APPROXIMATE METHOD FOR PERFORMANCE ANALYSIS AND OPTIMIZATION OF PARTIAL BUFFER SHARING IN ATM SWITCHES

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Performance evaluations of the buffer allocation strategies are computationally difficult problems due to the complexity of the large state space when the number of traffics and/or the buffer size is large. In this paper, we propose the approach based on the state space merging to avoid these difficulties for the systems supporting two types of services, namely, real-time and nonreal-time services in ATM networks when buffer size is large enough. For this type of systems, the efficiency in regard of low computational complexity approximate formulae to calculation of the system behavior for the Partial Buffer Sharing (PBS) strategy are obtained. The results of appropriate numerical experiments are carried out.

Keywords: ATM, buffer management, state space merging, algorithms.

1. INTRODUCTION

In ATM networks traffic of various applications (i.e. real-time and nonreal-time services) require various Quality-of-Service (QoS). In order to provide different performance levels to several traffic classes an efficient buffer management mechanism is necessary. These problems have intensively been investigated during the recent two decades and comparative performance analysis of various buffer management mechanisms has been achieved (see, e.g. [1,2]).

Main element of buffer management mechanisms is buffer allocation strategies. Buffer allocation strategies can be broadly classified into push-out strategies and nonpush-out strategies. Strategies, which can accept an arriving packet (called cells in ATM terminology) by dropping another packet from the buffer, are known as push-out strategies [3–9]. In this paper, we focus on the nonpush-out type strategies, which do not allow the drop of already buffered packet of any type. Among nonpush-out type strategies the partial buffer sharing (PBS) have better performance than others [10] with respect to the controllability of the cell loss probability (CLP) and the low complexity of implementation [11]. In [11], to calculate the CLP iterative matrix methods was developed. Note that performance evaluation of the buffer allocation strategies is computationally a difficult problem due to the complexity of the large state space when the number of traffics and/or the buffer size is large. In this paper, we propose a new approach to avoid this problem for the PBS strategy in case two types of services with large buffer size. Our approach is based on state space merging [12].

2. MODEL AND PBS STRATEGY

To evaluate the performance of the buffer allocation strategies for shared-memory ATM switches the model of multi-stream queuing system with finite common waiting room and typed channels in which each stream has its own channels has been used. The system consists of a buffer shared by packets destined to two output ports. Packets of nonreal-time service (real-time service) are said to be of type 1 (2) and they are destined to port 1 (2). Type-1 packets arrive to the buffer according to a Poisson process with finite rate λ_1. An arriving process of the type-2 packets forms an Interrupted Poisson Process (IPP) [13]. In an IPP, there is an ON period during which arrivals occur in a Poisson fashion, followed by an OFF period during which no arrivals occur. These two periods alternate continuously and are exponentially distributed respectively with parameters σ_{ON} and σ_{OFF}. The mean number of packets arriving per unit time in ON period is λ_{ON}. Therefore, the average arrival rate of type-2 packets per unit time is obtained by

$$\lambda_2 = \frac{\lambda_{ON}\sigma_{OFF}}{\sigma_{ON} + \sigma_{OFF}}.$$

The service time of the packets is deterministic, corresponding to the fixed size of ATM cells. This time is denoted by μ_i for output port i, $i = 1, 2$ (in a special case it is possible that $\mu_1 = \mu_2$). We assume that arriving and transmission processes are mutually independent. The total buffer size is B, and a packet releases the buffer when it has completely been transmitted.

PBS strategy is defined as follows. It introduces a threshold r, $0 < r \leq B$, on the total number of occupied buffers. If the total number of cells in the buffer exceeds the given threshold r, then arriving type-1 cells are discarded. An arriving cell of type-2 is accepted if any storage space is available.

Remark 1. If we define a threshold for type-2 cells also, say r^*, $0 < r^* \leq B$, then part of buffer with size $B - \max(r, r^*)$ will be unused. Because the threshold for a type-2 cells does not imposed.

3. CALCULATION ALGORITHM

A two-dimensional embedded Markov Chain (MC) with states $n = (n_1, n_2)$, where n_i is the number of the type-i packet in the buffer might be used to describe the functioning of the system at equilibrium. The embedded moments are cells departure ones. The state space E of the given MC is defined as follows:

$$E = \left\{ n : n_1 = \overline{0, r}, n_2 = \overline{0, B}, n_1 + n_2 \leq B \right\}. \quad (1)$$

The elements $q(n, n')$, $n, n' \in E$, of the infinitesimal generator matrix Q of the given MC are calculated as follows:

$$q(n,n') = \begin{cases} \lambda_1, & \text{if } n_1 + n_2 < r, n' = n + e_1, \\ \lambda_2, & \text{if } n' = n + e_2, \\ \mu_i, & \text{if } n' = n - e_1, i = 1, 2, \\ 0 & \text{otherwise}, \end{cases} \quad (2)$$

where $e_1 = (1,0)$, $e_2 = (0,1)$.

