Statistical CAC Methods in ATM

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Abstract. *Admission control is a very useful tool for a network operator. It enables effective link utilization with QoS guaranty. Without doubts, CAC function will be important part in evolution of 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: Method of Effective Bandwidth, Diffusion Approximation Method and Gaussian Approximation Method.*

Keywords

Connection Admission Control, Method of Effective Bandwidth, Diffusion Approximation Method, Gaussian Approximation Method.

1. Introduction

Connection admission control (CAC) is a traffic control function, which decides whether or not to allow a new connection into multiplex in ATM network. 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 Quality of Service (QoS) characterization of the new connection and the existing connections. The traffic parameters are e.g. Peak Cell Rate (PCR), Sustainable Cell Rate (SCR) and Maximum Burst Size (MBS). To provide the 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. The QoS is often formulated in the 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 the new connection acceptance are bound with CLR estimation. Our assumption is that CDV and MaxCTD for real-time services will be satisfied with a small buffer size and proper method of buffer allocation [1,2]. If a simple FIFO queuing scheme is used, the worst case estimation for latency and jitter as a ratio of the buffer size (in cells) to the output link capacity (in cells/s) can be used.

2. Requirements on CAC Methods

Main CAC function is realized by using properly created CAC method. In CAC method's acceptance decision, several ATM features must be taken into account.

- 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].
- There are many services in ATM, so they are divided into 5 categories: 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 having 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 with the traffic parameters and a traffic model specification. The basic traffic models are with constant, variable and on-off traffic [2,11].

3. Classification of CAC Methods

CAC methods are based on many principles and approximations e.g. stationary, effective bandwidth, fluid flow methods etc [7]. Some of the CAC methods exploits on-line traffic measurements or analyzes buffer load status. The task of CAC is common and can be formulated as follows: Suppose that there are N connections in multiplex, output link bandwidth capacity is C. Probability, that the current cell rate of N connections exceeds the link capacity C, is lower than ε value. If $r_i(t)$ is the current cell rate for the ith connection, then the CAC task is given by

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

The common classification of the CAC methods is shown in Fig. 1. The first basis is whether the CAC method takes into account buffer effect. Methods in which the buffering effect is considered are called rate-sharing multiplexing (RSM) methods. If we consider a RSM method, we need to model an appropriate queuing method at the output link buffer. They are high 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 does not need to 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 effective bandwidth (EB method). In the former case, if the requested CLR in QoS objective is higher than the 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 a 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.

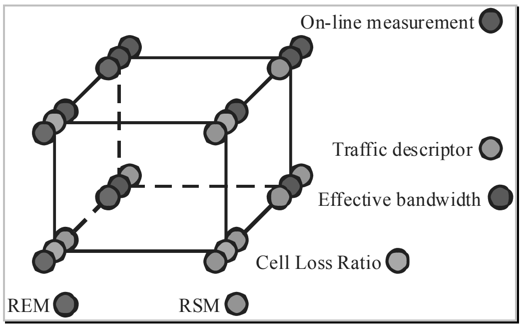

Fig. 1. Classification of CAC methods.

The third basis is whether a method uses a declared traffic descriptor (traffic descriptor based method) or uses an 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 efficiency can be low, because a user declares an upper bound of parameters in traffic descriptor (e.g. mean SCR and peak cell rate PCR). In the case of the 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. Statistical CAC Methods

The following two principles are the most used ones – 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 (or bit/sec) and b is the average on (burst) period in seconds (or equivalent cells). The output link capacity is C cells/s, the 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 except as otherwise stated.

4.1 Method of Effective Bandwidth

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

$$C_i = R_i \frac{y_i - B + \sqrt{(y_i - B)^2 + 4 y_i a_i B}}{2 y_i} \tag{2}$$

where

$$y = (-\ln \varepsilon)\left(\frac{1}{\beta_i}\right)(1 - a_i) R_i \tag{3}$$

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 the source activity factor

$$a_i = \frac{b_i}{b_i + d_i} \text{ where } d_i = \theta_i^{-1} \tag{4}$$

and d_i is the average length of the "off" period. This method gives the equivalent bandwidth for a 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 to

$$\min\{C_e, C_g\} \tag{5}$$

where

$$C_e = \sum_{i=1}^{N} C_i \text{ and } C_g = \lambda + \sigma \sqrt{-2 \ln \varepsilon - \ln 2\pi} \tag{6}$$

where λ is the total mean rate and σ^2 is the total variance given by (7) and (8).

4.2 Gaussian Approximation Method

This approach is based on the zero length buffer assumption; the buffer's capacity to absorb traffic bursts is ignored. The 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 the total mean rate and the total variance

$$\lambda = \sum_{i=1}^{N} \lambda_i, \quad \sigma^2 = \sum_{i=1}^{N} \sigma_i^2 \tag{7}$$

where

$$\lambda_i = r_i R_i, \quad \sigma_i^2 = \lambda_i (R_i - \lambda_i). \tag{8}$$

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

$$P_{overflow} = P(R(t) \geq C) \approx \frac{1}{\sqrt{2\pi}} e^{-\frac{(\lambda - C)^2}{2\sigma^2}}$$

$$P_{loss} = \frac{E\left[(R(t) - C)^+\right]}{\lambda} \approx \frac{\sigma}{\lambda\sqrt{2\pi}} e^{-\frac{(\lambda - C)^2}{2\sigma^2}} \quad (9)$$

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

4.3 Diffusion Approximation Method

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, the statistical bandwidth tends to overestimate the required bandwidth.

