EVALUATION OF THREE CAC METHODS: GAUSSIAN APPROXIMATION METHOD, METHOD OF EFFECTIVE BANDWIDTH AND DIFFUSION APPROXIMATION METHOD

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The greatly variable requirements of different applications, particularly those of video and data sources, make high demands on the development of traffic control in ATM networks. Connection admission control is a traffic control function which requires knowledge of traffic behavior, switching architecture, etc. and its impact on Quality of Service (QoS). Development of CAC schemes depends on many factors and it is not possible to have one single universal method suitable for all instances. CAC method must be first verified, if it is suitable as traffic control in ATM node with specific input traffic behavior. In this paper the intensive and weak properties of three CAC methods are presented: Gaussian, effective bandwidth and diffusion approximation method.

Keywords: ATM, connection admission control, statistical CAC methods, Gaussian approximation method, method of effective bandwidth, diffusion approximation method

1 INTRODUCTION TO CAC

Main advantage of ATM technology is hidden in its traffic control functions which are very properly proposed. Connection admission control (CAC) is a very important function in the preventive part of traffic control. This function decides whether or not to allow new connection into multiplex in ATM network. The result is effective bandwidth usage and Quality of Service (QoS) guaranty. The decision is based on the current ATM node and network load, on the available network resources (output link bandwidth capacity, buffer size), on the values of traffic parameters and required QoS characterization of new connection and existing connections. Traffic parameters are *eg* Peak Cell Rate (PCR), Sustainable Cell Rate (SCR) and Maximum Burst Size (MBS). To provide guaranteed QoS, a traffic contract is established during connection setup, which contains a connection traffic descriptor and conformance definition between the network and the user [2]. QoS is often formulated in terms of network performance parameters: Cell Loss Ratio (CLR), Cell Delay Variance (CDV) and Maximum Cell Transfer Delay (MaxCTD). In this paper, CAC methods in the case of new connection acceptance are bound with CLR estimation. Our assumption is that CDV and MaxCTD will be satisfied with a proper method of buffer allocation [1, 2].

2 ATM FEATURES IMPORTANT FOR CAC

CAC method is a tool for CAC functionality. Excellent proposition of CAC method must take many factors into account. There are several ATM features which must be implicitly taken into account:

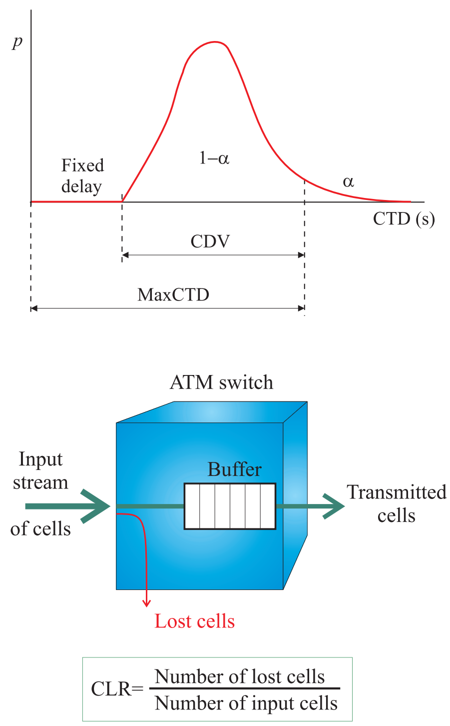

Fig. 1. QoS parameters: a) Cell Delay Variation b) Cell Loss Ratio.

- CAC methods are dependent on the ATM node architecture. For proper CAC functionality, buffer size, cells queuing method in buffer, number of input and output links, etc. must be taken into account [1, 2].

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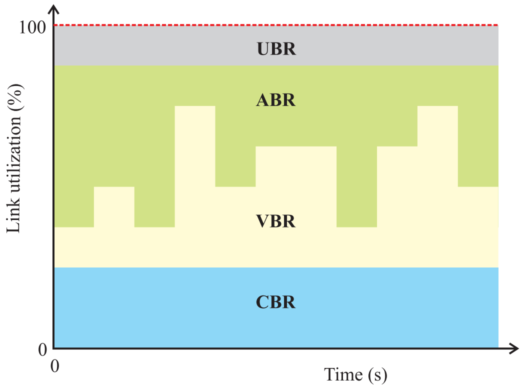

Fig. 2. ATM service categories.

