and 1000 cell places, respectively. The proposed evaluation gives accurate and conservative CLRs. Although the upper-bound CLR evaluation gives also accurate and conservative CLRs for small capacities of buffer, for large capacity, it can not gives accurate CLRs. This is because the upper-bound CLR evaluation is based only on PCR and SCR, and it can not take the effects from the relation between MBS and the capacity of a cell buffer into consideration.

Figures 2 (a)–(d) show CLR evaluations under the condition that mixture ratio of VCs is 1:2. The horizontal axis denotes VP utilization, and the vertical axis denotes evaluated and simulated CLRs. These buffer



(a) buffer capacity: 50

(b) buffer capacity: 100

(c) buffer capacity: 500

(d) buffer capacity: 1000

Fig. 3 Mixture ratio: 2:1 (in # of VCs).

Table 2 Calculation time for CLR evaluation.

iterations N	10	20	30
calculation time (msec)	0.7	0.8	1.0

capacity have 50, 100, 500, and 1000 cell places, respectively. The proposed evaluation also gives accurate and conservative CLRs.

Similarly, Figs. 3 (a)–(d) show CLR evaluations under the condition that mixture ratio of VCs is 2:1. The horizontal axis denotes VP utilization, and the vertical axis denotes evaluated and simulated CLRs. These buffer capacity have 50, 100, 500, and 1000 cell places, respectively. The proposed evaluation also gives accurate and conservative CLRs.

5.2 Calculation Time for CLR Evaluation

Supposing CAC applications, we assume that the call processor in an ATM switch is model 68040 with a floating-point co-processor, and its processing rate is 15 Mips. The CLR evaluation algorithm requires a truncation parameter N in (25). This refers to a truncation of summation to the first N terms, and is closely related to the time for CLR evaluation and the accuracy of an evaluated CLR. In applying the CLR evaluation algorithm to CAC, it gives sufficient accuracy when $N \geqq 10$ [3]. This is because (25) remains the same form of CLR evaluation formula in [3]. Table 2 shows the time for the CLR evaluation with respect to $N = 10, 20, 30$. These calculation times are independent of both the number of VCs and the capacity of a cell buffer. The results show that the CLR evaluation process always terminates within a millisecond. These calculation times can be reduced by using a higher speed processor.

6. Conclusion

In this paper, we proposed a realtime CLR evaluation algorithm. Since the algorithm does not require convolution calculations, the time necessary for CLR evaluation is short and independent of the number of VCs accommodated in the VP. Moreover, the time is also independent of the capacity of a cell buffer by using the Allan variance of VP utilization. These remarkable characteristics are good for application to CAC.

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