Let $p(n)$ denotes the stationary probability of the state $n \in E$. Various performance measures can be calculated from the stationary distribution. Hence, the stationary $CLP_i(B,r)$ for packets type – i are

$$CLP_1(B,r) = \sum_{n \in E} p(n) I(n_1 + n_2 \geq r), \quad (3)$$

$$CLP_2(B,r) = \sum_{n \in E} p(n) I(n_1 + n_2 = B), \quad (4)$$

where $I(A)$ is an indicator function of the event A.

Remark 2. From (3), (4) in a special case when $r = B$ we have $CLP_1(B,B) = CLP_2(B,B)$, i.e. in this case *PBS* is same with Complete Sharing (CS) strategy [10].

The utilization, $PU_i(B,r)$, of the output port i is a measure fraction of the time that the port is busy and is calculated as follows:

$$PU_i(B,r) = \sum_{n \in E} p(n) I(n_i > 0), i = 1, 2. \quad (5)$$

The buffer utilization by packets of type i, $BU_i(B,r)$ is measured by means average number of packets of given type in buffer and is calculated as follows:

$$BU_1(B,r) = \sum_{n \in E} \sum_{j=1}^{r} j p(n) I(n_1 = j), \quad BU_2(B,r) = \sum_{\bar{n} \in E} \sum_{j=1}^{B} j p(n) I(n_2 = j). \quad (6)$$

Formulae (3), (4) and (6) allows us calculate the waiting time of packets of type i, $W_i(B,r)$, by using the Little's formulae for finite queue:

$$W_i(B,r) = BU_i(B,r)/\lambda_i(1 - CLP_i(B,r)), i = 1, 2. \quad (7)$$

It is well known that the stationary distribution $p(n)$, $n \in E$, of this MC has not product form. It means that to calculate the stationary distribution it is necessary derive and solve the system of global balance equations for given values of structural and loading parameters of the model. Latter is nontrivial problem when buffer size is large. Now, we propose a new approach to avoid this difficulty.

Assumption: $\lambda_2 >> \lambda_1$ and $\mu_2 >> \mu_1$. This is a regime that commonly occurs in multimedia networks, in which real-time calls arrive and depart more frequently than nonreal-time ones [6]. Moreover, as it will be shown below, the final results do not depend directly on λ_i and μ_i but depend only on their ratio $\nu_i = \lambda_i/\mu_i$, $i = 1, 2$ However, this assumption is useful to provide rare transition between classes of states underlying MC for the carefully application of the state space merging algorithms [12].

In this paper the following algorithm to calculate the performance measures of the given system is proposed.

Step 1. Input ν_1, ν_2, r, B.

Step 2. For $i = 0, 1, \dots, r$ calculate $\pi(<i>)$ as follows:

$$\pi(<i>) = \nu_1^i \prod_{j=0}^{i-1} C(j)\pi(<0>), \qquad i = 0, 1, \dots, r, \tag{8}$$

where

$$\pi(<0>) = \left(1 + \sum_{j=1}^{r} \nu_1^j \prod_{k=0}^{j-1} C(k)\right)^{-1}, \quad C(k) = \frac{1 - \nu_2^{r-k}}{1 - \nu_2^{B-k+1}}, \qquad k = 0, 1, \dots, r-1. \tag{9}$$

Step 3. Calculate $CLP_i(B,r)$, $PU_i(B,r)$, $BU_i(B,r)$, $W_i(B,r)$ as follows:

$$CLP_1(B,r) = (1 - \nu_2^{B-r+1}) \sum_{k=0}^{r} \nu_2^{r-k} \frac{1}{1 - \nu_2^{B-k+1}} \pi(<k>), \tag{10}$$

$$CLP_2(B,r) = \sum_{k=B-r}^{B} L(\nu_2, k)\pi(<B-k>), \tag{11}$$

$$BU_1(B,r) = \pi(<0>) \sum_{k=1}^{r} k\nu_1^k \prod_{j=0}^{k-1} C(j), \tag{12}$$

$$BU_2(B,r) = (1 - \nu_2)\left[\sum_{k=0}^{r} \frac{1}{1 - \nu_2^{B+1-k}} \pi(<k>) \sum_{k=1}^{B-r} k\nu_2^k + \right.$$
$$\left. + \sum_{k=B-r+1}^{B} k\nu_2^k \sum_{i=0}^{B-k} \frac{1}{1 - \nu_2^{B+1-i}} \pi(<i>)\right], \tag{13}$$