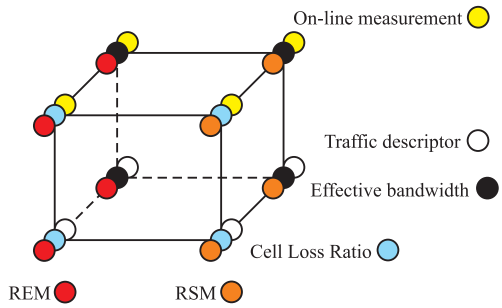

Fig. 3. Classification of CAC methods.

- There are many services in ATM, so they are divided into five categories (see Fig. 2): Constant Bit Rate (CBR), Variable Bit Rate (VBR) in real time or non-real time, Available Bit Rate (ABR) and Unspecified Bit Rate (UBR) [10]. Each category has different requirements on QoS.
- Typical ATM source can transmit at any cell rate due to the selected category, in the traffic flow there can be cell burstiness and fluctuations in cell rate. Traffic source's description is related to the traffic parameters and traffic model specification. The basic traffic models are with constant, variable and on-off traffic [2, 11].

3 BASIC PRINCIPLES FOR CAC METHODS

The task of CAC is seemingly simple and can be formulated as follows: Suppose that there are N connections in multiplex, the output link bandwidth capacity is C. The probability that the current cell rate of N connections exceeds link capacity C is lower than ε value. If $r_i(t)$ is the current cell rate for ith connection, then CAC task is given by:

$$P\Big(\sum_{i=1}^{N} r_i(t) \geq C\Big) < \varepsilon\,. \qquad (1)$$

Because of large variety of traffic sources, CAC methods are based on many principles and approximations *eg* stationary, effective bandwidth, fluid flow, self similarity, Markov chains *etc* [7]. Some of the CAC methods exploit on-line traffic measurements or analyze the buffer load status. They require a corresponding traffic mechanism to ensure this specific functionality and can therefore increase expenses.

The common classification of CAC methods is shown in Fig. 3. The first basis is whether CAC method takes into account the buffer effect. Methods in which the buffering effect is considered are called rate-sharing multiplexing (RSM) methods. If we consider RSM method, we need to model an appropriate queuing method at the output link buffer. They are highly efficient, but require a fair amount of processing power. Those in which the buffering effect is not considered are called rate-envelope multiplexing (REM) methods. The output link buffer need not be considered. When the total cell rate of all connections is higher than the output link capacity, excess cells are discarded immediately.

The second basis for classification is whether we evaluate CLR (CLR method) or the effective bandwidth (EB method). In the former case, if requested CLR in QoS objective is higher than evaluated CLR, the connection is accepted; otherwise it is rejected. The strength is their precision in estimation. Its weakness is fair amount of processing. In the case of EB method, if sufficient bandwidth exists to support the effective bandwidth, the connection is admitted; otherwise it is rejected. The strength of EB method is simplicity in the case of admission decision.

The third basis is whether a method uses a declared traffic descriptor (traffic descriptor based method) or uses on-line measurement as well (measurement based method). The strength of the traffic descriptor method is that it can guarantee the declared QoS in traffic descriptor. Its weakness is that the efficiency can be low because the user declares upper bound of parameters in the traffic descriptor (*eg* mean SCR and peak cell rate PCR). In the case of measurement based method we can not directly measure CLR. CLR value is very small and measurement requires a fair amount of transferred cells (approximately 10^{12} cells or more). Therefore we measure the cell stream and calculate the CLR. The strength of the measurement based method is that it does not require an accurate traffic model beforehand.

4 MATHEMATICAL INTERPRETATION OF CAC METHODS

These two principles are the most used ones because of their simplicity and universality — equivalent bandwidth and Gaussian approximation. The third investigated CAC method is the method of diffusion approximation. These methods can be found in [5]. The paper will follow with a short overview of mentioned CAC methods. Connection as on-off source (transmits at rates of PCR or 0 value only) is characterized with ordered triplet (R, r, b) where R is the source peak cell rate, r is the source's average (equivalently sustainable) cell rate, both in cells/sec

