Blocking Probability for Priority Classes in Optical Burst Switching Networks

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Abstract—**This letter proposes a method to strictly prioritize switching access in Just-Enough-Time (JET)-based optical burst switching networks. A queueing model is developed by which the blocking probability for each traffic class can be analytically evaluated. The analytical results are validated by simulations.**

Index Terms—**Burst blocking probability, optical burst switching, QoS.**

I. INTRODUCTION

OPTICAL burst switching (OBS) is a new paradigm proposed to efficiently support the growing broadband multimedia traffic either directly or indirectly (e.g., via IP) over all optical WDM networks. OBS is based on one-way reservation protocols, such as Just-Enough-Time (JET) and Tell-And-Go (TAG) [1], in which a data burst follows a corresponding control packet without waiting for an acknowledgment. In this letter we only consider the JET-based OBS protocol.

Under JET, a source sends out a control packet, which is followed by a burst after a certain period of time called *offset time*. This offset time is required because the control packet incurs processing delay at each switch while the burst does not. In particular, the offset time T is set to be at least Hd, where H is the number of hops between the source and the destination, and d is the (expected) processing time incurred by the control packet at hop j ($1 \leq j < H$). Thus, as shown in Fig. 1, the processing of a control packet, at any switch, is completed before the corresponding burst arrival, and the bandwidth on hop j is reserved from the time the burst is expected to arrive (t) until the moment it leaves the switch ($t+L$), where L is the burst length. In Fig. 1, t' is the time the control packet arrives at switch j, and $T(j)$ is the *remaining offset time* between the control packet and its corresponding burst, thus $t = t' + T(j)$, and $T(j) = T - (j-1)d$.

If the requested bandwidth is not available, the burst is said to be blocked and dropped. In [3]–[5], the authors assign different offset time values to provide different quality of service (QoS) requirements for different traffic classes. Their focus is on the tradeoff between blocking probabilities of different traffic classes, while the focus of this letter is on provision of strict priority to higher priority classes and accurate analytical results for blocking probability for all traffic classes.
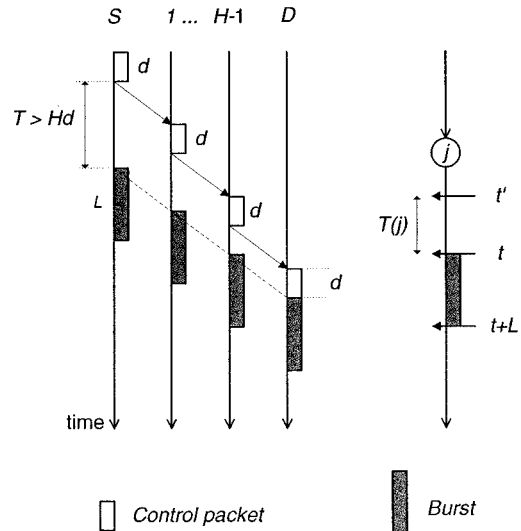

Fig. 1.   Basic concept of OBS.

To this end, we develop a queueing model for multiclass OBS. The model leads to exact evaluation of blocking probability for each class for the case of exponential burst size and an accurate approximation for the case of a more realistic burst size distribution.

The motivation of the strict priority regime relies on the following proposed architecture for the future Internet [6]. The first priority is given to voice traffic which will use a negligible amount of the network capacity. The second priority to nonvoice cooperative users who adapt their rate to network congestion. This will include data users (TCP) and video users (MPEG4) [1] that support adaptive rates. The lowest priority will be given to all other users. In this architecture, users will be encouraged to adapt their rate to congestion, and congestion collapse will be confined only to those who ignore congestion.

II. PROVISION OF A STRICT PRIORITY REGIME

Consider n strict priority classes, so that class 1 has the highest priority, class 2 has the second highest priority etc. Assume that class i ($1 \leq i \leq n$) generates bursts according to a Poisson process with rate λ_i. Let L_i be a random variable representing the class i burst size with the upper bound $\hat{L}_i$. The class i service times are assumed to be independent and identically distributed (i.i.d.). Furthermore, let $H_i^{(sd)}$ be a random variable representing the number of hops end-to-end of a particular connection between source and destination (sd). For each class i, we define $\hat{H}_i$ to be the hop limit, i.e., the

[1][Online.] Available: http://www.nms.lcs.mit.edu/projects/videocom/

maximum number of hops between source and destination. Thus, $\hat{H}_i = \max_{sd}\{H_i^{(sd)}\}$. Define $\hat{T}_i$ by $\hat{T}_i = \hat{L}_i + \hat{H}_i d$. To ensure the strict priority regime, we set the offset time for class i as

$$\begin{cases} T_n = H_n^{(sd)} d & i = n, \\ T_i = \sum_{j=i+1}^{n} \hat{T}_j + H_i^{(sd)} d, & i = n-1, \ldots, 1. \end{cases} \quad (1)$$

It can be shown from (1) that $T_i \geq L_{i+m} + T_{i+m}$ ($i = 1, 2, \ldots, n-1$, and $m = 1, 2, \ldots, n-i$), and this guarantees that the burst of class i will never arrive into a full system, where all wavelengths are busy, while the burst of class $(i + m)$ is being served, therefore, the class i has strict priority over class $(i + m)$.