For N on-off sources we have the total mean rate and the total variance using equation (7) and (8). The instantaneous variance of cell arrival process α is

$$\alpha = \sum_{i=1}^{N} \lambda_i CV_i^2 \quad (10)$$

where

$$CV_i^2 = \frac{1 - (1 - \beta_i T_i)^2}{(\beta_i T_i + \theta_i T_i)^2} \text{ and } T_i = \frac{1}{R_i}, \beta_i = \frac{1}{b_i}. \quad (11)$$

Then we get the two expressions (one for Finite Buffer and the other for Infinite Buffer model respectively) for the statistical bandwidth

$$C_{FB} = \lambda - \delta + \sqrt{\delta^2 - 2\sigma^2\omega_1},$$

$$C_{IB} = \lambda - \delta + \sqrt{\delta^2 - 2\sigma^2\omega_2} \quad (12)$$

where

$$\delta = \frac{2B}{\alpha}\sigma^2, \quad \omega_1 = \ln\left(\varepsilon\sqrt{2\pi}\right) \quad (13)$$

and

$$\omega_2 = \ln\left(\varepsilon\lambda\sqrt{2\pi}\right) - \ln(\sigma). \quad (14)$$

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

$$\max\{C_{FB}, C_{IB}\}. \quad (15)$$

5. Simulation Results

The first simulation compares the estimation's precision in the case of effective bandwidth and diffusion approximation methods and eventually their dependency on parameters:

- ***Buffer size B:*** 20 values of the interval $\langle 5{,}500 \rangle$ cells).
- ***CLR:*** 20 values of the interval $\langle 5 \cdot 10^{-2}, 10^{-11} \rangle$.

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 the ith connection we get

$$PCR_i = \frac{C}{N} k \quad (16)$$

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

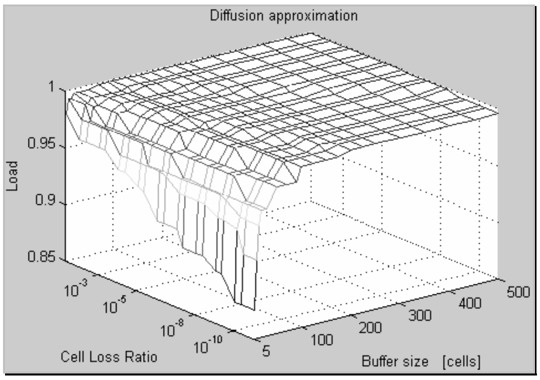

Fig. 2. CAC method simulation: Diffusion Approximation Method.

The result (see Fig. 2 and 3) plot the real load which is admitted with the concrete CAC method. The traffic on-off model is same in both cases; we can only see the method's admission dependency on the B and CLR request. Comparing these two methods we can see that the estimation of the effective bandwidth method is more conservative. Moreover, the effect of buffer size is the most significant; we can also see the low link utilization in the case of very small buffer size.

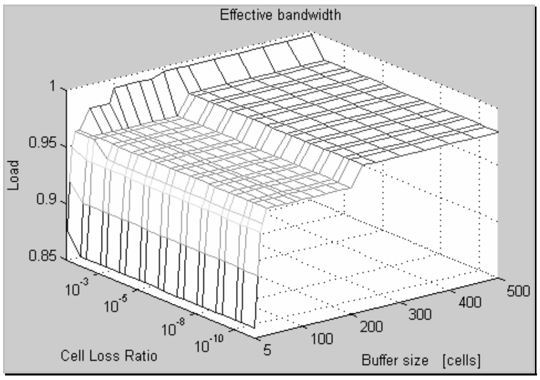

Fig. 3. CAC method simulation: Diffusion Approximation Method.

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

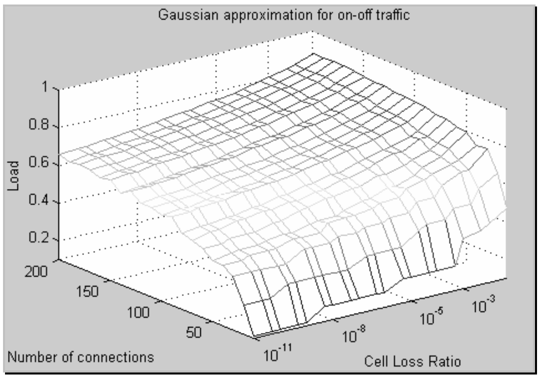

Fig. 4. Gaussian Approximation Method simulation: On-off traffic.

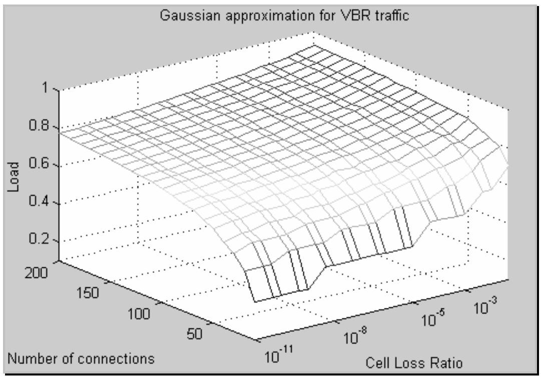

Fig. 5. Gaussian Approximation Method simulation: Variable Bit Rate traffic.

As we can see (Fig. 4 and 5), the Gaussian approximation method is more conservative in policing of on-off traffic sources. The traffic aggregation in the case of VBR traffic sources gets the Gaussian probability distribution of cell rates sooner as 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 the higher statistical bandwidth.

6. Conclusion

As we can see from our simulation 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 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 accurate and universal CAC method for all traffic conditions. That is why CAC methods are field of study for many researches.

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