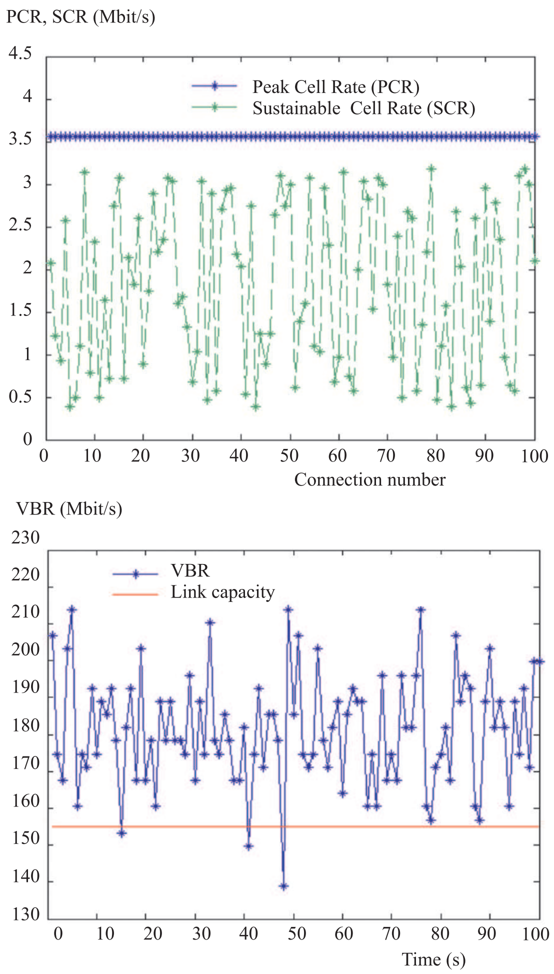

Fig. 4. a) PCR and SCR request b) Data flow

(or bit/sec) and b is the average on (burst) period in seconds (or equivalent cells). The output link capacity is C cells/sec, buffer size is set to B cells and for simplicity all connections request CLR equal to ε. All terms in this paper will be measured in cells, cells/second and seconds unless otherwise stated.

Equivalent bandwidth: This method is quite simple but highly conservative, when the buffer size is small or moderate. The equivalent bandwidth C_i for ith source for the buffer size B is defined as

$$\begin{aligned} C_i &= R_i \frac{y_i - B + \sqrt{(y_i - B)^2 + 4 y_i a_i B}}{2 y_i}, \\ y &= (-\ln \varepsilon)\Big(\frac{1}{\beta_i}\Big)(1 - a_i) R_i, \end{aligned} \tag{2}$$

where R_i is the source peak rate, $b_i = \beta_i^{-1}$ is the average source length of the "on" (burst) period and a_i is source activity factor

$$a_i = \frac{\theta_i}{\theta_i - \beta_i}, \tag{3}$$

where θ_i^{-1} is average length of the "off" period.

This method gives an equivalent bandwidth for the source in isolation and fails to account for the statistical multiplexing gain. A compromise was made in such a way that the required bandwidth for N sources equals

$\min\{C_e, C_g\}$ where,

$$C_e = \sum_{i=1}^{N} C_i \text{ and } C_g = \lambda + \sigma\sqrt{-2\ln\varepsilon - \ln 2\pi}, \tag{4}$$

where λ is the total mean rate and σ^2 is the total variance given by equation (5).

Gaussian approximation: This approach is based on zero length buffer assumption; the buffer's capacity to absorb traffic bursts is ignored. Resulting bandwidth can be excessively conservative, when the number N of multiplexed sources is small. If the number of sources N is sufficiently large, the aggregate traffic can be approximated by a Gaussian process with total mean rate and total variance

$$\lambda = \sum_{i=1}^{N} \lambda_i, \quad \sigma^2 = \sum_{i=1}^{N} \sigma_i^2 \quad \text{where}$$
$$\lambda_i = r_i R_i, \; \sigma_i^2 = \lambda_i (R_i - \lambda_i). \tag{5}$$

Using the Gaussian approximation we can estimate the overflow probability and upper bound to cell loss probability (equivalently CLR)

$$\begin{aligned} P_{\text{overflow}} &= P\big(R(t) \geq C\big) \approx \frac{1}{\sqrt{2\pi}} e^{-\frac{(\lambda - C)^2}{2\sigma^2}}, \\ P_{\text{loss}} &= \frac{E\lfloor (R(t) - C)^+ \rfloor}{\lambda} \approx \frac{\sigma}{\lambda\sqrt{2\pi}} e^{-\frac{(\lambda - C)^2}{2\sigma^2}}, \end{aligned} \tag{6}$$

where $R(t)$ is the instantaneous cell arrival rate.