Note that in practice, the offset delay of the highest priority, even under the strict priority regime, can be designed to be acceptable. If we consider the case of three priorities, the burst assembly delay (the delay of burst aggregation at the source) of the lower priorities can be set so that the burst transmission delay is around 3 ms, say, then the offset delay of the highest priority will not be more than 10 ms, which is suitable even for the delay sensitive services such as voice.

III. OBS AS A QUEUING MODEL

Let $T_i(j)$ be the remaining offset time at switch j of class i. In this letter, we assume that the total processing time $H_i d$ of a control packet of class i ($i = 1, 2, \ldots, n-1$) on its way to the destination is a negligible part of the total offset time T_i of that class [1]. Notice that this assumption is not required for $i = n$. Due to this assumption, the control packets of class i that arrive at switch j will have the same remaining offset time, i.e., $T_i(j) = T_i, \forall i, j$.

We assume that for a given output port at a switch the burst arrival process follows a Poisson process. Let k be the number of wavelengths used at each output port. If we have only one priority class and the remaining offset time is equal for each burst at any switch (as mentioned above), the OBS system behaves exactly like an M/G/k/k system for which exact blocking probability can be obtained using the Erlang B formula. The reader is reminded that the Erlang B formula is insensitive to the service time distribution. Therefore, in this case we expect Erlang B to provide accurate evaluation of the burst blocking probability.

However, when we consider more than one priority class, an application of M/G/k/k is not that straightforward. Assume that we have two priority classes. Fig. 2(a) illustrates the case when the burst of class 2 (B_2) arrives at the switch before the arrival of the burst of class 1 (B_1), however, B_2 will be blocked since the offset time of B_1 (T_1) will ensure the control packet of B_1 arrives before the control packet of B_2 by setting $T_1 \geq T_2 + L_2$ where L_2 is the length of B_2, hence B_1 will get through even it arrives later than B_2.

In our modeling of this system, we consider the simplification where the control packets C_1, C_2 and offset times T_1, T_2 do not exist. This model is illustrated in Fig. 2(b). In this case class 1 bursts will have preemptive priority over class 2 bursts.
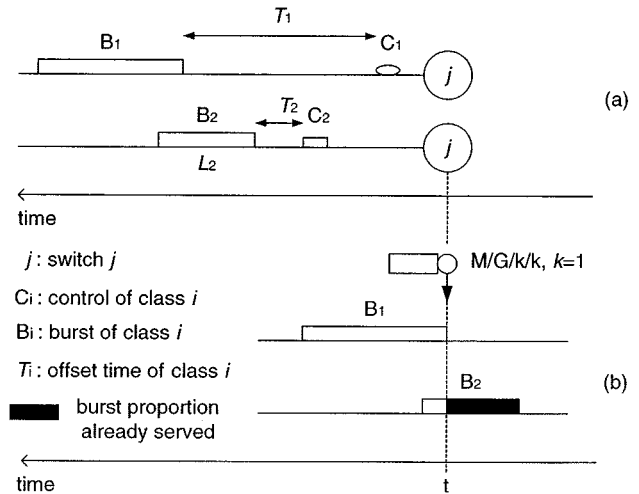

Fig. 2. (a) OBS with priority; (b) corresponding queueing model.

Due to the fact that class 1 bursts have strict priority over class 2 bursts, the blocking probability of class 1 bursts is simply obtained by the Erlang B formula. The interesting question is how to evaluate the blocking probability of class 2 bursts. One way to answer this question is by mixing all class 1 and class 2 traffic together and using the Erlang B formula to evaluate the blocking probability of the combined traffic. And since we know the blocking probability of class 1, the blocking probability of class 2 can be easily obtained.

The problem that remains is how exact is the evaluation of the blocking probability of the mix traffic by the Erlang B formula. To answer this question, we consider the M/G/k/k system with $k = 1$ shown in Fig. 2(b). In this figure, B_1 preempt B_2. If we consider the mix traffic of class 1 and 2, then if all burst size have the same exponential distribution, having B_1 preempting and replacing B_2 does not effect the blocking probability results. This is because at time t the *excess life* (also called forward recurrence time) [8] distribution of B_2 and the distribution of B_1 service time are equal due to the memoryless property of exponential distribution.

This is not the case, however, if the distribution of B_1 and B_2 is not exponential. Nevertheless, in this letter, we approximate the blocking probability of the mix traffic using the Erlang B formula results, and we expect that for cases of small blocking probability, it will give an accurate approximation. This is because, in this case, preemptions are very rare and the insensitivity of M/G/k/k to the service time distribution will be the dominant factor. Note that our arguments are valid also for the case when there are more than two classes ($n > 2$).

IV. EVALUATION OF BLOCKING PROBABILITIES

Define $\mu_i = 1/E[L_i]$, where $E[L_i]$ is the expected value of the class i burst lengths. As discussed in the previous section, we model the switch by an M/M/k/k queue with preemptive priorities, where class i arrival rate is λ_i and its service rate is μ_i.