$$PU_1(B,r) = 1 - \pi(<0>), \tag{14}$$

$$PU_2(B,r) = 1 - (1 - \nu_2) \sum_{i=0}^{r} \frac{1}{1 - \nu_2^{B+1-i}} \pi(<i>), \tag{15}$$

where $L(\nu_2, m)$ denotes the stationary loss probability in $M/M/1/m$ system with the offered load ν_2, that is

$$L(\nu_2, m) = \nu_2^m (1 - \nu_2)/(1 - \nu_2^{m+1}).$$

It should be noted that the complexity of the given algorithm is too low, that is, it can be estimate as $O(B,r)$. Moreover, it is very convenient to calculate because it applies well-known parameters $L(\nu, m)$ for which there exists a perfect software product (also commonly tabulated).

4. OPTIMIZATION OF PBS STRATEGY

Now consider the constrained optimization problems for PBS strategy. Suppose that the value of buffer size (i.e. B) is uncontrollable and only controllable parameter is r (i.e. threshold for nonreal-time packets). For the same concretize we assume that QoS is given by indicating the upper limits of blocking probabilities and of waiting time of real-time packets. Accordingly our problem is to find extremal (minimal or maximal) values of parameter r of PBS strategy that provides the desirable level of QoS. First consider the problem for minimization of r, that is, formally this problem may be written as follows:

$$r \to \min \tag{16}$$

$$s.t. CLP_i(B, r) \le \varepsilon_i, \quad i = 1, 2, \tag{17}$$

$$W_2(B, r) \le \tilde{W}, \tag{18}$$

where $\varepsilon_i, i = 1, 2$ and $\tilde{W}$ are given upper limits of the appropriate QoS parameters.

For developing the algorithm to solving the given problem more useful are following unimprovable bounds of QoS parameters:

$$CLP_1(B, B) \le CLP_1(B, r) \le CLP_1(B, 1), \tag{19}$$

$$CLP_2(B, 1) \le CLP_2(B, r) \le CLP_2(B, B), \tag{20}$$

$$W_2(B, B) \le W_2(B, r) \le W_2(B, 1), \tag{21}$$

for any r in $[1, B]$.

By taking into account monotony property of QoS parameters with respect to r and above mentioned their bounds (19)–(21) we can propose the following algorithm for solution of the given problem.

Step 1. If $\varepsilon_1 < CLP_1(B, B)$ or $\varepsilon_2 < CLP_2(B, 1)$ or $\tilde{W} < W_2(B, B)$ then the problem (16)–(18) has no solution.

Step 2. If $W_2(B, 1) \le \tilde{W}$ then an optimal solution (if exist) must be find in [1,B]. In this interval by dichotomy find minimal value r_1^* such that the condition (18) is hold.

Step 3. If $\varepsilon_1 > CLP_1(B, r_1^*)$ and $\varepsilon_2 > CLP_2(B, r_1^*)$ then an optimal solution of the problem (16)–(18) is $r^* := r_1^*$. Else go to next step.

Step 4. If $CLP_1(B, B) < \varepsilon_1 < CLP_1(B, r_1^*)$ and $CLP_2(B, r_1^*) < \varepsilon_2 < CLP_2(B, B)$ then by dichotomy find minimal value r_2^* such that conditions (17) is hold for $i = 1$ and go to next step.

Step 5. If $CLP_2(B, r_2^*) > \varepsilon_2$ then the problem (16)–(18) has no solution. Else an optimal solution of the given problem is $r^* := r_2^*$.

5. NUMERICAL RESULTS

In order to show the numerical tractability and some results for calculate the system performance measures in PBS strategy, we have solved the set of equation (10)–(15). It is worthwhile to note that the proposed here formula enables us to realize appropriate calculations in any traffic regime and buffer size.

It is noteworthy that difference between approximate values of performance measures that calculated by proposed here formulae and their exact values calculated by balance equations are negligible. So, for instance, in exact approach the values of $CLP_1(30, 15) = 0.0521354$ and $CLP_2(40, 15) = 0.0521361$ for $v_1 = 0.9$, $v_2 = 0.7$. The appropriate approximate values of these parameters are $CLP_1(30, 15) = 0.0519909$, $CLP_2(40, 15) = 0.0520491$, i.e. with increasing of B this difference is close to zero. Analogous situations are valid for other performance measures and buffer size and loading parameters. Latter indicates that the proposed formulae are refined approximations for the system performance measures in engineering practice.

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