Diffusion approximation: This method uses the statistical bandwidth obtained from a closed-form expression based on the diffusion approximation models. When the number of multiplexed connections is small and the ratio of burst length to buffer size (both in cells) is significantly long, then method's estimation of the required bandwidth can be overestimated.

For N on-off sources we have the total mean rate and total variance using equation (5). The instantaneous variance of cell arrival process α is

$$\alpha = \sum_{i=1}^{N} \lambda_i CV_i^2, \text{ where}$$
$$CV_i^2 = \frac{1 - (1 - \beta_i T_i)^2}{(\beta_i T_i + \theta_i T_i)^2} \text{ and } T_i = \frac{1}{R_i}, \; \beta_i = \frac{1}{b_i}, \tag{7}$$

where $b_i = \beta_i^{-1}$ is the mean "on" period and θ_i^{-1} is the mean "off" period of ith source. Then we get two expressions (one for Finite Buffer and the other for Infinite Buffer model respectively) for the statistical bandwidth

$$C_{\text{FB}} = \lambda - \delta + \sqrt{\delta^2 - 2\sigma^2\omega_1}, \; C_{\text{FB}} = \lambda - \delta + \sqrt{\delta^2 - 2\sigma^2\omega_2}, \tag{8}$$

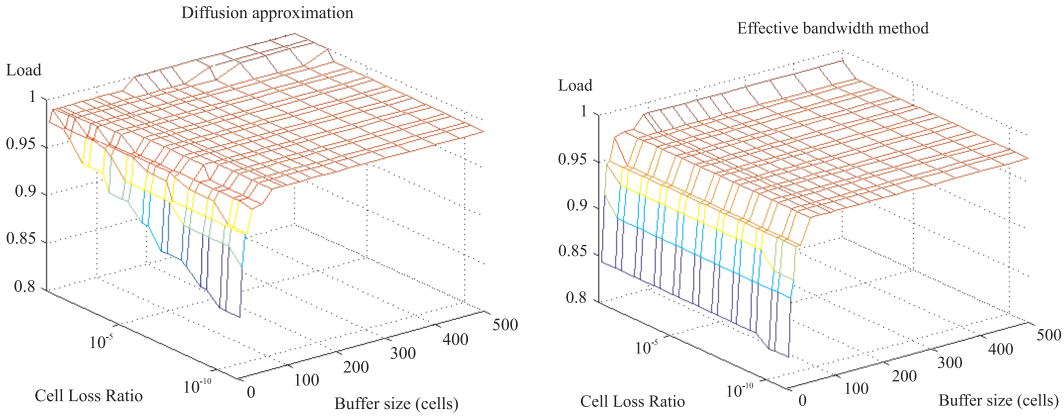

Fig. 5. CAC method simulation: a) Diffusion approximation b) Effective bandwidth.

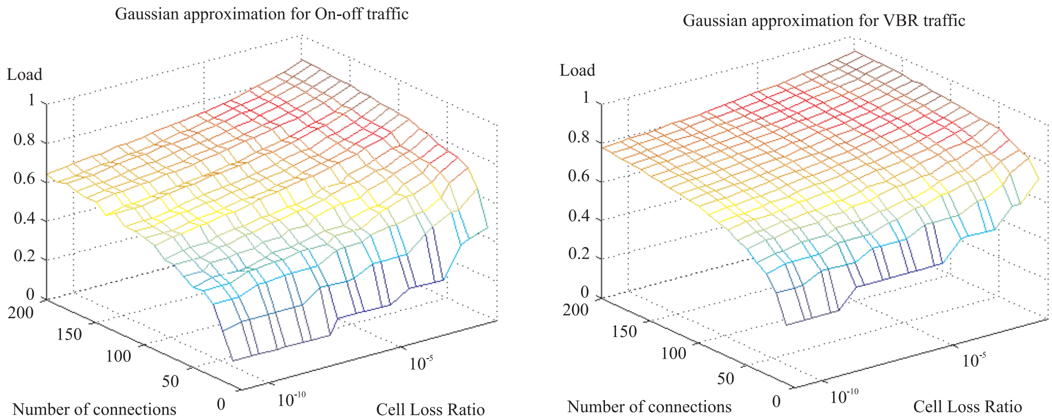

Fig. 6. Gaussian approximation for: a) On-off traffic b) VBR traffic.