Since the first class has an absolute priority over all other classes as seen before, the blocking probability of this class can

be calculated by the Erlang B formula in M/M/k/k queue as following [3], [7]

$$P_B(1) = (\rho_1^k/k!) \left/ \left(\sum_{m=0}^{k} \rho_1^m/m! \right) \right. \tag{2}$$

where $\rho_1 = (\lambda_1/\mu_1)$ is a traffic load of class 1.

Similarly, both the first and second classes are never blocked by the lower classes, hence the blocking probability of the superposition of the two classes is

$$P_B(1, 2) = (\rho_{1,2}^k/k!) \left/ \left(\sum_{m=0}^{k} \rho_{1,2}^m/m! \right) \right. \tag{3}$$

where $\rho_{1,2} = \rho_1 + \rho_2$. Note that a burst size in the superposition is not exponentially distributed, however (3) is still correct due to insensitivity of the blocking probability of M/G/k/k to the service time distribution.

Having $P_B(1)$ and $P_B(1, 2)$, the value of $P_B(2)$ is obtained using the following relationship:

$$P_B(1, 2) = p_1 P_B(1) + p_2 P_B(2) \tag{4}$$

where $p_i = \lambda_i/(\lambda_1 + \lambda_2)$, $i = 1, 2$.

Since $P_B(1, 2) > P_B(1)$, from (4) it can be shown that $P_B(2) > P_B(1)$, thus the lower priority class will always have the higher blocking probability.

In general, the blocking probability of class i can be calculated as follows:

$$P_B(i) = (1/\lambda_i) \left(\sum_{j=1}^{i} \lambda_j \right) [P_B(1, 2, \ldots, i)$$
$$- p_{1,2,\ldots,i-1} P_B(1, 2, \ldots, i-1)] \tag{5}$$

where $p_{1,2,\ldots,i-1} = (\sum_{j=1}^{i-1} \lambda_j)/(\sum_{j=1}^{i} \lambda_j)$ and $P_B(1, 2, \ldots, i) = ((\sum_{j=1}^{i} \rho_j)^k/k!)/(\sum_{m=0}^{k}(\sum_{j=1}^{i} \rho_j)^m/m!), i = 2, \ldots, n$. These calculations are analogous to those in [5].

V. SIMULATION

In this section, we validate our analytical results by simulation. First we calculate the blocking probability of each class in n priority regime using k wavelengths using (2) and (5). We then simulate the OBS system with preemptive priorities as discussed in Section III for both exponential and general service time and calculate the blocking probability for each class. We assume the average arrival and service rate are the same for all the classes and we are looking at the traffic load in the ranges between 0 and k. The service time distribution can be exponential or general distribution, but they all have the same average value equal to $1/15$. The general distribution is set according to the assumption that 10% of bursts are very long (with service time of $1/2.6$), 50% of bursts are short (with service time of $1/39$) and the remaining 40% bursts have service time of $1/26$.

Fig. 3 shows the blocking probability versus traffic load for two classes (CL_1, CL_2) in an M/M/k/k system with $k = 10$. Both analytical and simulation results using exponential (Exp.) and general (Gen.) distribution service time are plotted.

As discussed when the service time is exponentially distributed, the Erlang B formula provides exact blocking
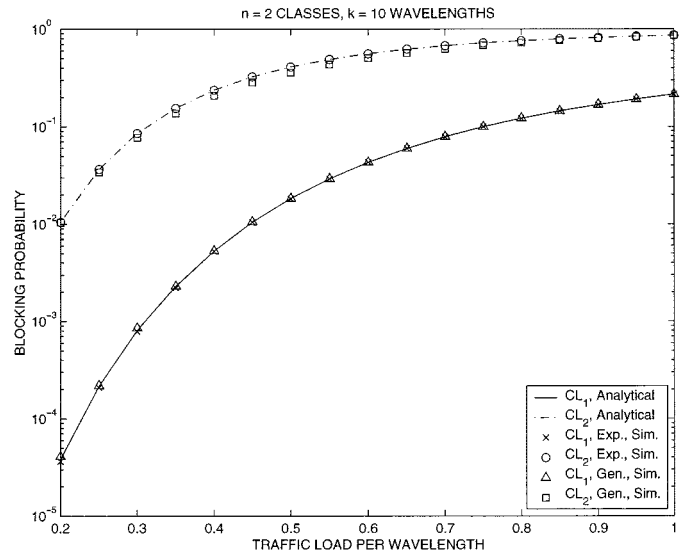

Fig. 3.   Blocking probabilities in strict priority regime.

probability for each class. This is confirmed by our simulation. Furthermore, the simulation results show that these blocking probabilities are also accurate estimations for the generally distributed burst length.

VI. CONCLUSIONS

In this letter, we have shown how to set the offset time in OBS networks that provides strict priority for different traffic classes. We have derived exact analytical results for the blocking probability of each class for the case of exponentially distributed burst size. We have used simulation to validate our analytical results and we also have shown that these results can be used to estimate blocking probabilities when the burst length distribution is general.

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