where

$$\delta = \frac{2B}{\alpha}\sigma^2 \,, \ \omega_1 = \ln(\varepsilon\sqrt{2\pi}) \text{ and } \omega_2 = \ln(\varepsilon\lambda\sqrt{2\pi}) - \ln(\sigma)\,. \tag{9}$$

As the worst case estimate of the statistical bandwidth it is possible to take

$$\max\{C_{\mathrm{FB}}, C_{\mathrm{IB}}\}\,. \tag{10}$$

5 EVALUATION AND SIMULATION RESULTS

Our simulation objective is to compare the methods' bandwidth estimation efficiency. The first simulation compares the estimation's precision in the case of the effective bandwidth and diffusion approximation methods and eventually their dependence on parameters:

- buffer size B (20 values from interval $\langle 5, 500\rangle$ cells),
- CLR parameter (20 values from interval $\langle 5\times, 10^{-11}\rangle$).

The output link capacity is set to 155 Mbit/s, there are 100 on-off connections in multiplex. Their peak cell rate is uniformly distributed, for ith connection we get

$$PCR_i = \frac{C}{N}k\,, \tag{11}$$

where N stands for the number of connections and k is a constant set to exceed output link capacity when aggregating connections altogether. Burstiness (or the ratio of the peak to the average rate) varies in range from 1.1 to 10 due to SCR_i value for ith connection (see Fig. 4).

The result (see Fig. 5) plots real load which is admitted with a particular CAC method. The traffic on-off model is the same in both cases; we can only see method's admission dependence on the B and CLR request. Comparing these two methods we can see that the effective bandwidth method estimation is more conservative. Moreover, the effect of the buffer size is the most significant; we can also see low link utilization in the case of a very small buffer size.

In the case of Gaussian approximation, this CAC method is proposed for buffer less switching architecture only. The second simulation tries to catch the method's dependence on the number of connections N and requested CLR. Two traffic models are used: on-off and variable bit rate traffic model (VBR source transmits at various rates ranging from 0 to PCR).

As we can see (Fig. 6), the Gaussian approximation method is more conservative in controlling on-off traffic sources. Traffic aggregation in the case of VBR traffic sources gets a Gaussian probability distribution of the cell rates sooner than in the case of on-off traffic sources. In both cases, the effect of N and CLR is clear: the more connections we have in multiplex, the better link utilization; if the QoS requirements are higher (lower CLR) the connection needs a higher statistical bandwidth.

6 CONCLUSION

Admission control is a very useful tool for the network operator. It allows effective link utilization with QoS guaranty. Without doubts, CAC function will be an important part in evolution of the next generation networks. The question, how to choose suitable CAC method as admission control, is crucial for effective exploitation of CAC function. In this paper, we compare three statistical CAC methods providing their suitability as control for specific traffic.

¿From the results of our simulations and admission control experiments with three admission control methods, we make the following observations:

- Both methods of effective bandwidth and diffusion approximation are suitable as admission control for on-off traffic. The admission region for ATM switch with a buffer size less than approximately 100 cells is very conservative in the case of the method of effective bandwidth. In this case, the resulting load can be very low. When we want a better link utilization, it is better to use diffusion approximation method for admission control.
- The method of Gaussian approximation is suitable for controlling both traffic types: on-off and variable bit rate traffic. We can see that method's estimation is better in the case of VBR traffic. The cell rate probability distribution of super positioned sources converges more quickly to the Gaussian probability density function in the case of variable bit rate sources because of their "smoother" probability distribution. If there is a higher number of sources in multiplex, their common probability distribution better fits the shape of the Gaussian probability density function. That is why it is better for this approach, when there are more connections in multiplex.

As we can see from these experiments, it is not easy to consider, which method is suitable as admission control in the given network environment. Furthermore, there is not only estimation dependence on the presented parameters. We used only basic traffic models and simplified ATM switch model, in real conditions we must investigate the effect of specific, in most cases more complex traffic and switching architectures on method's estimation. It is impossible to propose an accurate and universal CAC method for all traffic conditions. That is why CAC methods are the field of study for many researches.

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